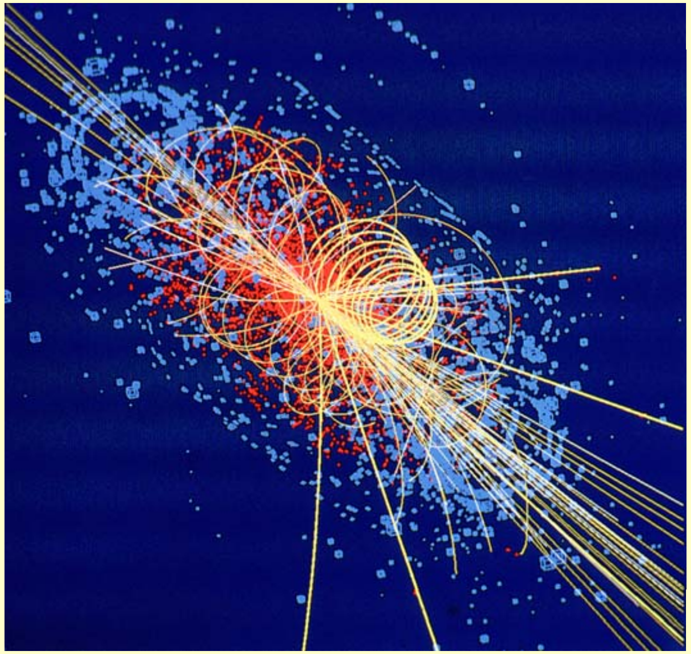
Higgs and SUSY at the LHC

- prospects for luminosities above 1 fb^{-1} -



- **Introduction**
- **Higgs**
  - **Updated results on Higgs boson searches**
  - **Measurement of Higgs boson parameters**
- **SUSY**
  - **Discovery prospects**
  - **Parameters of the SUSY model**

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Key Questions of Particle Physics

Answers to some of these questions are expected at the TeV mass scale, i.e. at the LHC

1. Mass: What is the origin of mass?

- How is the electroweak symmetry broken ?
- Does the **Higgs boson** exist ?

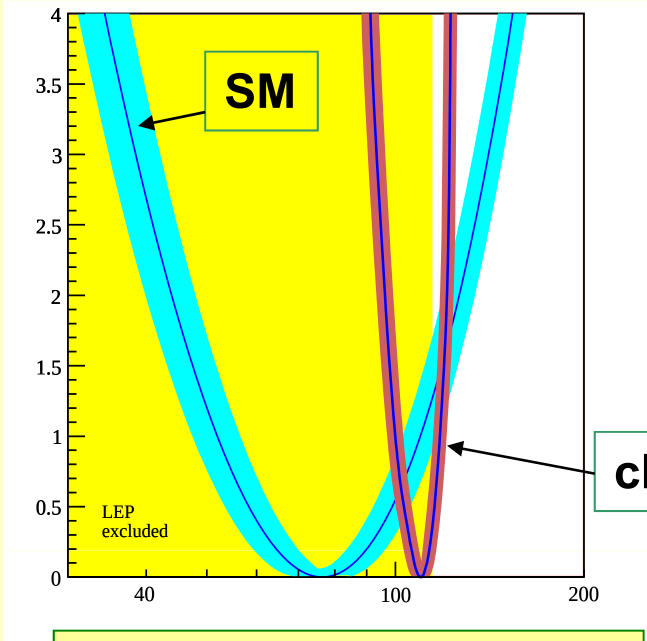
2. Unification: What is the underlying theory ?

- Can the interactions be unified at larger energy?
- How can gravity be incorporated ?
- Is our world **supersymmetric** ?
- What is the nature of Dark Matter / Dark Energy

3. Flavour: **or the generation problem**

- Why are there three families of matter?
- Neutrino masses and mixing?
- What is the origin of CP violation?

O. Buchmüller et al., arXiv:0707.3447



m_h = 110 (+8) (-10) ± 3 (theo) GeV/c^2

Includes
- WMAP
- $b \rightarrow s\gamma$
- a_μ

….watch the low mass region !

… but don‘t focus too much on it, be open for surprises !!

The Search for

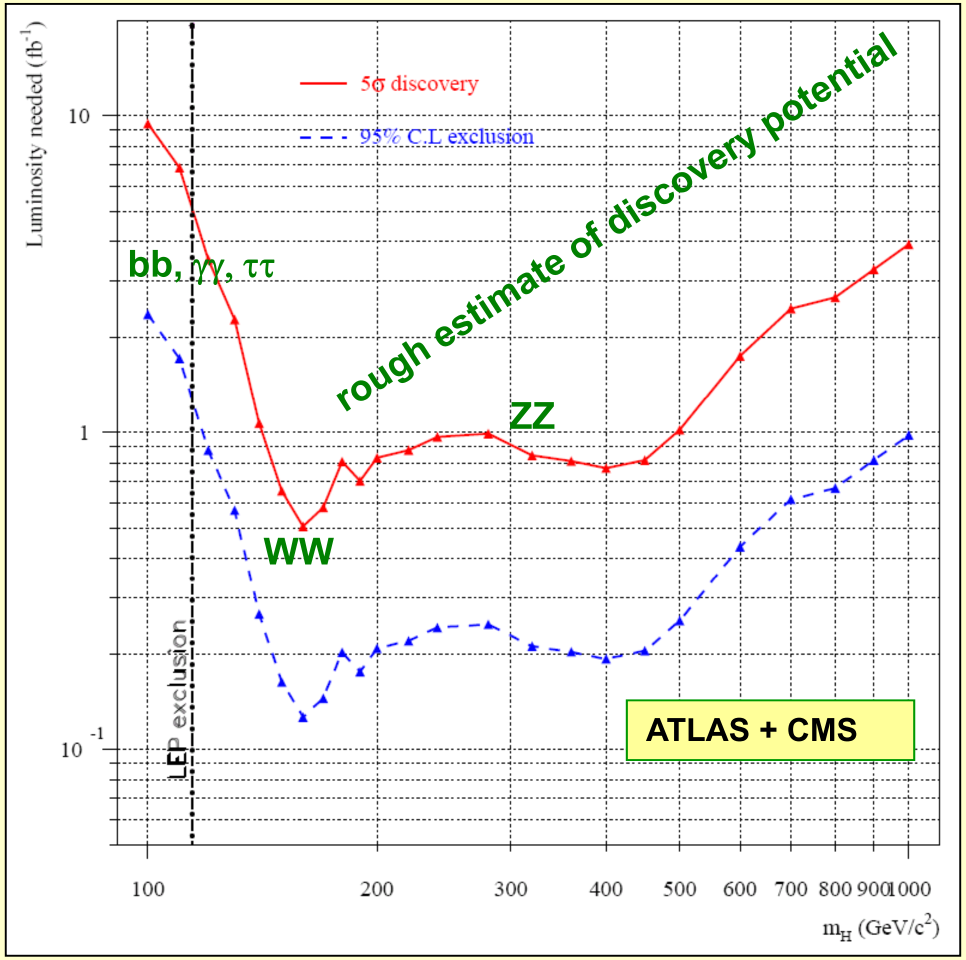
The Higgs boson

In contrast to the TeVatron:

the first Higgs has already been seen at ATLAS

…. also the prospects for the discovery of the Higgs particle are good

- Luminosity required for a 5σ discovery or for a 95% CL limit – (< 2006 estimates)



J.J. Blaising, A. De Roeck, J. Ellis, F. Gianotti, P. Janot, G. Rolandi and D. Schlatter,
Eur. Strategy workshop (2006)

~ < 1 fb^{-1} needed to set a 95% CL limit in most of the mass range
(low mass ~ 115 GeV/c^2 more difficult)

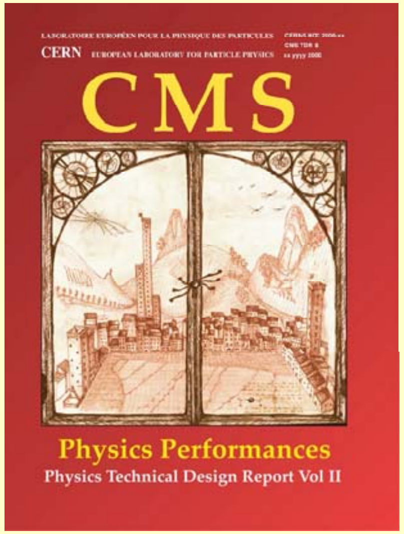
comments:
- these curves are optimistic on the ttH, H→ bb performance
- systematic uncertainties assumed to be luminosity dependent (no simple scaling, σ ~ √L, possible)

This talk: "grand LHC picture"
- *discovery potential (large L)*
- *parameter measurements*
- *MSSM scenarios*

Y. Sirois:
- *low luminosity discovery channels, e.g. WW;*
- *how to start up;*
- *data driven background determinations*

What is new on LHC Higgs studies ?

- Many studies have meanwhile been performed using detailed GEANT simulations of the detectors
  - Physics Performance Technical Design Report from the CMS collaboration
  - ATLAS CSC (Computing System Challenge) notes in preparation, to be released towards the end of 2008



CMS: CERN / LHCC 2006-021

ATLAS: CERN-OPEN 2008-020 (to appear)

- New (N)NLO Monte Carlos (also for backgrounds)
  - MCFM Monte Carlo, J. Campbell and K. Ellis, http://mcfm.fnal.gov
  - MC@NLO Monte Carlo, S.Frixione and B. Webber, wwwweb.phy.cam.ar.uk/theory/
  - T. Figy, C. Oleari and D. Zeppenfeld, Phys. Rev. D68, 073005 (2003)
  - E.L.Berger and J. Campbell, Phys. Rev. D70, 073011 (2004)
  - C. Anastasiou, K. Melnikov and F. Petriello, hep-ph/0409088 and hep-ph/0501130
  - …..

- New approaches to match parton showers and matrix elements
  - ALPGEN Monte Carlo + MLM matching, M. Mangano et al.
  - SHERPA Monte Carlo, F. Krauss et al.
  - …

  Tevatron data are extremely valuable for validation, work has started

- More detailed, better understood reconstruction methods

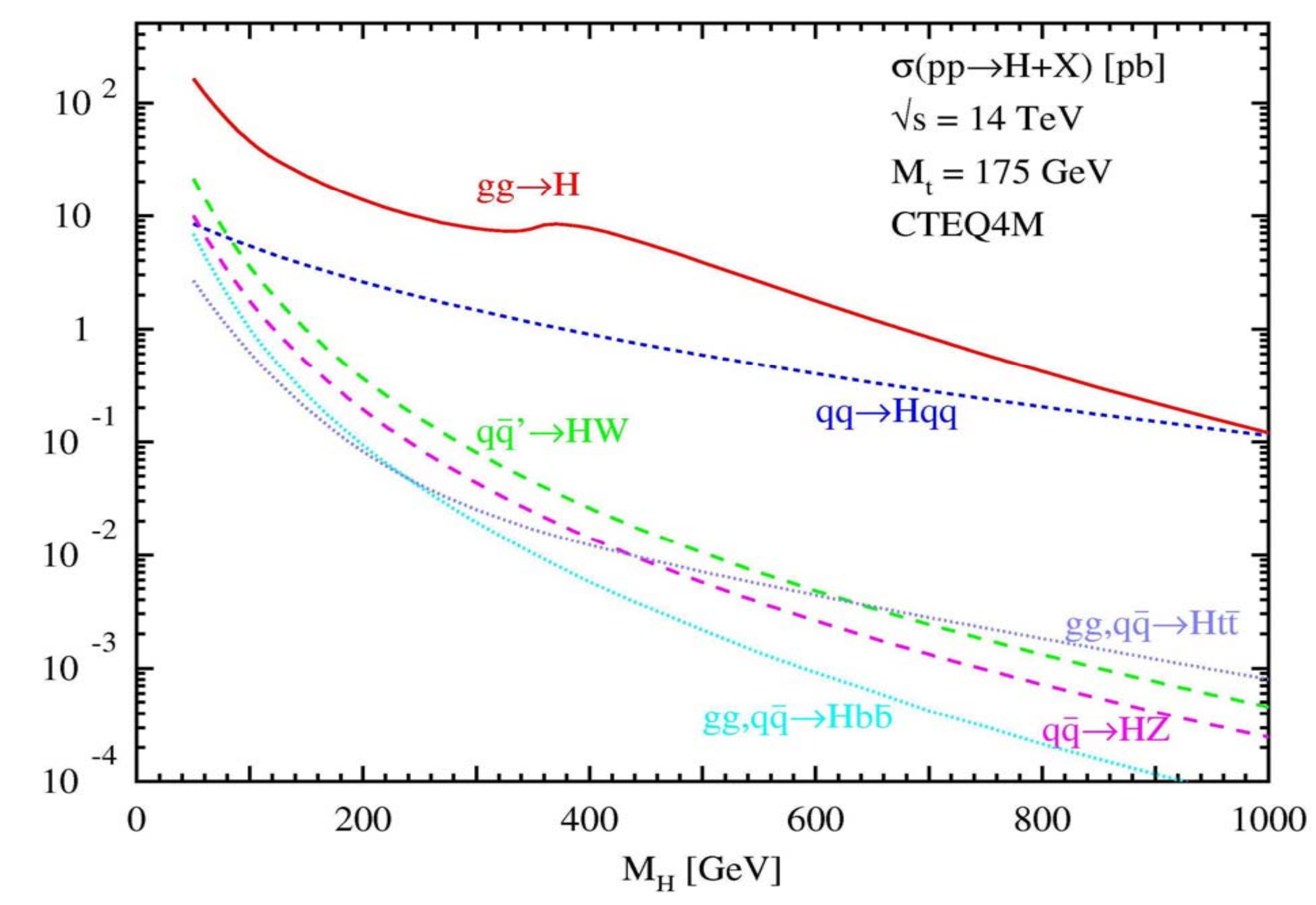
  (partially based on test beam results,…)

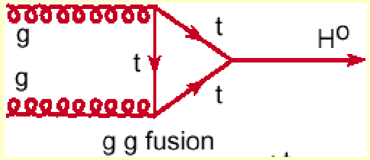
- Further studies of new Higgs boson scenarios

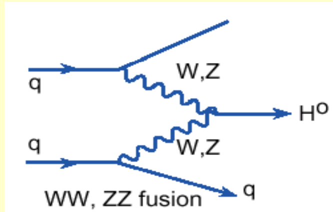
  (Various MSSM benchmark scenarios, CP-violating scenarios, Invisible Higgs boson decays,…..)

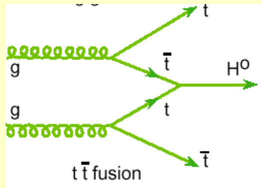
Standard Model
Higgs Boson Searches

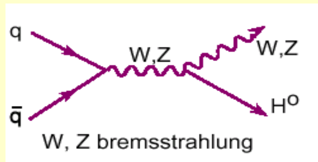
NLO cross sections, M.Spira et al.



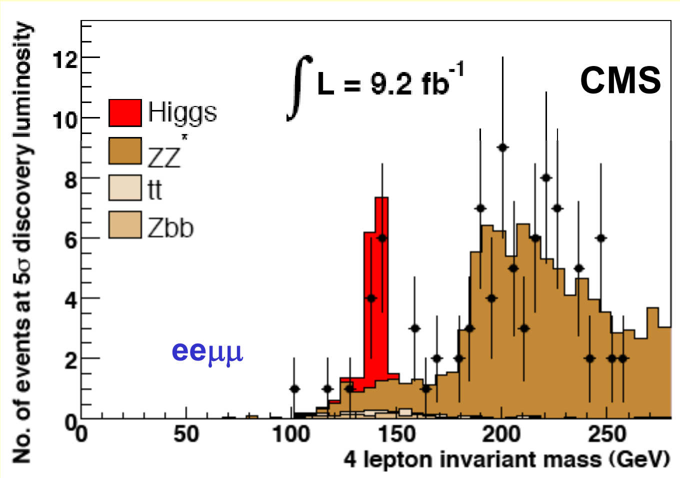








$H \rightarrow ZZ^* \rightarrow \ell\ell\ \ell\ell$



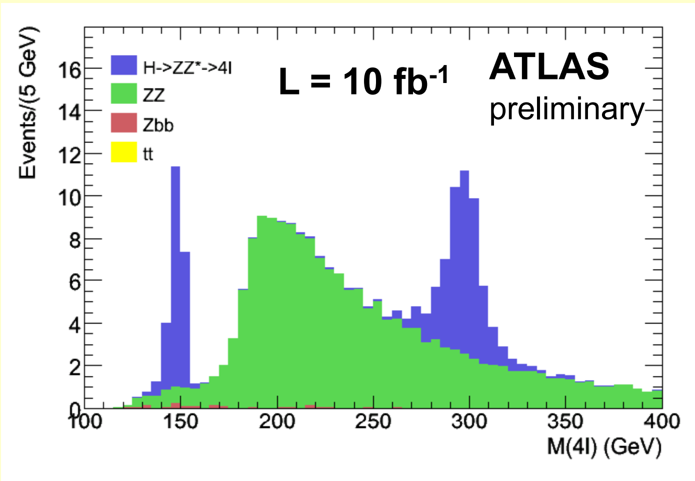
- Main backgrounds: ZZ (irreducible), tt, Zbb (reducible)

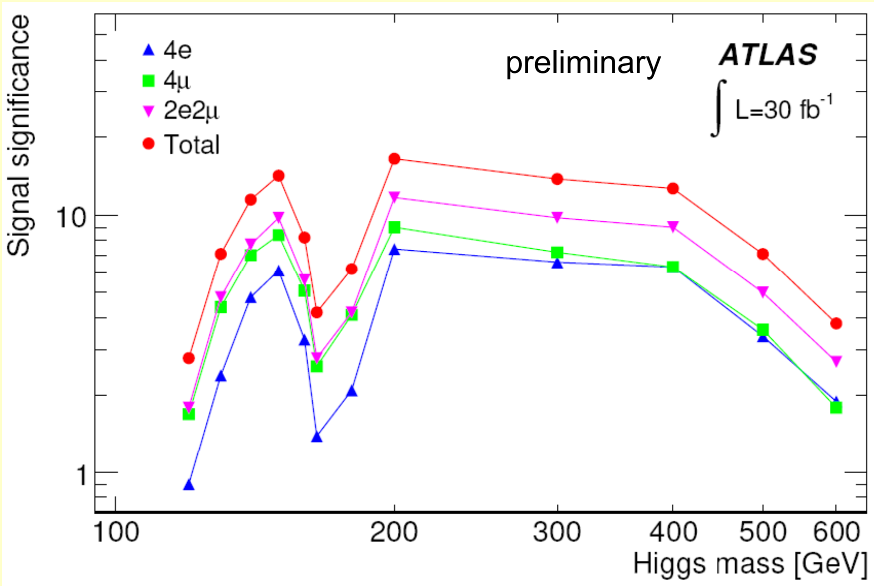
- Main experimental tools for background suppression:
  - lepton isolation in the tracker and in the calorimeter
  - impact parameter

Updated ATLAS and CMS studies:

- ZZ background: NLO K factor used
- background from side bands

(gg->ZZ is added as 20% of the LO qq->ZZ)

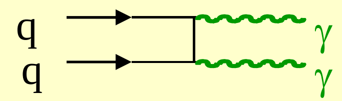




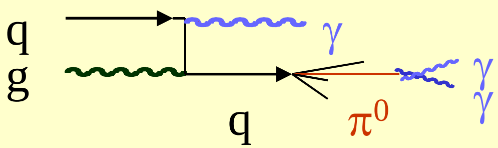
$H \to \gamma\gamma$

Main backgrounds:

$\gamma\gamma$ irreducible background



γ-jet and jet-jet (reducible)



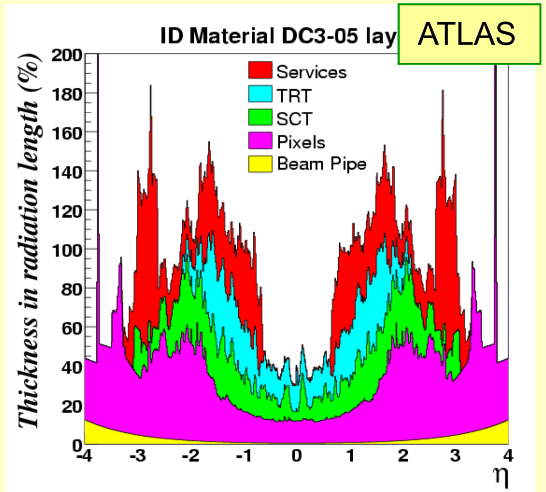
$\sigma_{\gamma j+jj} \sim 10^6\, \sigma_{\gamma\gamma}$ with large uncertainties

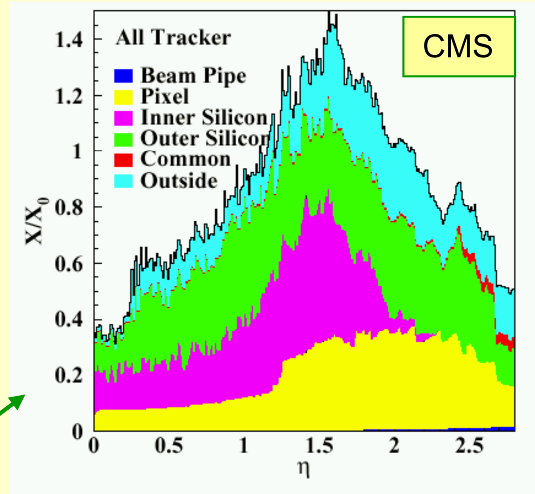
$\rightarrow$ need $R_j > 10^3$ for $\varepsilon_\gamma \approx 80\%$ to get

$\sigma_{\gamma j+jj} \ll \sigma_{\gamma\gamma}$

- Main exp. tools for background suppression:
  - photon identification
  - γ / jet separation (calorimeter + tracker)

  - note: also converted photons need to be reconstructed
    (large material in LHC silicon trackers)



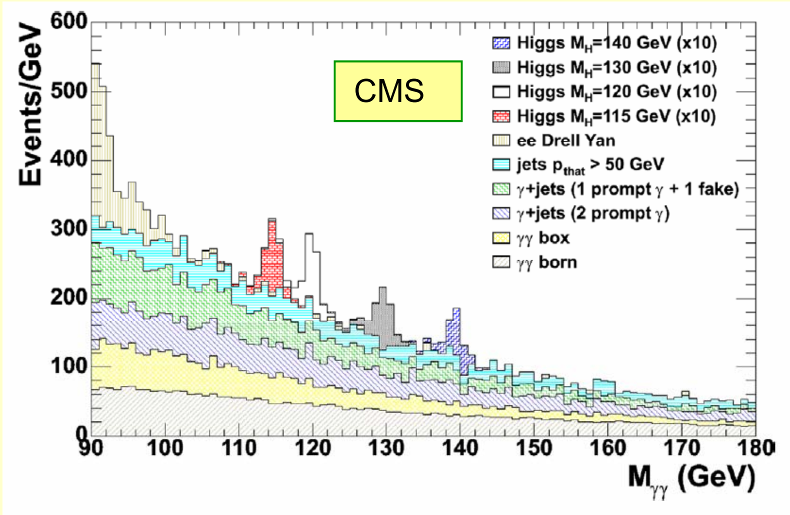


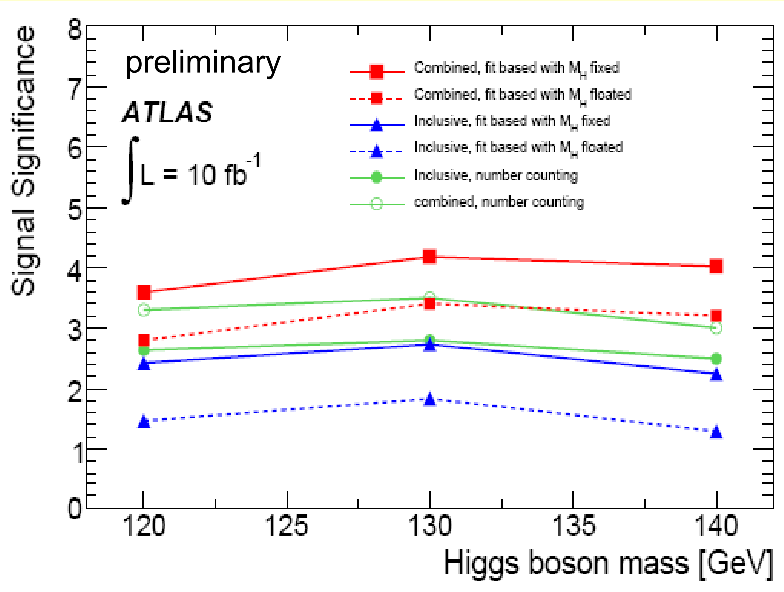
CMS: fraction of converted γs

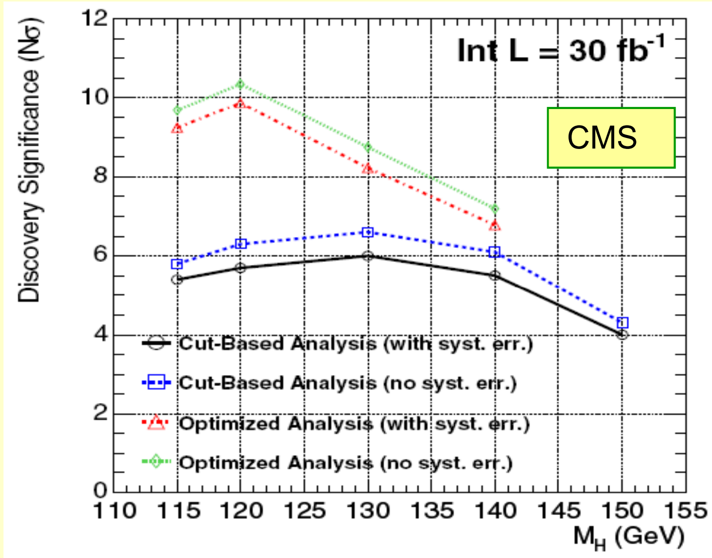
Barrel region:	42.0 %
Endcap region:	59.5 %

New elements of the analyses:

- NLO calculations available
  (Binoth et al., DIPHOX, RESBOS)
- Realistic detector material
- More realistic K factors (for signal and background)
- Split signal sample acc. to resolution functions







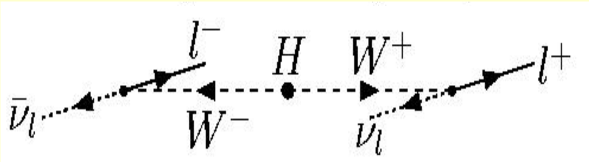
- Comparable results for ATLAS and CMS
- Improvements possible by using more exclusive $\gamma\gamma$ + jet topologies

$H \rightarrow WW \rightarrow \ell\nu\,\ell\nu$

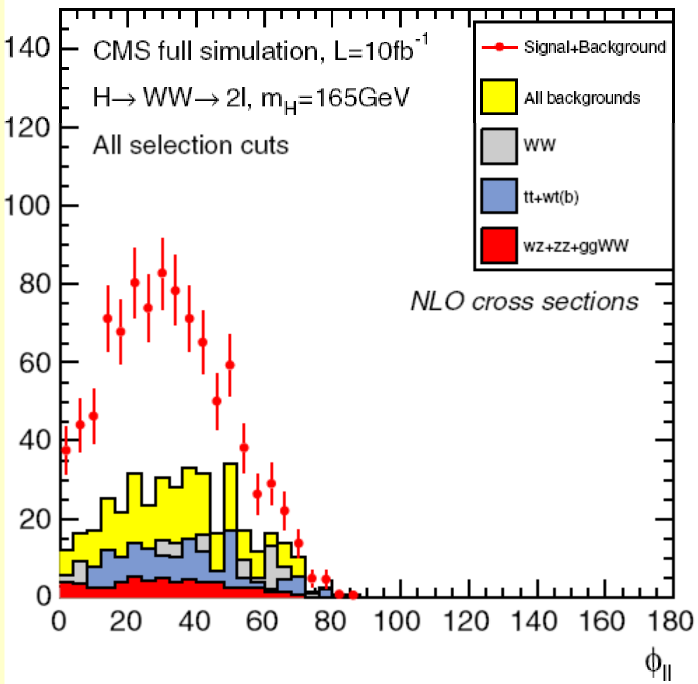
- Large $H \rightarrow WW$ BR for $m_H \sim 160$ GeV/c^2
- Neutrinos → no mass peak,
  → use transverse mass
- Large backgrounds: WW, Wt, tt

- Two main discriminants:

  (i) Lepton angular correlation



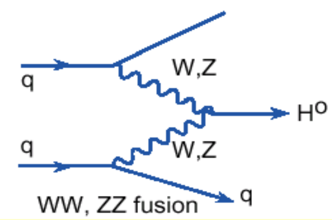
  (ii) Jet veto: no jet activity
  in central detector region



Discovery channel at low L
→ see talk by Y. Sirois

Difficulties:
(i) need precise knowledge of the backgrounds
Strategy: use control region(s) in data, extrapolation in signal region
(ii) jet veto efficiencies need to be understood for signal and background events
→ reliable Monte Carlo generators, data driven-background normalizations

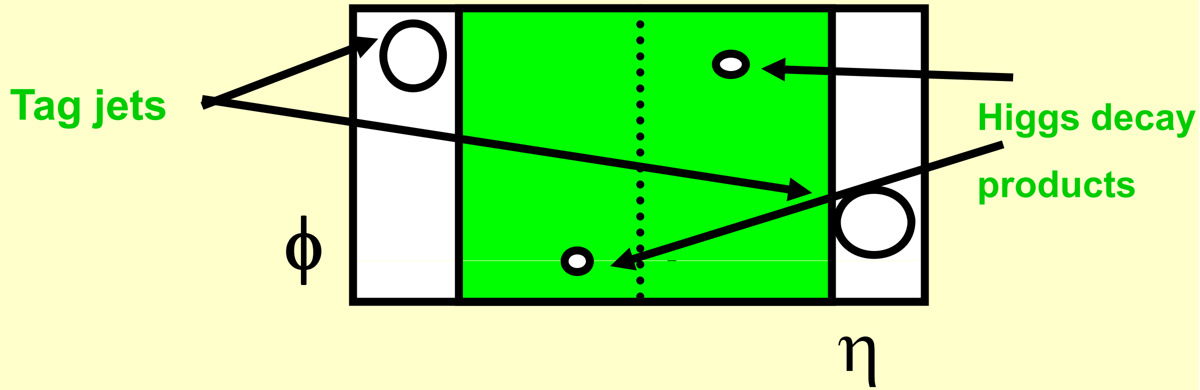
Vector Boson Fusion qq H



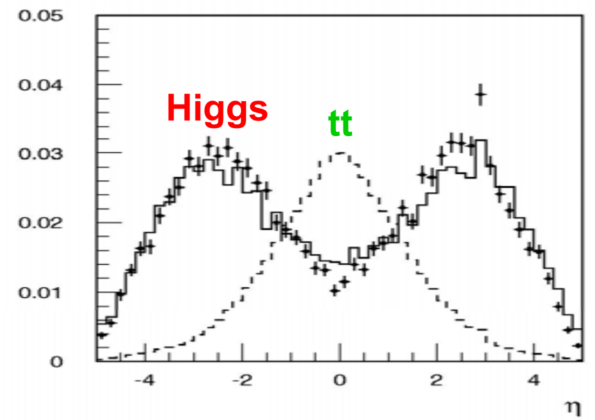
Motivation: Increase discovery potential at low mass
Improve and extend measurement of Higgs boson parameters
(couplings to bosons, fermions)

Established (low mass region) by D. Zeppenfeld et al. (1997/98)
Earlier studies: R.Kleiss W.J.Stirling, Phys. Lett. 200 (1988) 193;
Dokshitzer, Khoze, Troyan, Sov.J. Nucl. Phys. 46 (1987) 712;
Dokshitzer, Khoze, Sjöstrand, Phys.Lett., B274 (1992) 116.

Distinctive Signature of:
- two high P_T forward tag jets
- little jet activity in the central region
  $\Rightarrow$ central jet Veto



Rapidity distribution of jets in tt and Higgs signal events:

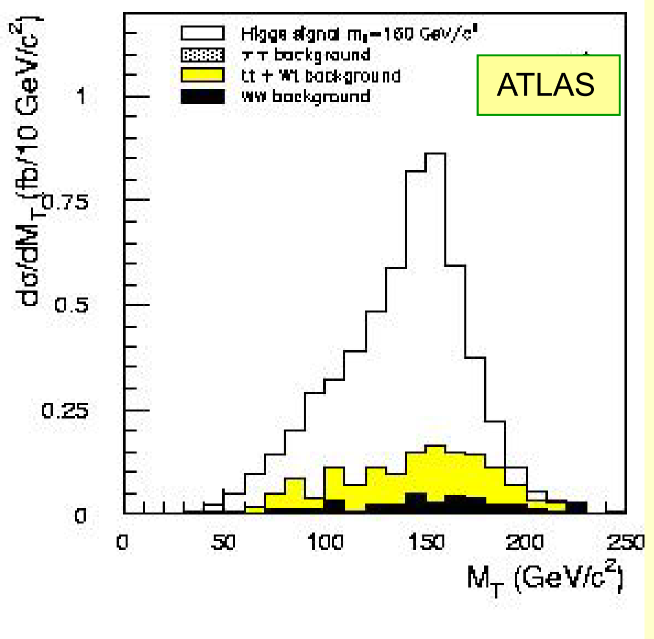


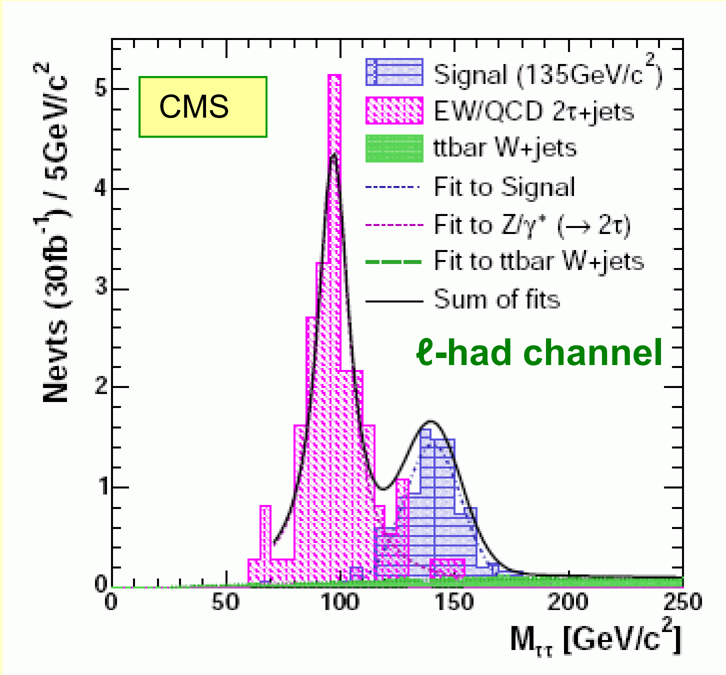
Two search channels at the LHC:

qq H → qq W W*
→ qq ℓν ℓν

qq H → qq τ τ
→ qq ℓνν ℓνν
→ qq ℓνν had ν

$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{\,e\mu} + \vec{p}_T^{\,miss})^2}$$





<u>Selection criteria:</u>

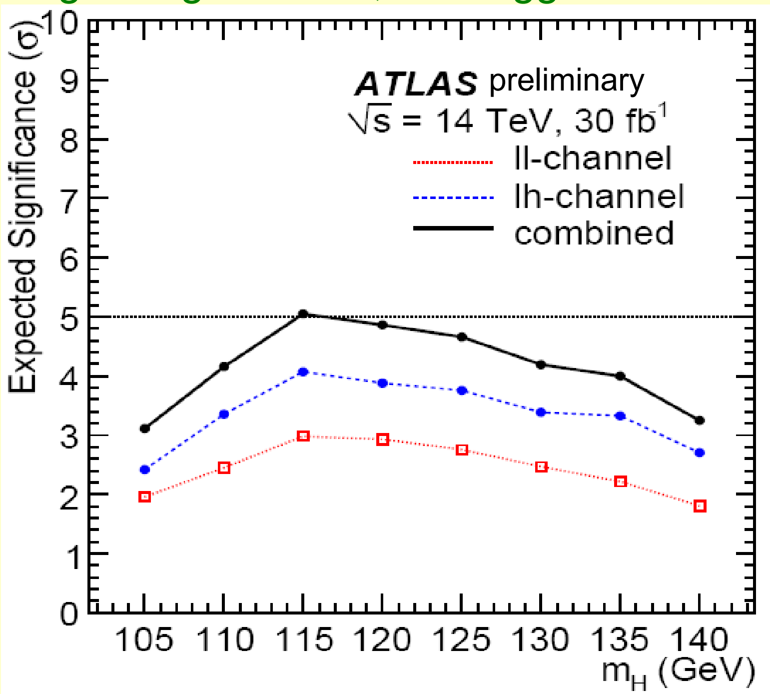
- Lepton P_T cuts and
- Tag jet requirements ($\Delta\eta$, P_T, Large mass)
- Jet veto (important)
- Lepton angular and mass cuts

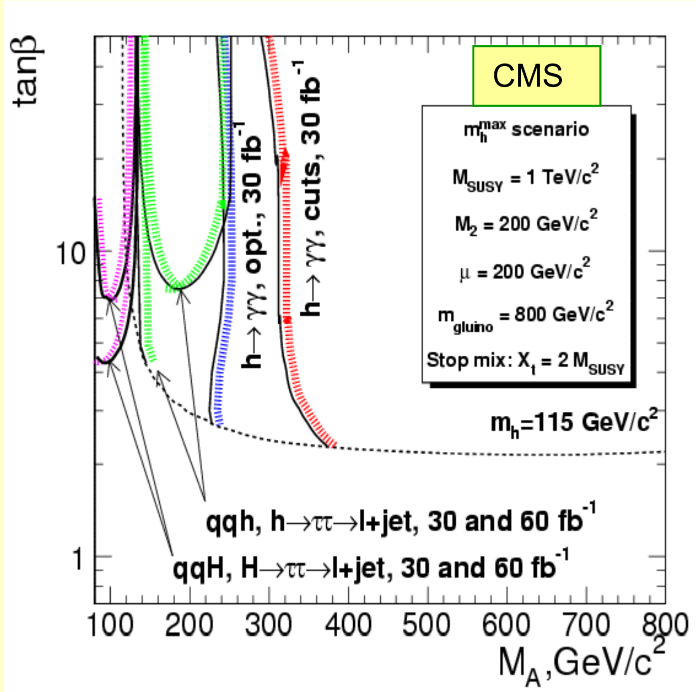
<u>Experimental challenge</u>:

- Identification of hadronic taus
- good E_T^{miss} resolution
  ($\tau\tau$ mass reconstruction in collinear approximation)
- control of the $Z \to \tau\tau$ background shape
  in the high mass region
  → use data to constrain the background ($Z \to \mu\mu$),
  see talk by Y. Sirois

(ii) Results from the first full simulation analysis of $qqH \rightarrow qq\ \tau\tau \rightarrow qq\ \ell\nu\nu\ had\ \nu$

Signal significance, SM Higgs





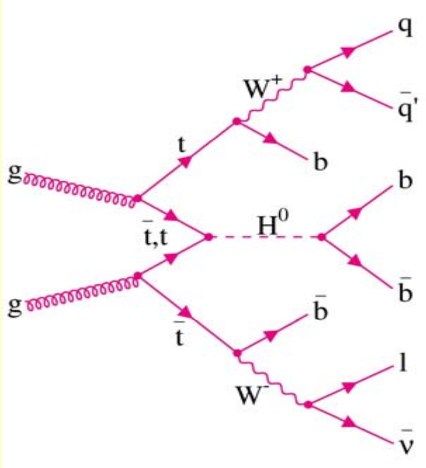
discovery region in the MSSM

- This channel plays an important rôle for the Higgs search at low mass at the LHC both in the Standard Model as well as in the MSSM

- Two key issues: efficient tau identification
  control of $Z \rightarrow \tau\tau$ background from data !

$t\bar{t}\,H \rightarrow t\bar{t}\,b\bar{b}$

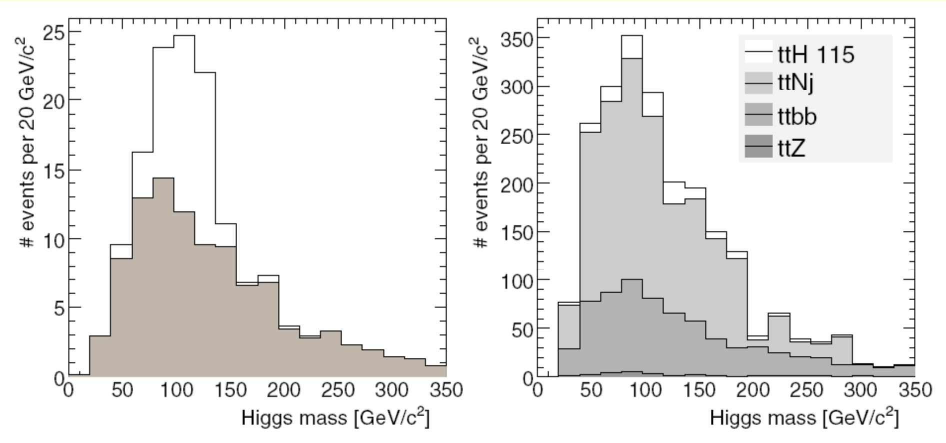
Complex final states: H→ bb, t → bjj, t → bℓν
t → bℓν, t → bℓν
t → bjj, t → bjj



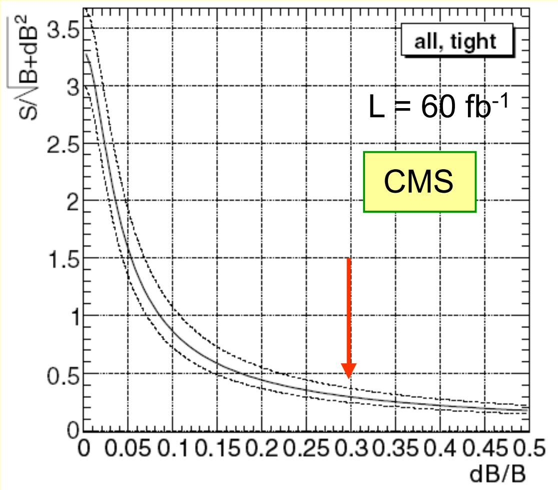
Main backgrounds:
- combinatorial background from signal (4b in final state)
- ttjj, ttbb, ttZ,…
- Wjjjjj, WWbbjj, etc. (excellent b-tag performance required)

• Updated CMS study (2006): ALPGEN matrix element calculations for backgrounds → larger backgrounds (ttjj dominant), experimental + theoretical uncertainties, e.g. ttbb, exp. norm. difficult…..

M (bb) after final cuts, 60 fb^{-1}



Signal events only …. backgrounds added

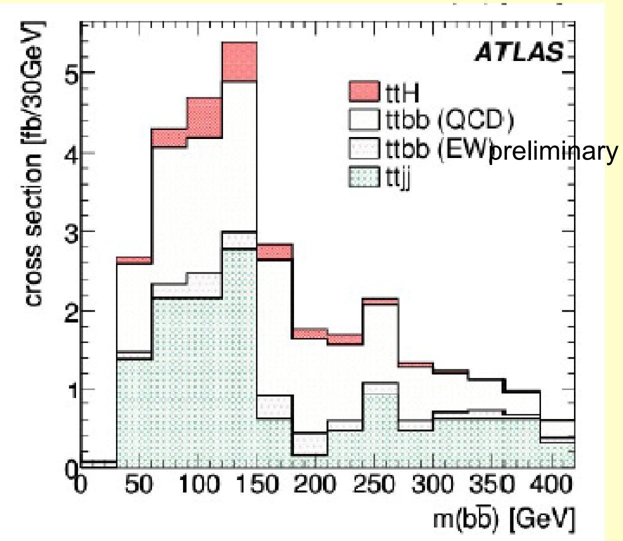


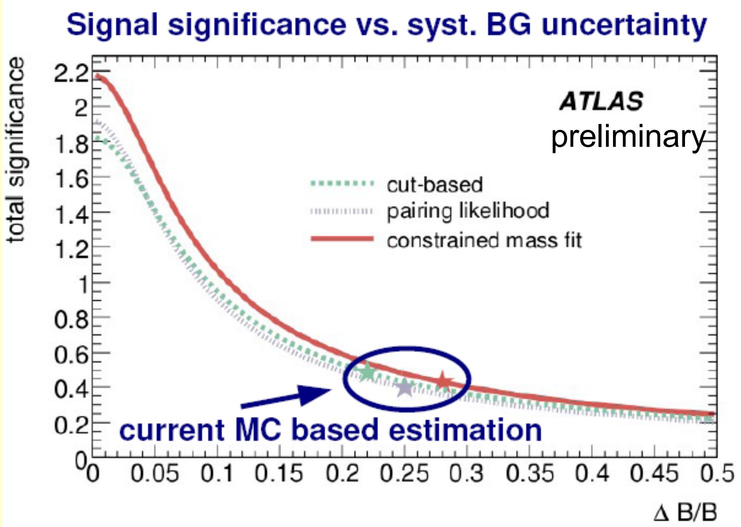
Signal significance as function of background uncertainty

…..comparable situation in ATLAS (ttH cont.)

preliminary

Preselection cut	$t\bar{t}H$(fb)	$t\bar{t}b\bar{b}$(EW) (fb)	$t\bar{t}b\bar{b}$(QCD) (fb)	$t\bar{t}X$ (fb)
lepton cuts (ID + p_T)	$57. \pm 0.2$	141 ± 1.0	1356 ± 6	63710 ± 99
+ ≥ 6 jets	36 ± 0.2	77 ± 0.9	665 ± 4	26214 ± 64
+ ≥ 4 loose b-tags	16.2 ± 0.2	23 ± 0.7	198 ± 3	2589 ± 25
+ ≥ 4 tight b-tags	3.8 ± 0.06	4.2 ± 0.2	30 ± 0.8	51 ± 2
	LO	LO	LO	NLO

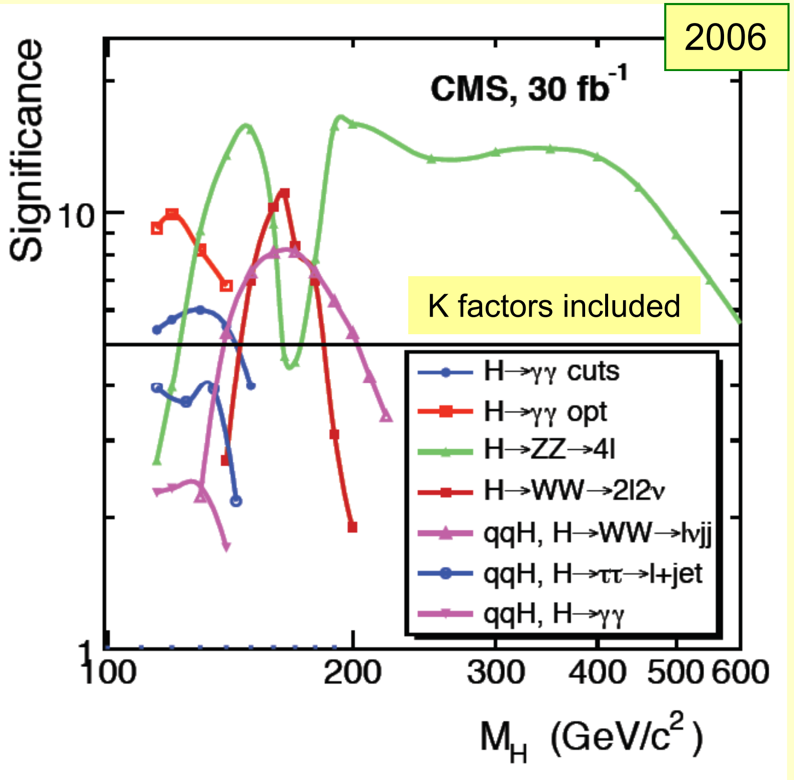


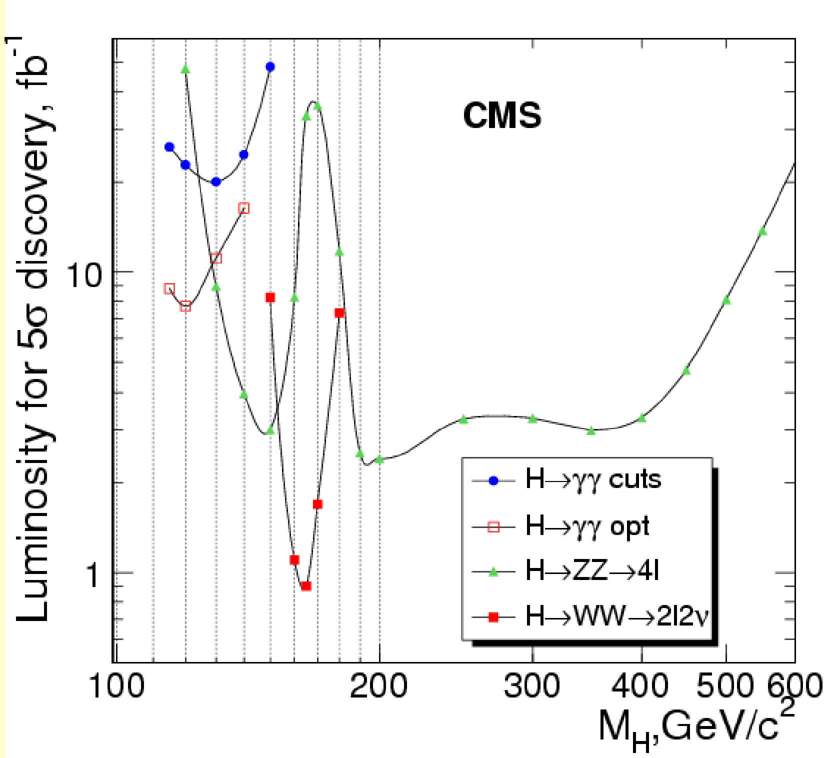


estimated uncertainty on the background: ± 25% (theory, + exp (b-tagging))
⇒ Normalization from data needed to reduce this (non trivial,…)

W/Z H associated production appears difficult as well;
re-assessed at present for highly boosted Higgs (see paper by J. Butterworth et al.)

LHC discovery potential for 30 fb^{-1}

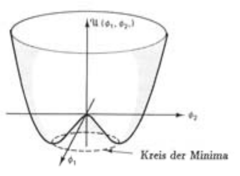




- Full mass range (up to ~ 1TeV/c^2) can be covered after a few years at low luminosity
  [at high mass: more channels (in WW and ZZ decay modes) available than shown here]
- Comparable performance in the two experiments
- Several channels available over a large range of masses

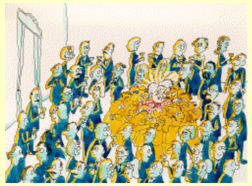
Important changes w.r.t. previous studies:

- **H → γγ** sensitivity of ATLAS and CMS comparable
- **ttH → tt bb** disappeared in both ATLAS and CMS studies



Is it a Higgs Boson ?

-can the LHC measure its parameters ?-



1. Mass

Higgs boson mass can be measured with a precision of 0.1%
over a large mass range (130 - ~450 GeV/c^2)
($\gamma\gamma$ and ZZ→ 4ℓ resonances, el.magn. calo. scale uncertainty assumed to be ± 0.1%)

2. Couplings to bosons and fermions

3. Spin and CP

Angular distributions in the decay channel H → ZZ(*) → 4 ℓ are sensitive to spin and CP eigenvalue

C.P. Buszello et al. Eur. Phys. J. C32 (2003) 209;
S. Y. Choi et al., Phys. Lett. B553 (2003) 61.
→ ATLAS and CMS studies on H → ZZ → 4ℓ
\+ new studies using VBF (CP from tagging jets) in ATLAS

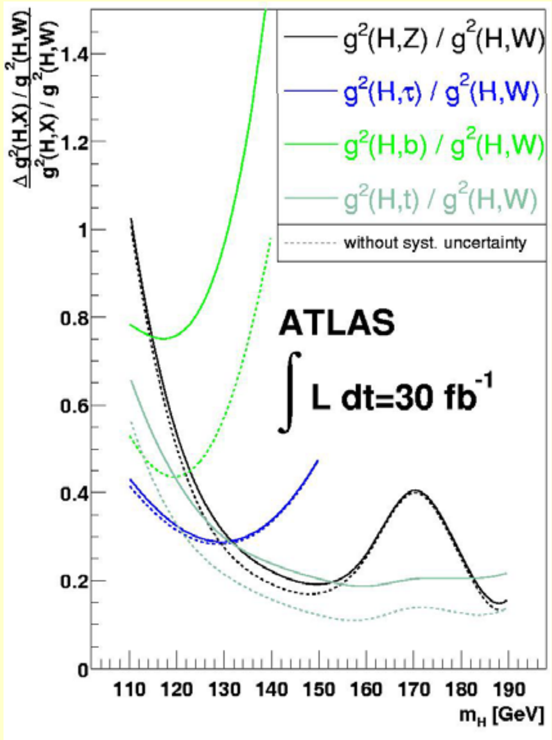
4. Higgs self coupling

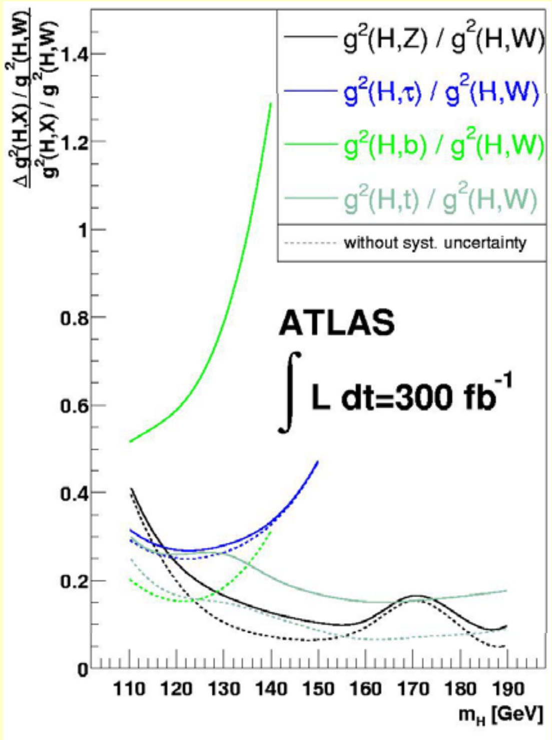
Possible channel: **gg → HH → WW WW → ℓν jj ℓν jj** (like sign leptons)

Measurement of Higgs Boson Couplings

Global likelihood-fit (at each possible Higgs boson mass)
Input: measured rates, separated for the various production modes

Output: Higgs boson couplings, normalized to the WW-coupling





Relative couplings (Z/W, τ/W, t/W) can be measured with a precision of ~20% (for 300 fb^{-1})

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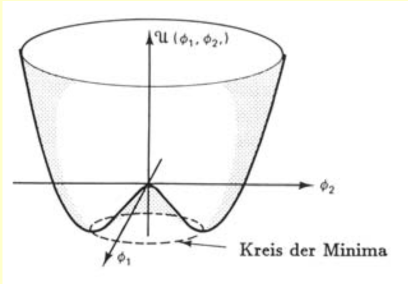
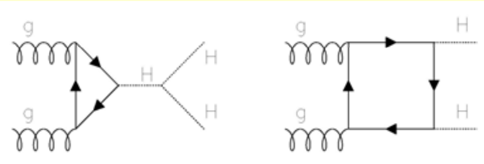
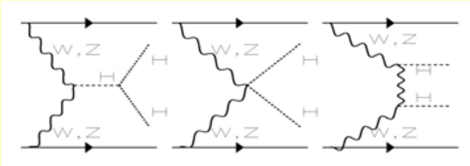
Higgs Bosons Self-coupling ? (prel., update 2007)

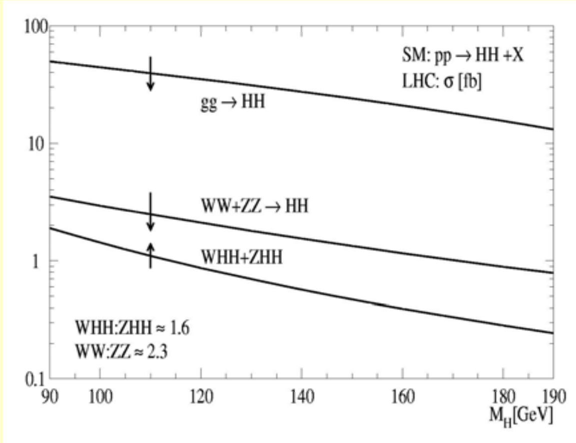
To establish the Higgs mechanism the Higgs boson self-coupling has to be measured:



Cross sections for HH production:







small signal cross sections,
large backgrounds from tt, WW, WZ, WWW, tttt, Wtt,...

$\Rightarrow$ no significant measurement possible at the LHC
need Super LHC L = 10^{35} cm^{-2} sec^{-1}, 6000 fb^{-1}

Most sensitive channel: **$gg \to HH \to WW\ WW \to \ell\nu\ jj\ \ell\nu\ jj$**

6000 fb^{-1} $\Rightarrow$ $\Delta \lambda_{HHH} / \lambda_{HHH}$ = 19 % (stat.) (for m_H = 170 GeV)

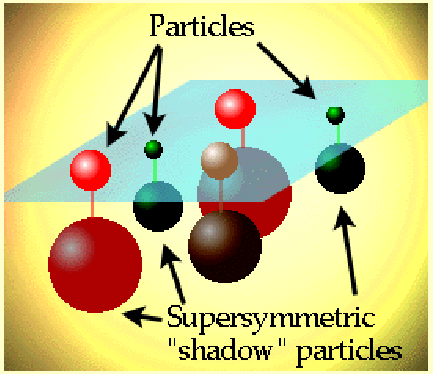
Sensitivity is restricted to a limited mass region around 165 GeV

Folie 19

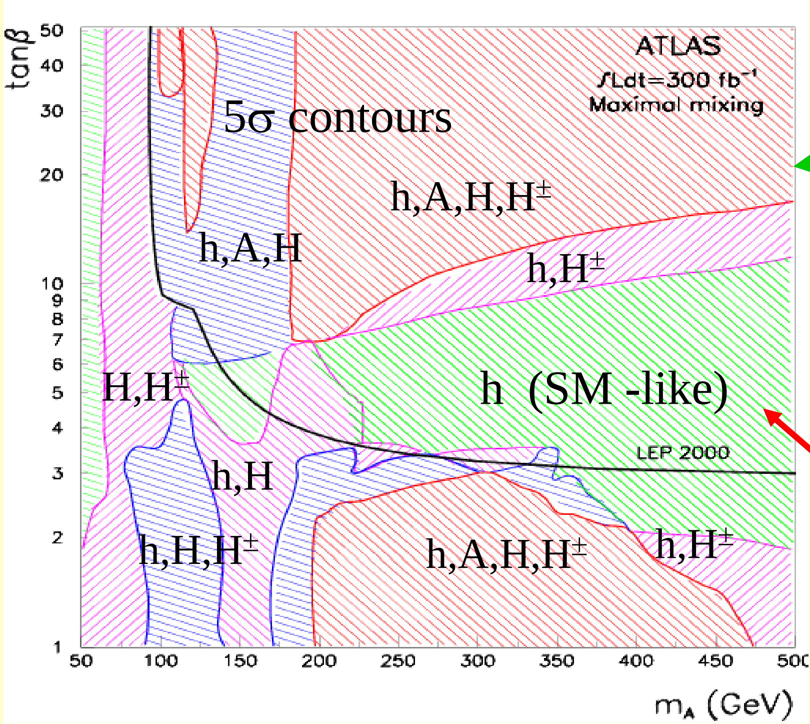
KJ1 Karl Jakobs; 13.10.2008

The Higgs Sector

in the MSSM



LHC discovery potential for SUSY Higgs bosons



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

A, H, H± cross-sections ~ $\tan^2\beta$

- best sensitivity from A/H → ττ, H± → τν
  (not easy the first year ....)

- A/H → μμ experimentally easier
  (esp. at the beginning)

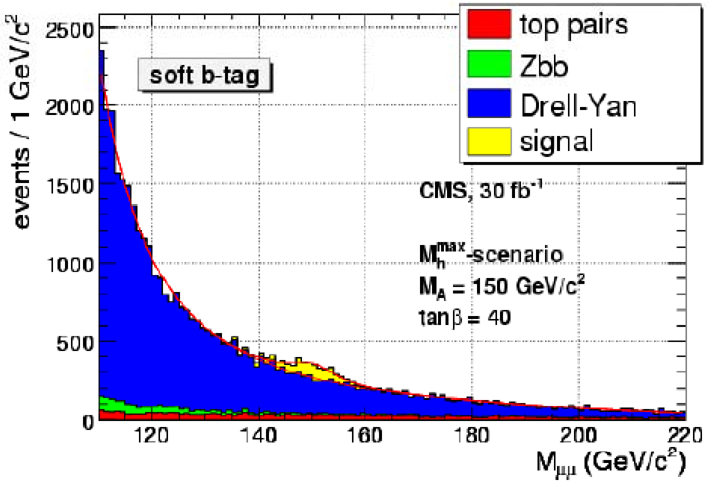
Here only SM-like h observable if SUSY particles neglected.

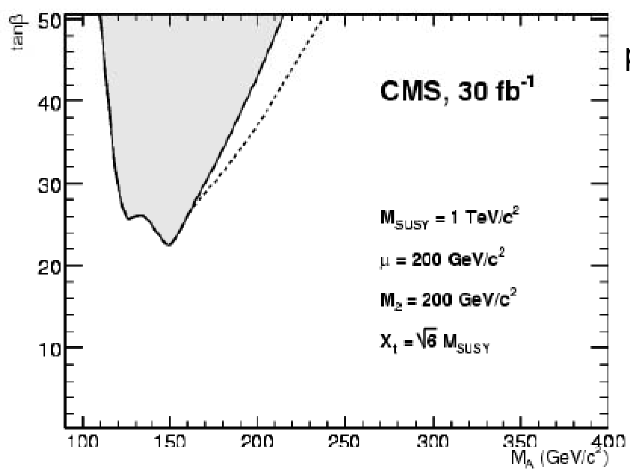
* Validated by recent ATLAS and CMS full simulation studies *

Coverage in the large m_A wedge region can be improved (slightly) by:
- Higher luminosity: sLHC
- Additional SUSY decay modes (however, model dependent)

Some examples of updated MSSM studies

CMS: A/H → μμ

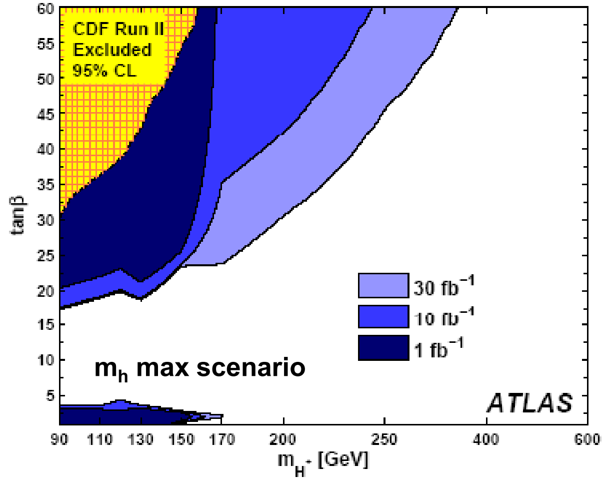




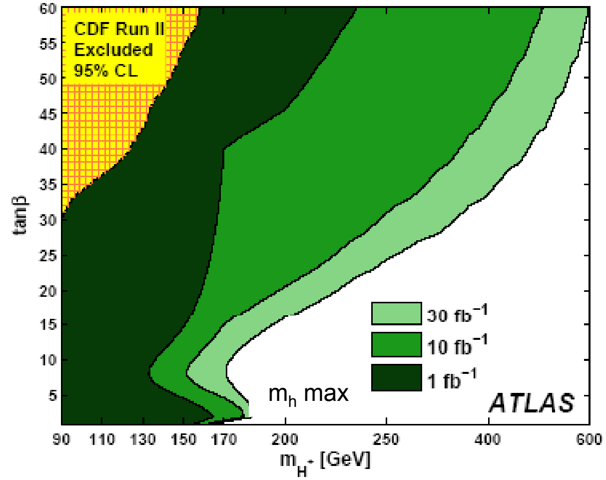
preliminary

ATLAS: Charged Higgs boson searches
$H^+ \rightarrow \tau\nu$ and tb decay modes

5σ discovery contours for 1 to 30 fb⁻¹



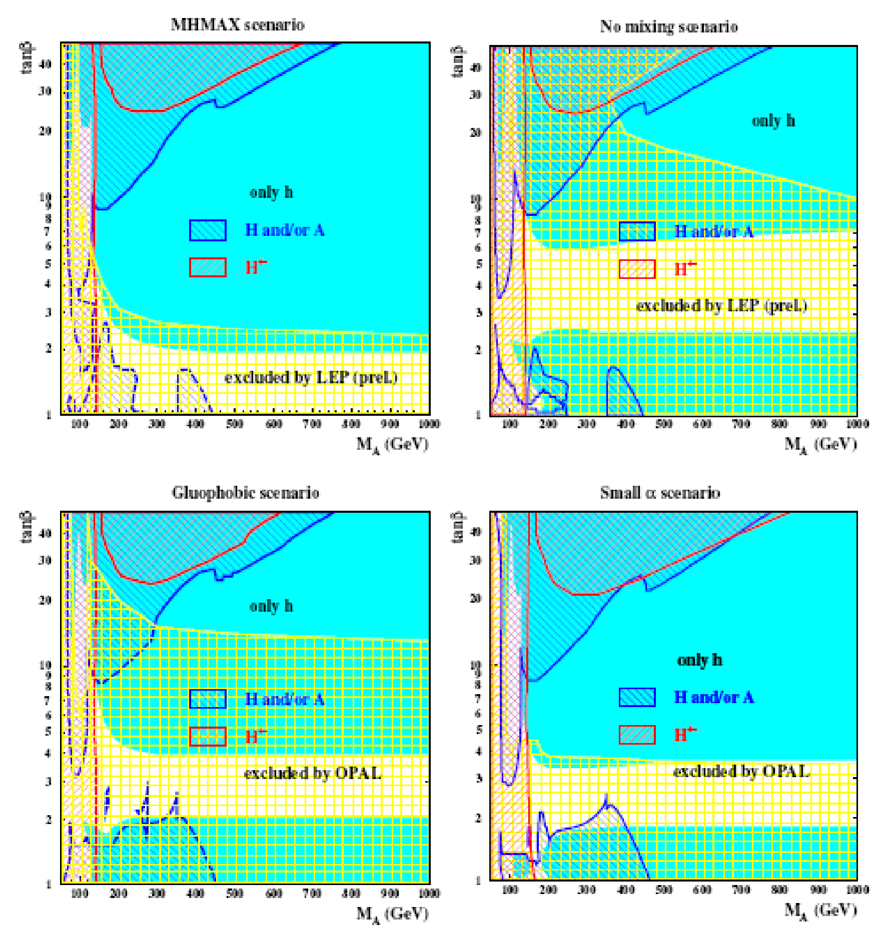
95% CL exclusions for 1 to 30 fb⁻¹



Updated MSSM scan for different benchmark scenarios

Benchmark scenarios as defined by M.Carena et al. (h mainly affected)

ATLAS preliminary,   30 fb^{-1},   5σ discovery



MHMAX scenario (M_{SUSY} = 1 TeV/c^2)
maximal theoretically allowed region for m_h

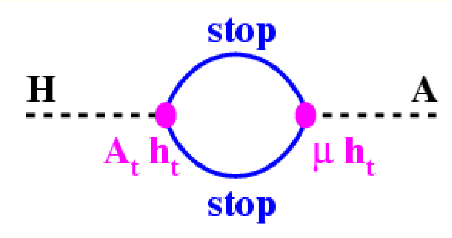
Nomixing scenario (M_{SUSY} = 2 TeV/c^2)
(1TeV almost excl. by LEP)
small m_h → difficult for LHC

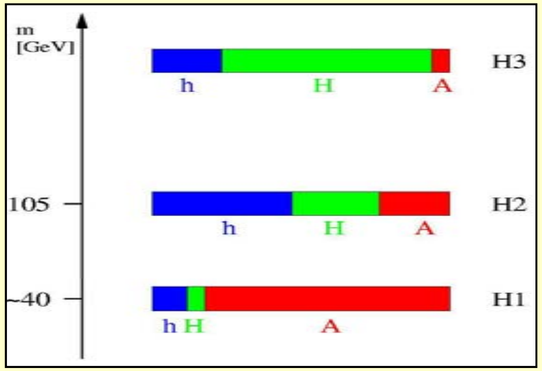
Gluophobic scenario (M_{SUSY} = 350 GeV/c^2)
coupling to gluons suppressed
(cancellation of top + stop loops)
small rate for g g → H, H→ γγ and Z→4 ℓ

Small α scenario (M_{SUSY} = 800 GeV/c^2)
coupling to b (and **t**) suppressed
(cancellation of sbottom, gluino loops) for
large tan β and M_A 100 to 500 GeV/c^2

Higgs search at the LHC in CP-violating scenarios

- CP conservation at Born level, but CP violation via complex **A_t, A_b, M….**





- CP eigenstates h, A, H mix to mass eigenstates H_1, H_2, H_3

- Effect maximized in a defined benchmark scenario (CPX)

  (M. Carena et al., Phys.Lett. B 495 155 (2000))

  $\arg(A_t) = \arg(A_b) = \arg(M_{gluino}) = 90°$

- No lower mass limit for H_1 from LEP !

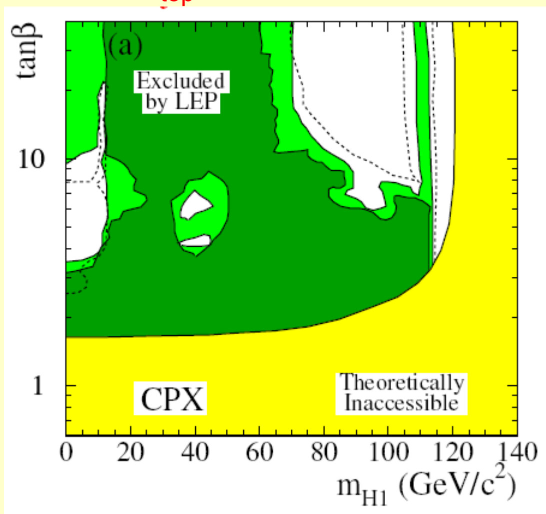
  (decoupling from the Z)

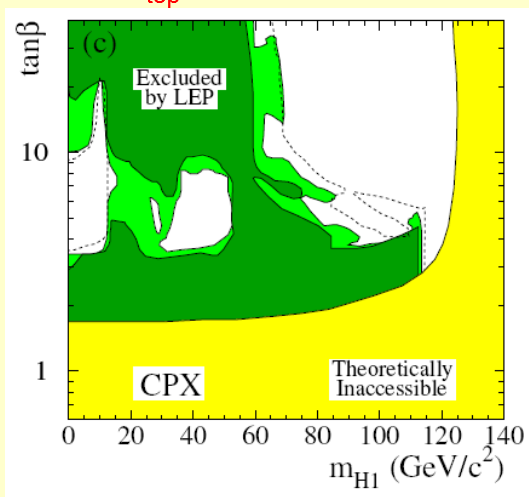
  details depend on m_{top} and on theory model

  (FeynHiggs vs. CPsuperH)

m_{top} = 169.3 GeV/c^2

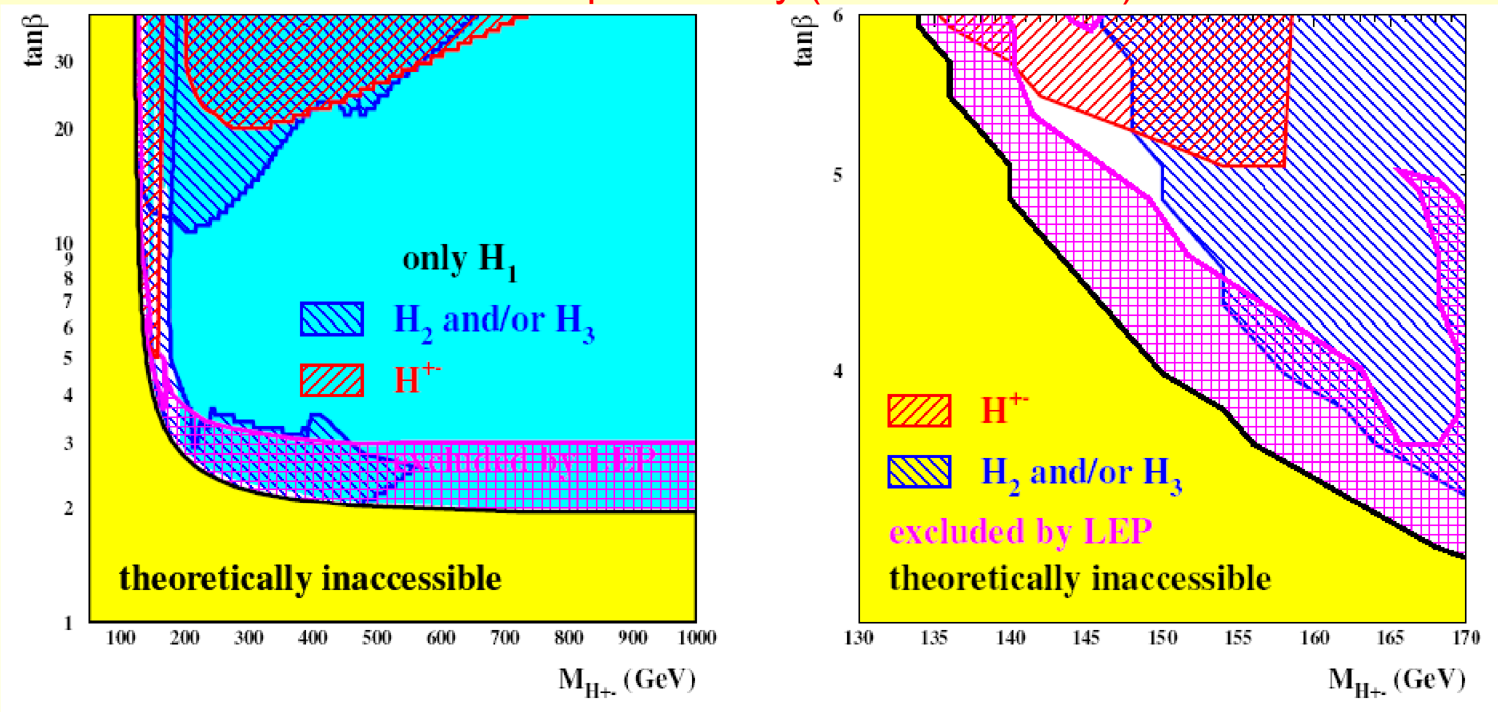
m_{top} = 174.3 GeV/c^2





MSSM discovery potential for the CPX scenario

ATLAS preliminary (M. Schumacher)



- Large fraction of the parameter range can be covered, however, small hole at (intermediate tanβ , low m_{H+}) corresponding to low m_{H_1}

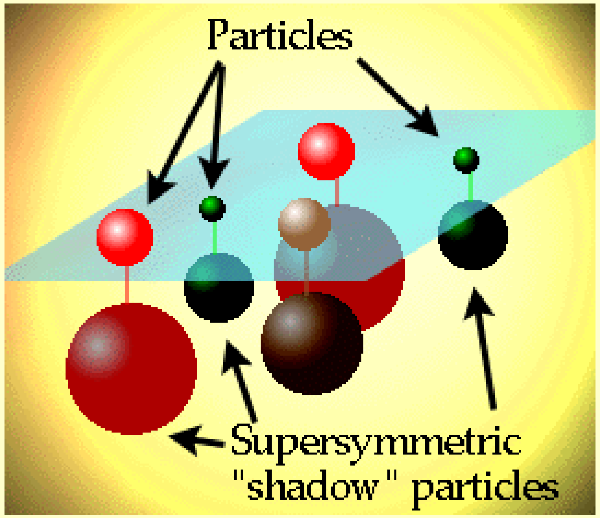
- More studies needed, e.g. investigate lower H_1 masses, additional decay channels: $tt \rightarrow Wb\ H^+b \rightarrow \ell\nu b\ WH_1b$, $H_1 \rightarrow bb$

Search for

Supersymmetry

First hints of supersymmetry might show up already in early data……

e.g. deviations from the Standard Model expectation in the E_T^{miss} spectrum



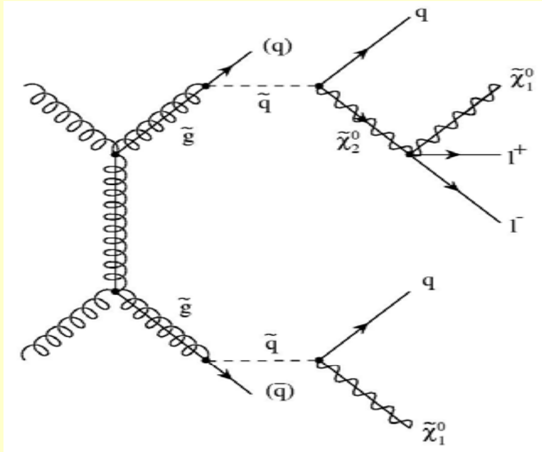
Here: overview

More details on individual analyses and data-driven background normalizations will be given in the talk of Beate Heinemann

Search for Supersymmetry

• Squarks and Gluinos are strongly produced

They decay through cascades to the lightest SUSY particle (LSP)



$\Rightarrow$ combination of
Jets, Leptons, E_T^{miss}

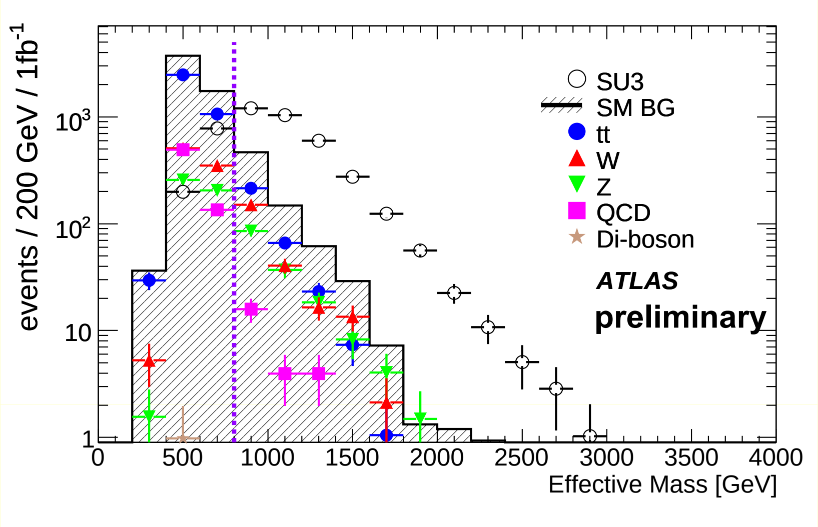
1. Step: Look for deviations from the Standard Model
   Example: Multijet + E_T^{miss} signature

2. Step: Establish the SUSY mass scale use inclusive variables, e.g. effective mass distribution

3. Step: Determine model parameters (difficult)
   Strategy: select particular decay chains and use kinematics to determine mass combinations

Squarks and Gluinos

- If R-parity conserved, cascade decays produce distinctive events:
  multiple jets, leptons, and E_T^{miss}
- Typical selection: $N_{jet} > 4$, $E_T > 100, 50, 50, 50$ GeV, $E_T^{miss} > 100$ GeV
- Define: $M_{eff} = E_T^{miss} + P_T^1 + P_T^2 + P_T^3 + P_T^4$ (effective mass)



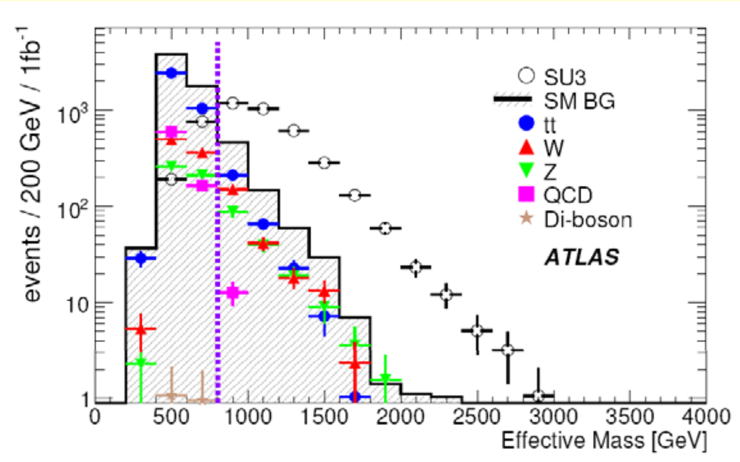
example: mSUGRA, point SU3 (bulk region)
m_0 = 100 GeV, $m_{1/2}$ = 300 GeV
tan β = 6, A_0 = -300 GeV, $\mu > 0$

LHC reach for Squark- and Gluino masses:

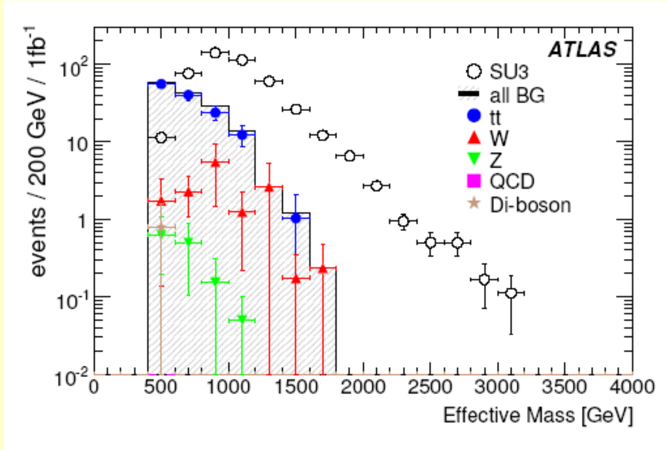
0.1 fb^{-1}	$\Rightarrow$	M ~ 750 GeV
1 fb^{-1}	$\Rightarrow$	M ~ 1350 GeV
10 fb^{-1}	$\Rightarrow$	M ~ 1800 GeV

Deviations from the Standard Model due to SUSY at the TeV scale can be detected fast !

…additional potential: inclusive searches with leptons

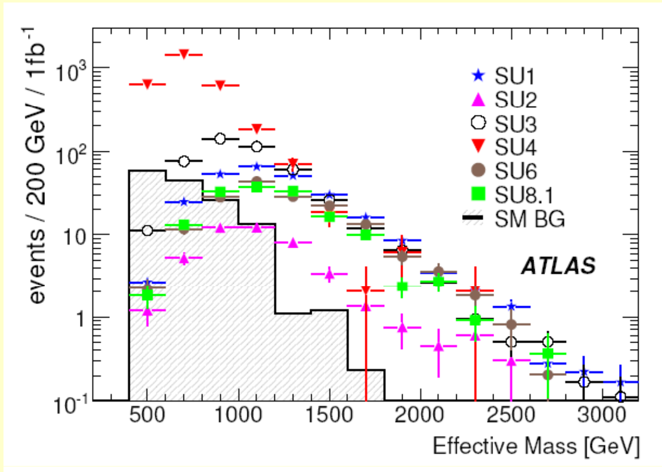


SU3, 4 jets + 0 lepton final states



SU3, 4 jets + 1 lepton final states

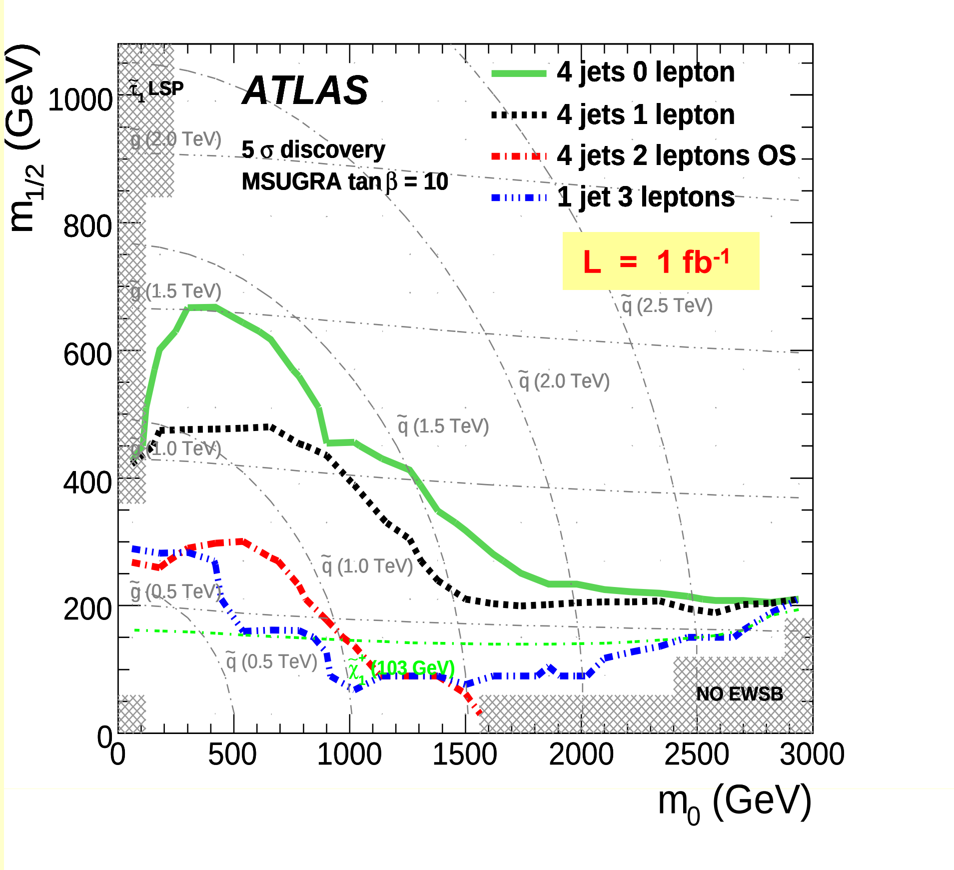
- smaller signal rates, but better S:B conditions
- Discovery potential is more robust, in particular at the beginning, when systematic uncertainties on the backgrounds are large
- Similar analyses with τ lepton and b quark final states



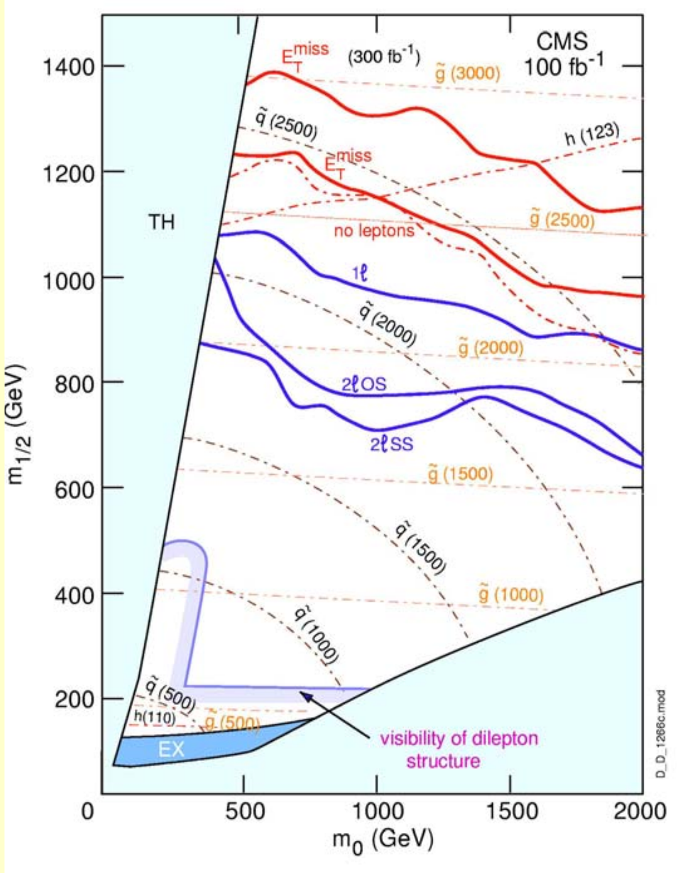
4 jets + 1 lepton final states for other benchmark points

LHC reach in the m_0 - $m_{1/2}$ mSUGRA plane:

Multijet + E_T^{miss} signature



SUSY cascade decays give also rise to many other inclusive signatures: **leptons, b-jets, τ's**

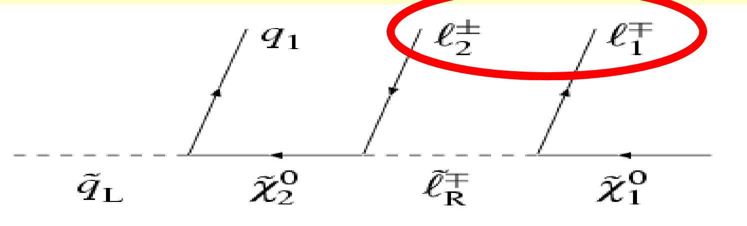


- Tevatron reach can be extended with early data
- Expect multiple signatures for TeV-scale SUSY
  Long term mass reach (300 fb^{-1}): 2.5 – 3 TeV

LHC Strategy for determination of model parameters:

End point spectra of cascade decays

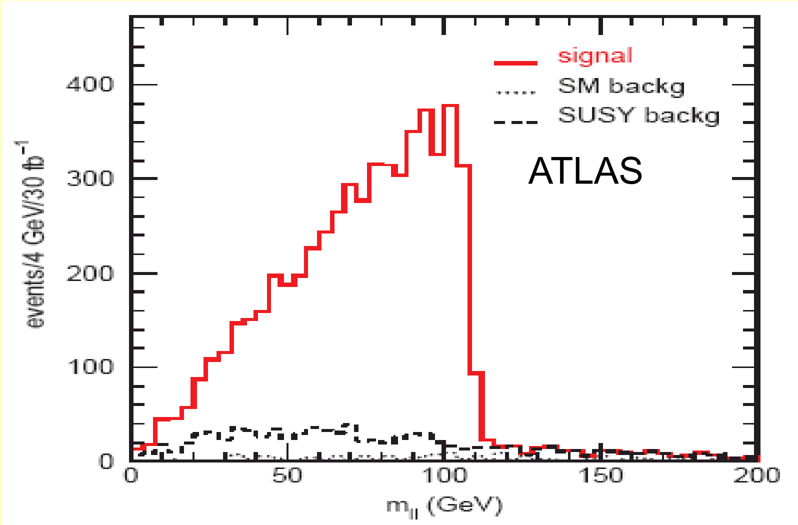
Example: $\tilde{q} \to q\tilde{\chi}_2^0 \to q\tilde{\ell}^\pm\ell^\mp \to q\ell^\pm\ell^\mp\tilde{\chi}_1^0$



$$M_{\ell^+\ell^-}^{max} = \frac{\sqrt{(m_{\chi_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\chi_1^0}^2)}}{m_{\tilde{\ell}}}$$

$$M_{\ell_1 q}^{max} = \frac{\sqrt{(m_{\chi_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{q}}^2 - m_{\chi_2^0}^2)}}{m_{\chi_2^0}}$$

- Due to LSPs in the final state the SUSY particle masses cannot be reconstructed
- Measure shapes of kinematic distributions of final state particles;
  endpoints depend on sparticle masses involved
- $\Rightarrow$ global fit



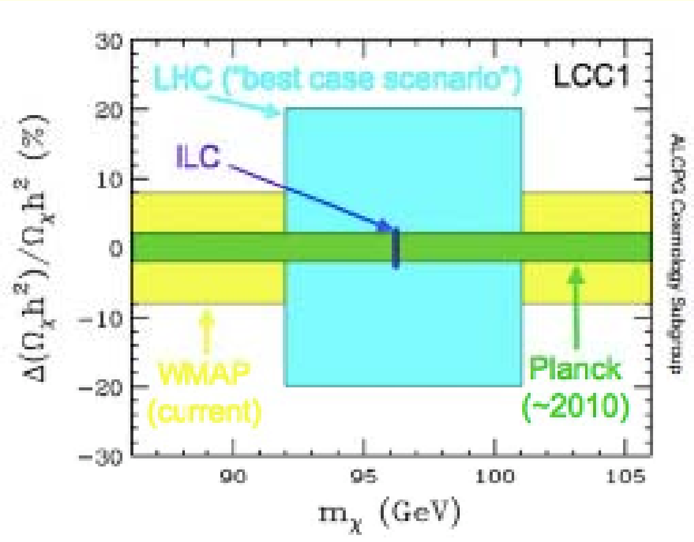
Strategy in SUSY Searches at the LHC:

- Search for multijet + E_T^{miss} excess
- Look for special features (γ's , long lived sleptons)
- Look for $\ell^\pm$, $\ell^+ \ell^-$, $\ell^\pm \ell^\pm$, b-jets, τ's
- End point analyses, global fit

  $\Rightarrow$ Parameters of the SUSY model

  Complex: requires close cooperation between experimentalists and theorists !

  $\Rightarrow$ Predict dark matter relic density, check consistency with other measurements



Models other than SUGRA

GMSB:

- LSP is light gravitino
- Phenomenology depends on nature and lifetime of the NLSP
- Generally longer decay chains, e.g. $\tilde{\chi}_2^0 \to \tilde{\ell}^{\pm}\ell^{\mp} \to \tilde{\chi}_1^0 \ell^+\ell^- \to \tilde{G}\gamma\ell^+\ell^-$

$\Rightarrow$ models with prompt NLSP decays give additional handles and hence are easier than SUGRA

- NLSP lifetime can be measured:
  - For $\tilde{\chi}_1^0 \to \tilde{G}\gamma,$ use Dalitz decays (short lifetime) or search for non-pointing photons
  - Quasi stable sleptons: muon system provides excellent „Time of Flight“ system

RPV :

- R-violation via $\chi^0_1 \to \ell\ell\nu$ or qqℓ, qqν gives additional leptons and/or E_T^{miss}

- R-violation via $\chi^0_1 \to$ cds is probably the hardest case; (c-tagging, uncertainties on QCD multijet background)

Conclusions

- The LHC experiments are well set up to explore the existence of Higgs Bosons and Supersymmetry
  …... and are well prepared for unexpected scenarios

- Higgs: the full Standard Model mass range and the full MSSM parameter space can be covered (CP-conserving models)

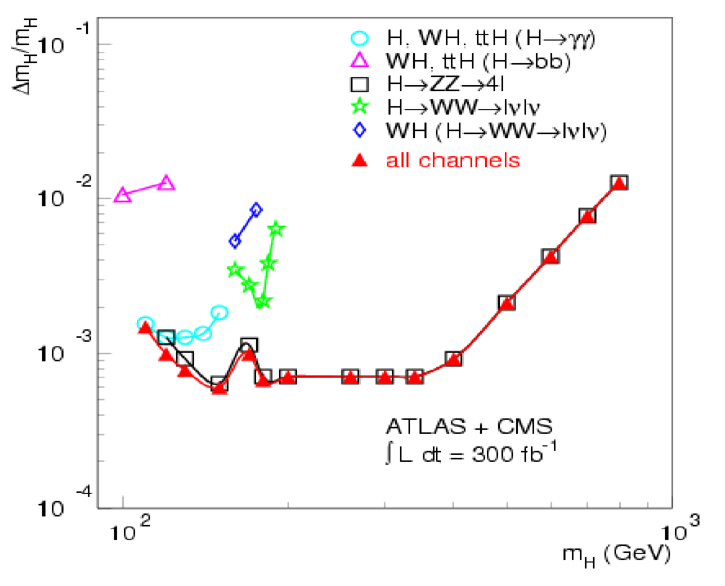
  in addition: important parameter measurements (mass, spin, ratio of couplings) can be performed

- SUSY: discovery of deviations from the Standard Model due to SUSY should be easy and fast, the determination of model parameters is more difficult

- LHC data will hopefully soon give guidance to theory and to future experiments

Backup Slides

Measurement of the Higgs boson mass



Dominated by ZZ→ 4ℓ and γγ resonances !

well identified, measured with a good resolution

Dominant systematic uncertainty: γ / ℓ E scale.

Assumed 1‰

Goal 0.2‰

Scale from $Z \rightarrow \ell\ell$ (close to light Higgs)

Higgs boson mass can be measured with a precision of 0.1%
over a large mass range (130 - ~450 GeV / c^2)

Measurement of Higgs-Boson Coupling Ratios

assumptions: only SM particles couple to Higgs boson,

no large couplings of light fermions

Fit parameters:

$$\frac{g_Z^2}{g_W^2} \quad \frac{g_\tau^2}{g_W^2} \quad \frac{g_b^2}{g_W^2} \quad \frac{g_t^2}{g_W^2} \quad \frac{g_w^2}{\sqrt{\Gamma_H}}$$

Global fit (ATLAS study)

(all channels at a given mass point)

Production cross sections

$$\sigma_{ggH} = \alpha_{ggH} \bullet g_t^2$$

$$\sigma_{VBF} = \alpha_{WF} \bullet g_w^2 + \alpha_{ZF} \bullet g_Z^2$$

$$\sigma_{ttH} = \alpha_{ttH} \bullet g_t^2$$

$$\sigma_{WH} = \alpha_{WH} \bullet g_W^2$$

$$\sigma_{ZH} = \alpha_{ZH} \bullet g_Z^2$$

b loop neglected for now in ggH

α from theory with assumed uncertainty $\Delta\alpha$

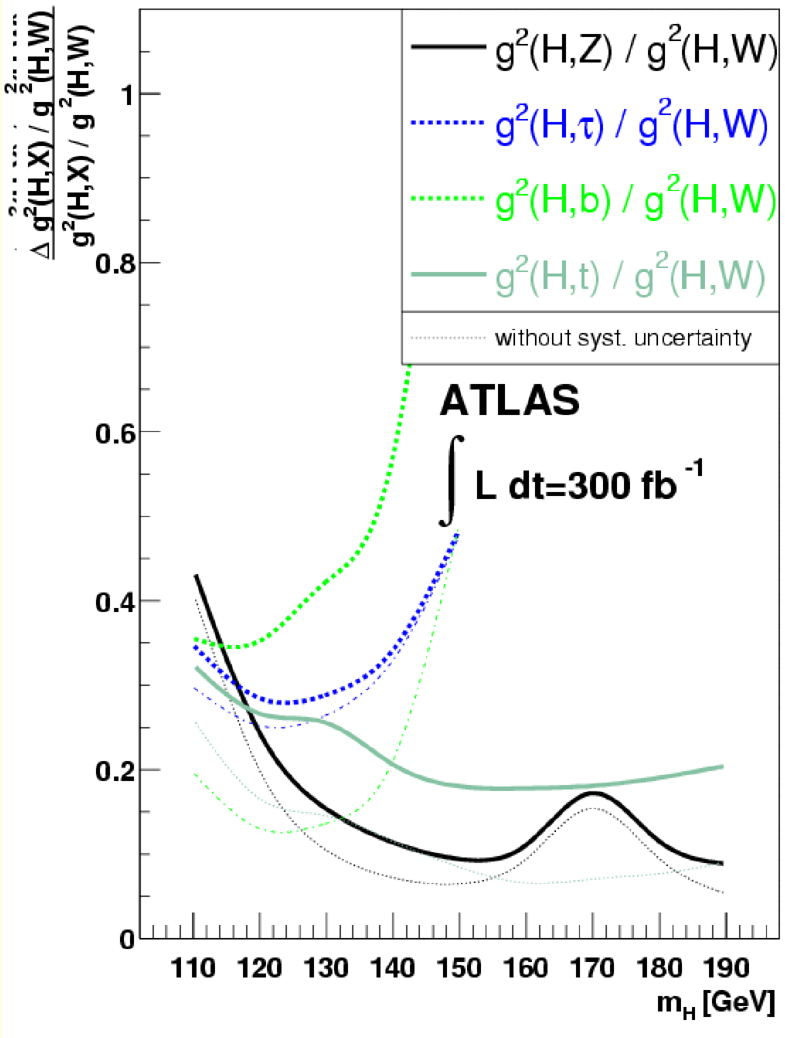
$$\Delta\alpha_{ggH} = 20\%$$

$$\Delta\alpha_{WF} = \alpha_{ZF} = 4\%$$

$$\Delta\alpha_{ttH} = 15\%$$

$$\Delta\alpha_{WH} = \Delta\alpha_{ZH} = 7\%$$

Ratio of Higgs-Boson Couplings



Branching ratios

$$BR(H \to WW) = \beta_W \frac{g_W^2}{\Gamma_H}$$

$$BR(H \to ZZ) = \beta_Z \frac{g_Z^2}{\Gamma_H}$$

$$BR(H \to \gamma\gamma) = \frac{\left(\beta_{\gamma(W)} g_W - \beta_{\gamma(t)} g_t\right)^2}{\Gamma_H}$$

$\Delta\beta = 1\ \%$

$$BR(H \to \tau\tau) = \beta_\tau \frac{g_\tau^2}{\Gamma_H}$$

$$BR(H \to bb) = \beta_b \frac{g_b^2}{\Gamma_H}$$

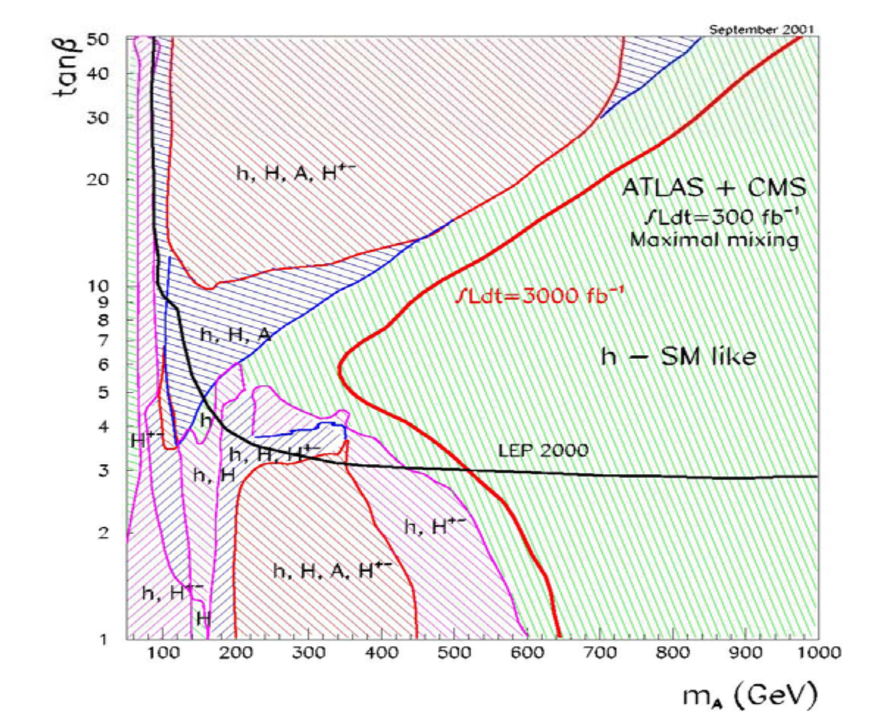
Rate as function of x_i, e.g.

$$(\sigma \bullet BR)_{ggH, H \to ZZ} =$$

$$\alpha_{ggH} \frac{g_t^2}{g_W^2} \frac{g_W^2}{\sqrt{\Gamma_H}} \beta_Z \frac{g_Z^2}{g_W^2} \frac{g_W^2}{\sqrt{\Gamma_H}}$$

MSSM discovery potential for Super-LHC

ATLAS + CMS,   2 x 3000 fb^{-1}



- Situation can be improved, in particular for m_A < ~400 GeV
- But: SLHC cannot promise a complete observation of the heavy part of the MSSM Higgs spectrum ....

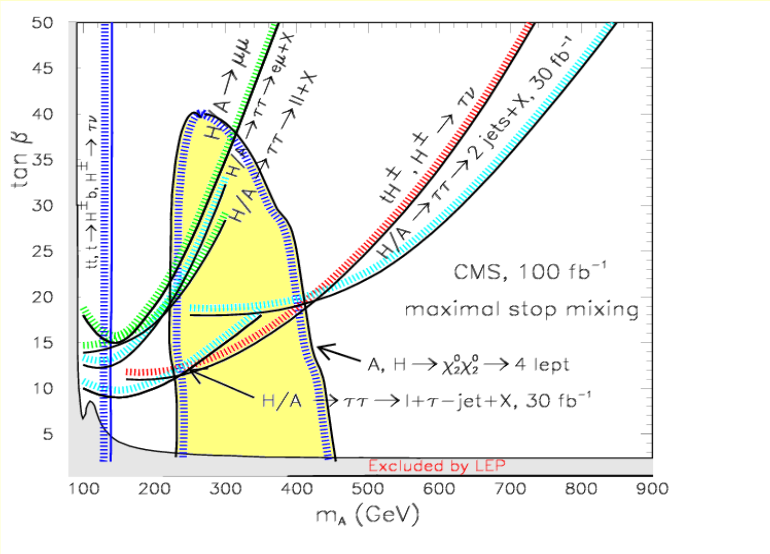
.... although the observation of sparticles will clearly indicate that additional Higgs bosons should exist.

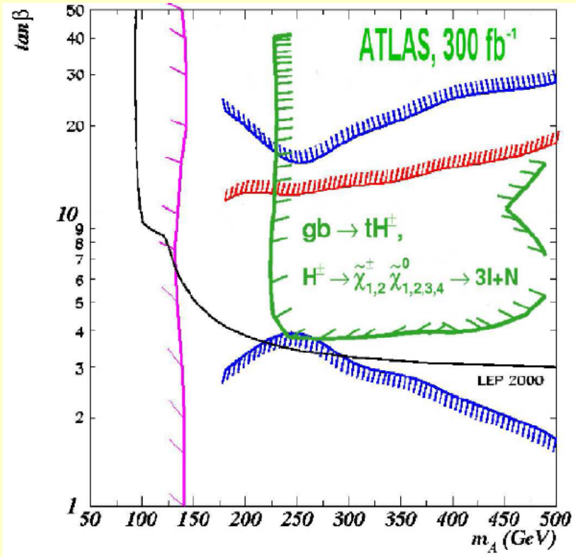
Higgs decays via SUSY particles

If SUSY exists : search for

$H/A \rightarrow \chi^0{}_2\chi^0{}_2 \rightarrow \ell\ell\chi^0{}_1\ \ell\ell\chi^0{}_1$

$gb \rightarrow tH^+,\ H^\pm \rightarrow \chi_{2,3}{}^0\ \chi_{1,2}{}^\pm \rightarrow 3\ell + E_T{}^{miss}$





CMS: special choice in MSSM (no scan)

M_1 = 60 GeV/c^2

M_2 = 110 GeV/c^2

μ = -500 GeV/c^2

ATLAS: special choice in MSSM (no scan)

M_1 = 60 GeV/c^2

M_2 = 210 GeV/c^2

μ = 135 GeV/c^2

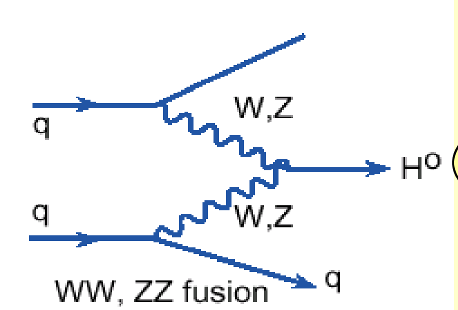
m(s-ℓ_R) = 110 GeV/c^2

m(s-τ_R) = 210 GeV/c^2

- Exclusions depend on MSSM parameters (slepton masses, m)
- More systematic studies are needed (initiated by A. Djouadi et al.)

Invisible Higgs decays ?

Possible searches: tt H $\rightarrow$ ℓνb qqb + P_T^{miss}
Z H $\rightarrow$ ℓℓ + P_T^{miss}
qq H $\rightarrow$ qq + P_T^{miss}

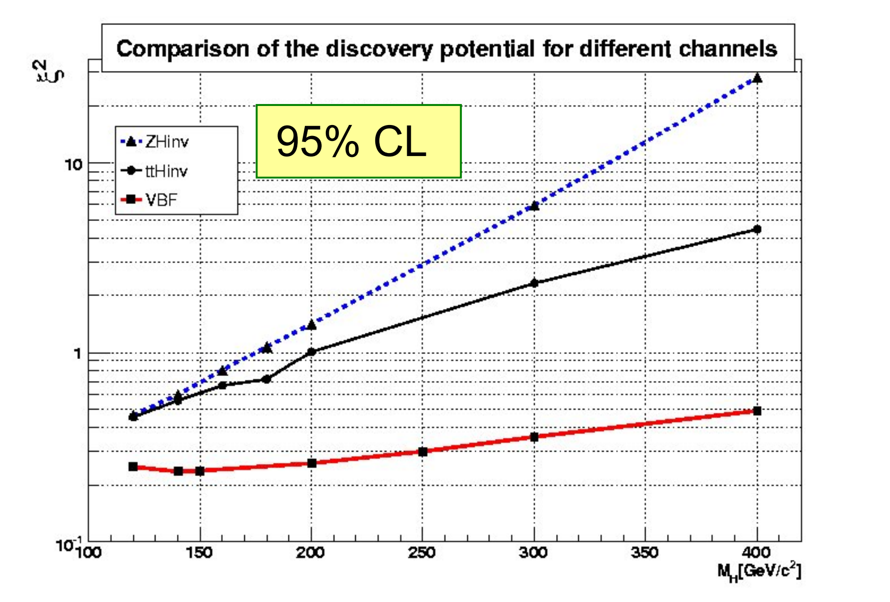


P_T^{miss}

- J.F. Gunion, Phys. Rev. Lett. 72 (1994)
- D. Choudhury and D.P. Roy, Phys. Lett. B322 (1994)
- O. Eboli and D. Zeppenfeld, Phys. Lett. B495 (2000)

All three channels have been studied:
key signature: excess of events above SM backgrounds with large P_T^{miss} (> 100 GeV/c)

Sensitivity: $$\xi^2 = Br(H \rightarrow Inv.) \frac{\sigma_{qq \rightarrow qqH}}{\sigma_{qq \rightarrow qqH}|_{SM}}$$



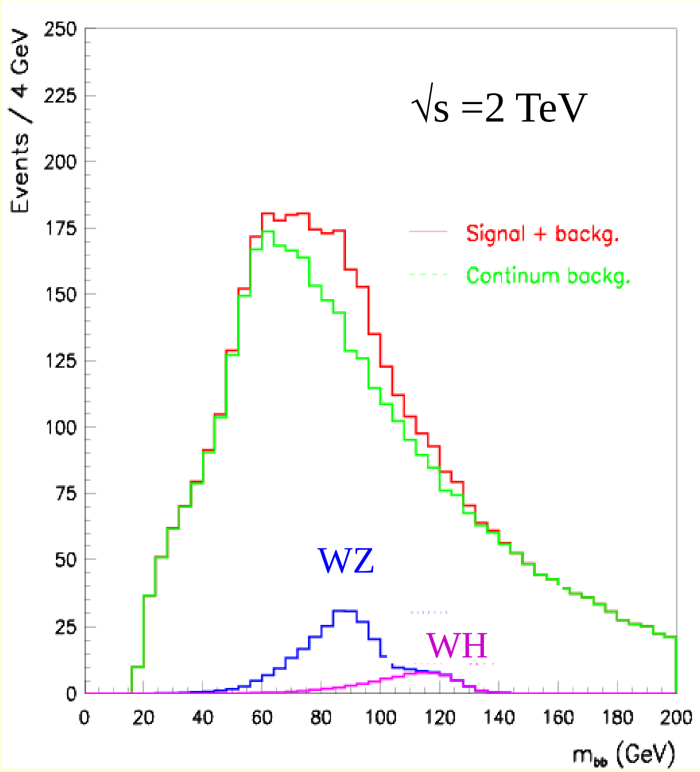
ATLAS preliminary

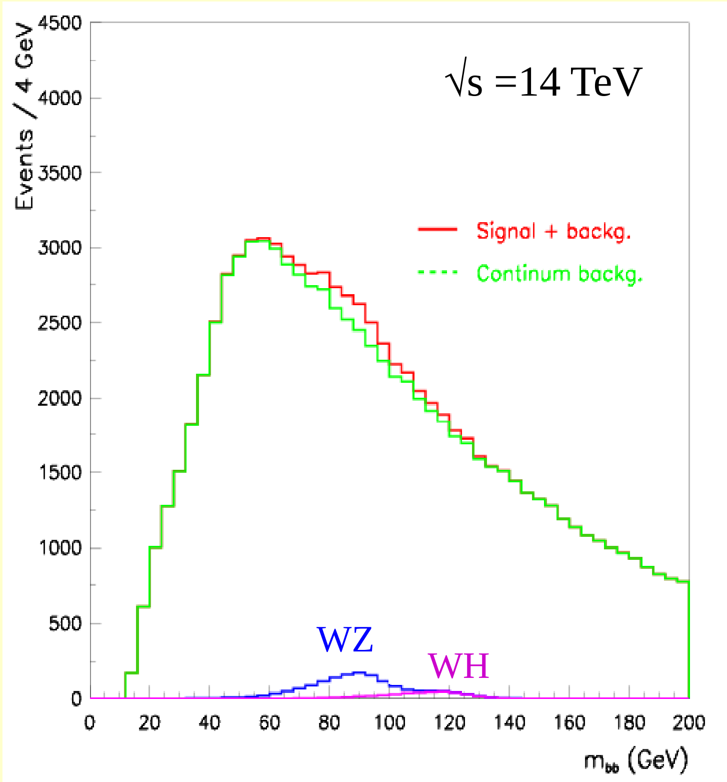
Problems / ongoing work:

- ttH and ZH channels have low rates
- More difficult trigger situation for qqH
- backgrounds need to be precisely known (partially normalization using ref. channels possible)
- non SM scenarios are being studied at present first example: SUSY scenario

WH Signals at the LHC and the Tevatron

M_H = 120 GeV/c^2,   30 fb^{-1}





important issues:

- needs excellent b-tagging
- needs excellent bb mass resolution
- needs good control of the background shapes, very difficult !

ATLAS benchmark points

SU1 $m_0 = 70$ GeV, $m_{1/2} = 350$ GeV, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$. Coannihilation region where $\tilde{\chi}_1^0$ annihilate with near-degenerate $\tilde{\ell}$.

SU2 $m_0 = 3550$ GeV, $m_{1/2} = 300$ GeV, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$. Focus point region near the boundary where $\mu^2 < 0$. This is the only region in mSUGRA where the $\tilde{\chi}_1^0$ has a high higgsino component, thereby enhancing the annihilation cross-section for processes such as $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WW$.

SU3 $m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $A_0 = -300$ GeV, $\tan\beta = 6$, $\mu > 0$. Bulk region: LSP annihilation happens through the exchange of light sleptons.

SU4 $m_0 = 200$ GeV, $m_{1/2} = 160$ GeV, $A_0 = -400$ GeV, $\tan\beta = 10$, $\mu > 0$. Low mass point close to Tevatron bound.

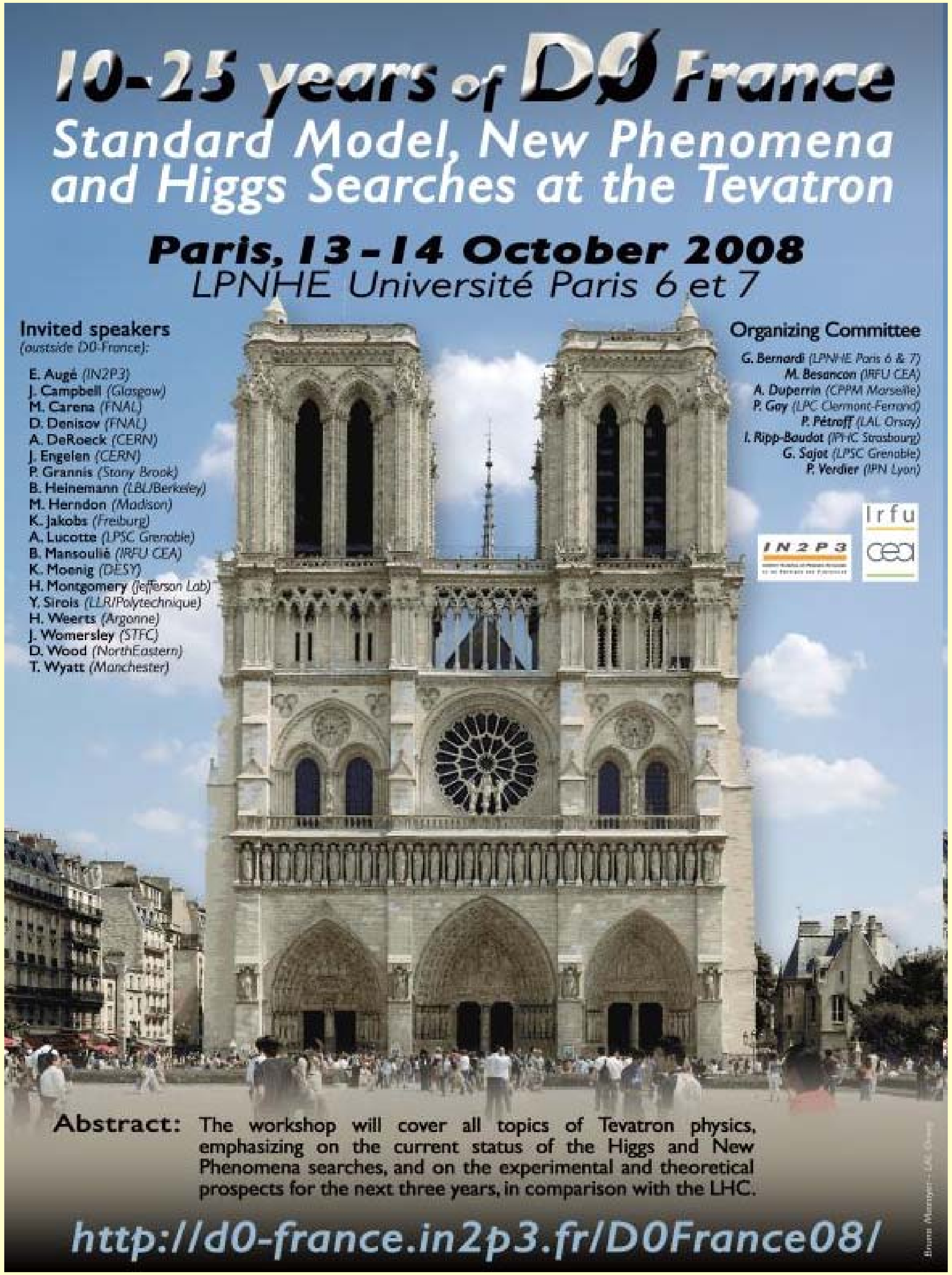
SU6 $m_0 = 320$ GeV, $m_{1/2} = 375$ GeV, $A_0 = 0$, $\tan\beta = 50$, $\mu > 0$. The funnel region where $2m_{\tilde{\chi}_1^0} \approx m_A$. Since $\tan\beta \gg 1$, the width of the pseudoscalar Higgs boson A is large and τ decays dominate.

SU8.1 $m_0 = 210$ GeV, $m_{1/2} = 360$ GeV, $A_0 = 0$, $\tan\beta = 40$, $\mu > 0$. Variant of coannihilation region with $\tan\beta \gg 1$, so that only $m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$ is small.

SU9 $m_0 = 300$ GeV, $m_{1/2} = 425$ GeV, $A_0 = 20$, $\tan\beta = 20$, $\mu > 0$. Point in the bulk region with enhanced Higgs production

CMS LM benchmark points

- Point LM1 :
  - Same as post-WMAP benchmark point B′ and near DAQ TDR point 4.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant
  - $B(\tilde{\chi}_2^0 \to \tilde{l}_R l) = 11.2\%$, $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 46\%$, $B(\tilde{\chi}_1^{\pm} \to \tilde{\nu}_l l) = 36\%$
- Point LM2 :
  - Almost identical to post-WMAP benchmark point I′.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant ($\tilde{b}_1 b$ is 25%)
  - $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 96\%$ $B(\tilde{\chi}_1^{\pm} \to \tilde{\tau}\nu) = 95\%$
- Point LM3 :
  - Same as NUHM point γ and near DAQ TDR point 6.
  - $m(\tilde{g}) < m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is forbidden except $B(\tilde{g} \to \tilde{b}_{1,2} b) = 85\%$
  - $B(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0) = 3.3\%$, $B(\tilde{\chi}_2^0 \to \tau\tau\tilde{\chi}_1^0) = 2.2\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 100\%$
- Point LM4 :
  - Near NUHM point α in the on-shell Z^0 decay region
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant with $\tilde{g} \to \tilde{b}_1 b = 24\%$
  - $B(\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0) = 97\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 100\%$
- Point LM5 :
  - In the h^0 decay region, same as NUHM point β.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant with $B(\tilde{g} \to \tilde{b}_1 b) = 19.7\%$ and $B(\tilde{g} \to \tilde{t}_1 t) = 23.4\%$
  - $B(\tilde{\chi}_2^0 \to h^0\tilde{\chi}_1^0) = 85\%$, $B(\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0) = 11.5\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 97\%$
- Point LM6 :
  - Same as post-WMAP benchmark point C′.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant
  - $B(\tilde{\chi}_2^0 \to \tilde{l}_L l) = 10.8\%$, $B(\tilde{\chi}_2^0 \to \tilde{l}_R l) = 1.9\%$, $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 14\%$, $B(\tilde{\chi}_1^{\pm} \to \tilde{\nu}_l l) = 44\%$
- Point LM7 :
  - Very heavy squarks, outside reach, but light gluino.
  - $m(\tilde{g}) = 678\,\mathrm{GeV/c^2}$, hence $\tilde{g} \to$ 3-body is dominant
  - $B(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0) = 10\%$, $B(\tilde{\chi}_1^{\pm} \to \nu l\tilde{\chi}_1^0) = 33\%$
  - EW chargino-neutralino production cross-section is about 73% of total.
- Point LM8 :
  - Gluino lighter than squarks, except $\tilde{b}_1$ and $\tilde{t}_1$
  - $m(\tilde{g}) = 745\,\mathrm{GeV/c^2}$, $M(\tilde{t}_1) = 548\,\mathrm{GeV/c^2}$, $\tilde{g} \to \tilde{t}_1 t$ is dominant
  - $B(\tilde{g} \to \tilde{t}_1 t) = 81\%$, $B(\tilde{g} \to \tilde{b}_1 b) = 14\%$, $B(\tilde{q}_L \to q\tilde{\chi}_2^0) = 26 - 27\%$,
  - $B(\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0) = 100\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 100\%$
- Point LM9 :
  - Heavy squarks, light gluino. Consistent with EGRET data on diffuse gamma ray spectrum, WMAP results on CDM and mSUGRA [674]. Similar to LM7.
  - $m(\tilde{g}) = 507\,\mathrm{GeV/c^2}$, hence $\tilde{g} \to$ 3-body is dominant
  - $B(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0) = 6.5\%$, $B(\tilde{\chi}_1^{\pm} \to \nu l\tilde{\chi}_1^0) = 22\%$
- Point LM10 :
  - Similar to LM7, but heavier gauginos.
  - Very heavy squarks, outside reach, but light gluino.
  - $m(\tilde{g}) = 1295\,\mathrm{GeV/c^2}$, hence $\tilde{g} \to$ 3-body is dominant
  - $B(\tilde{g} \to t\bar{t}\tilde{\chi}_4^0) = 11\%$, $B(\tilde{g} \to tb\tilde{\chi}_2^{\pm}) = 27\%$


10-25 years of DØ France
Standard Model, New Phenomena
and Higgs Searches at the Tevatron
Paris, 13 - 14 October 2008
LPNHE Université Paris 6 et 7
Invited speakers
(oustside D0-France):
E. Augé (IN2P3)
J. Campbell (Glasgow)
M. Carena (FNAL)
D. Denisov (FNAL)
A. DeRoeck (CERN)
J. Engelen (CERN)
P. Grannis (Stony Brook)
B. Heinemann (LBL/Berkeley)
M. Herndon (Madison)
K. Jakobs (Freiburg)
A. Lucotte (LPSC Grenoble)
B. Mansoulié (IRFU CEA)
K. Moenig (DESY)
H. Montgomery (Jefferson Lab)
Y. Sirois (LLR/Polytechnique)
H. Weerts (Argonne)
J. Womersley (STFC)
D. Wood (NorthEastern)
T. Wyatt (Manchester)
Organizing Committee
G. Bernardi (LPNHE Paris 6 & 7)
M. Besancon (IRFU CEA)
A. Duperrin (CPPM Marseille)
P. Gay (LPC Clermont-Ferrand)
P. Pétroff (LAL Orsay)
I. Ripp-Baudot (IPHC Strasbourg)
G. Sajot (LPSC Grenoble)
P. Verdier (IPN Lyon)
Abstract: The workshop will cover all topics of Tevatron physics, emphasizing on the current status of the Higgs and New Phenomena searches, and on the experimental and theoretical prospects for the next three years, in comparison with the LHC.
http://d0-france.in2p3.fr/D0France08/