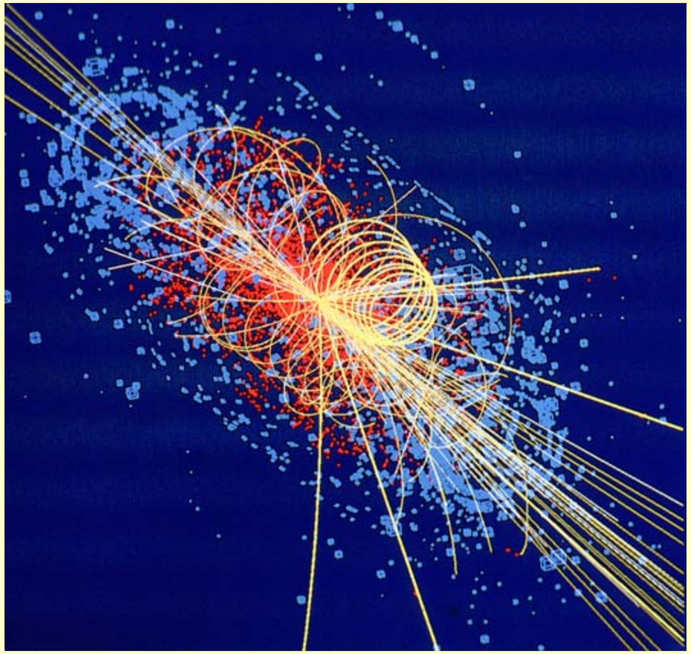
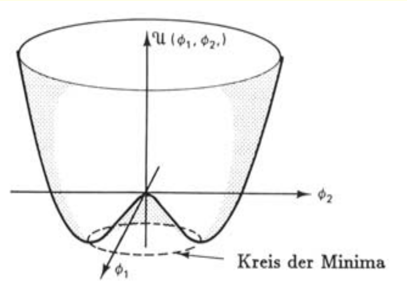
Prospects for Higgs Boson Searches at the LHC

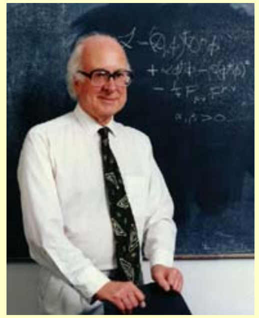


- Introduction, Status of machine and detectors
- Updated results on SM Higgs Searches
- Measurement of Higgs Boson parameters
- MSSM Higgs bosons and more exotic scenarios

Karl Jakobs
Physikalisches Institut
Universität Freiburg / Germany



The Higgs Boson

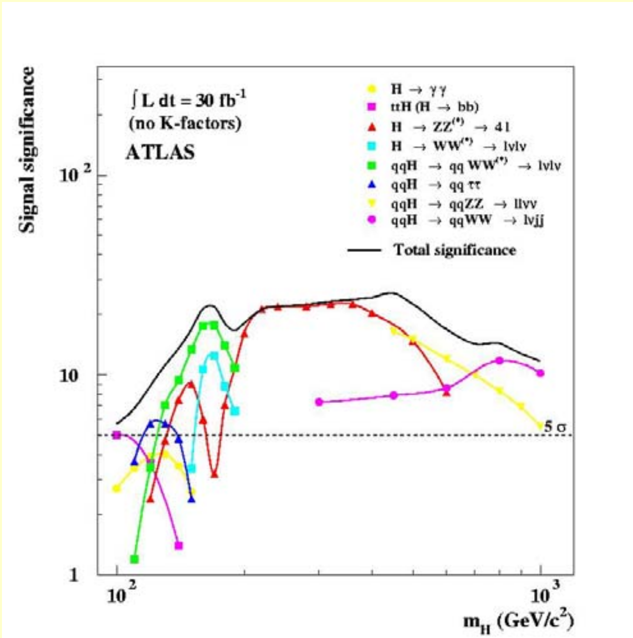


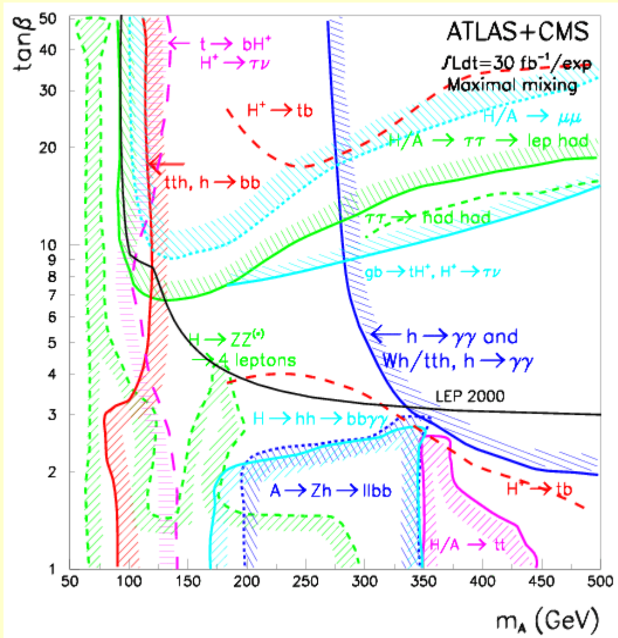
- „Revealing the physical mechanism that is responsible for the breaking of electroweak symmetry is one of the key problems in particle physics”

- „A new collider, such as the LHC must have the potential to detect this particle, should it exist.”

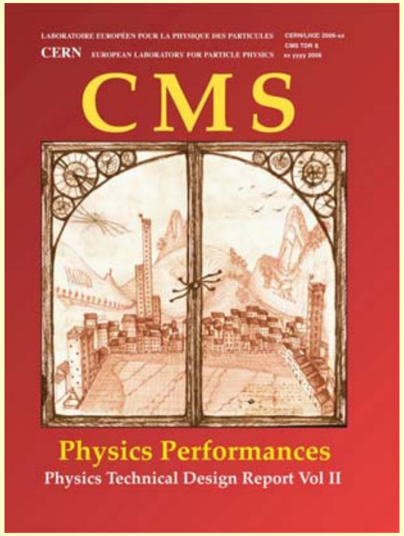
- Seems to be possible

ATLAS & CMS studies





What is new on LHC studies ?



CERN / LHCC 2006-021

- 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 2007

- 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.
  - PYTHIA, adapted by S. Mrenna
  - SHERPA Monte Carlo, F. Krauss et al., www.sherpa-mc.de
  - …

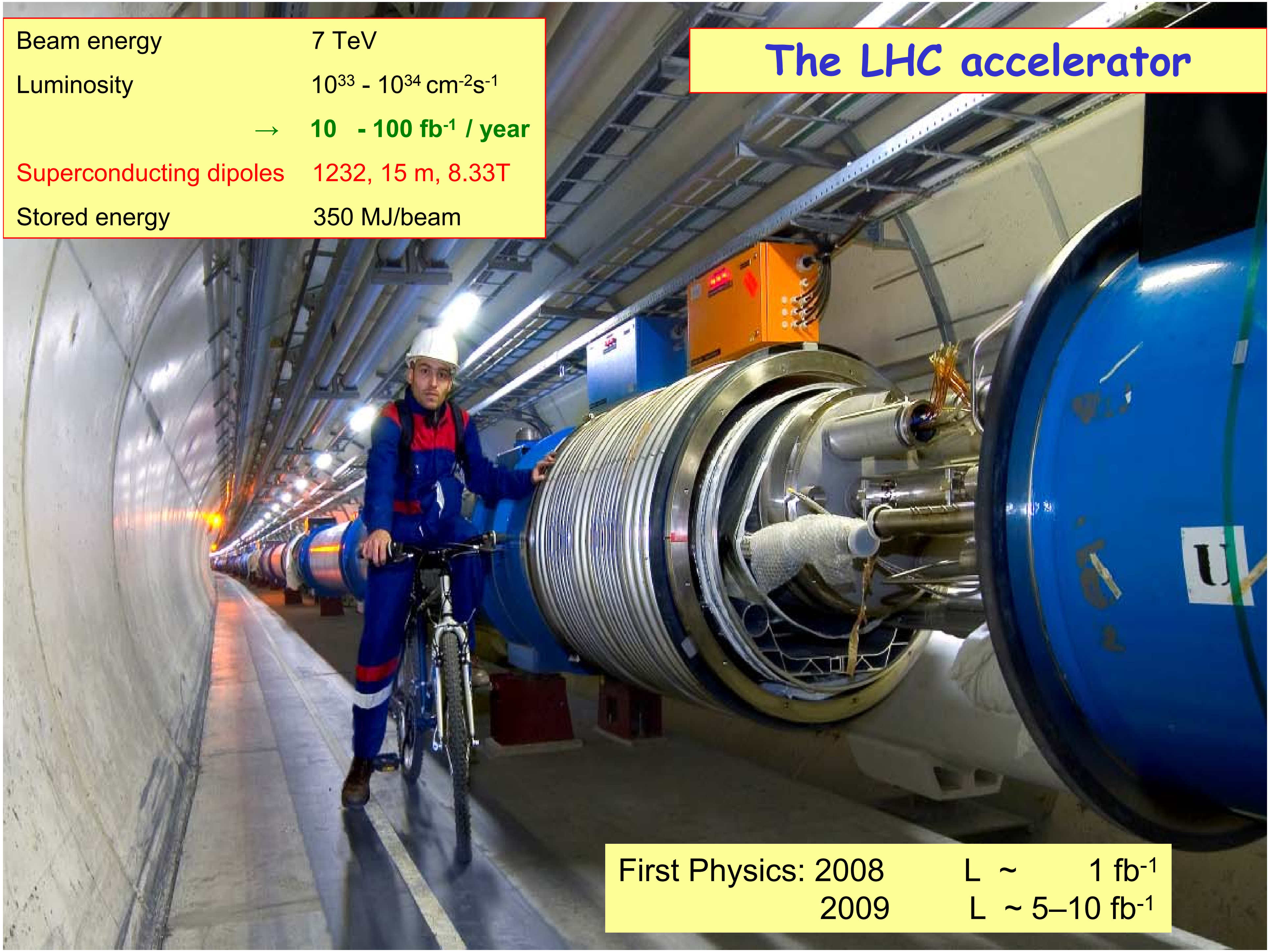
  Tevatron data are extremely valuable for validation, work has started

- 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,…..)

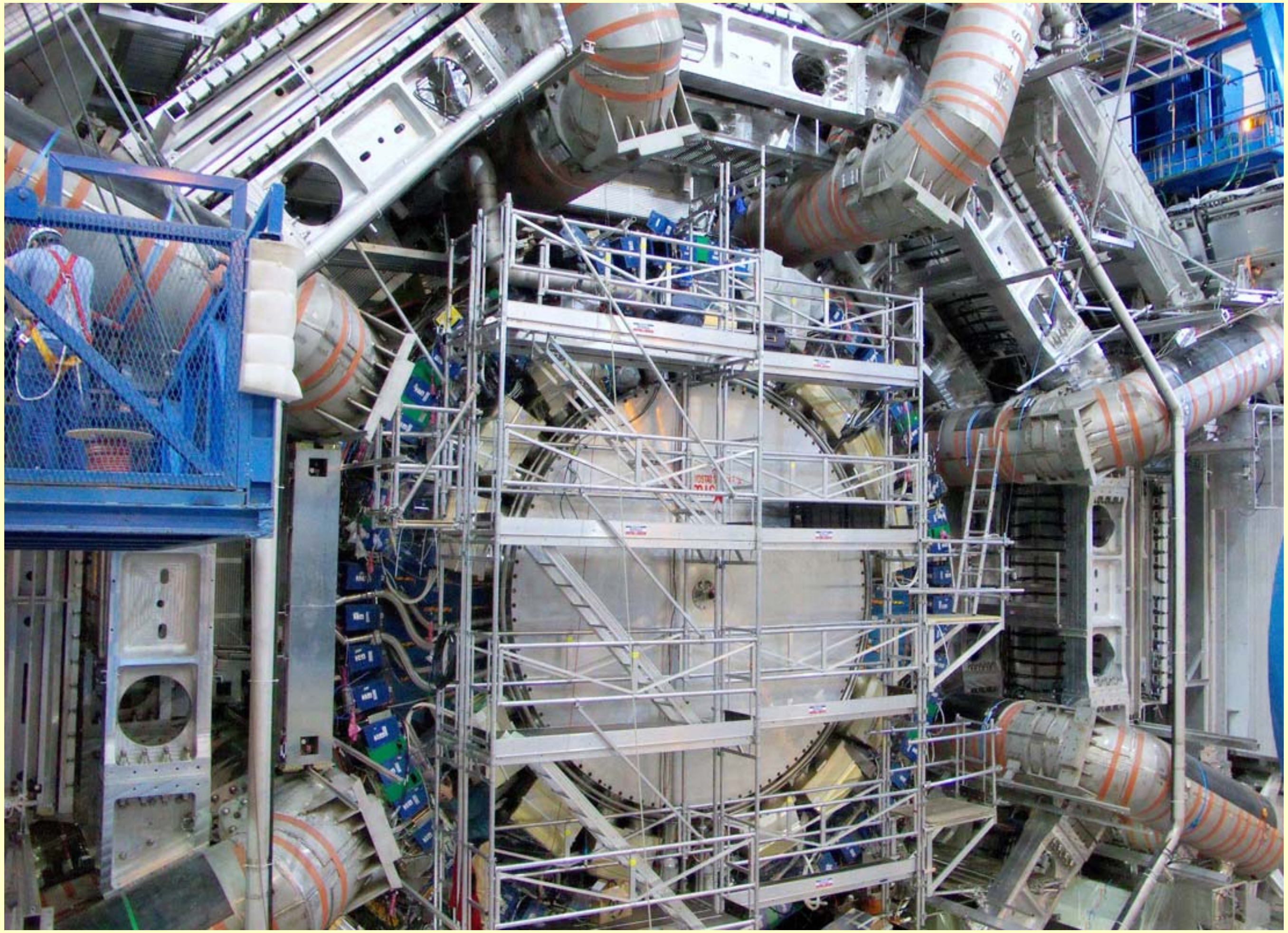
The LHC accelerator

Beam energy	7 TeV
Luminosity	10^{33} - 10^{34} $cm^{-2}s^{-1}$
→	**10 - 100 fb^{-1} / year**
Superconducting dipoles	1232, 15 m, 8.33T
Stored energy	350 MJ/beam



First Physics: 2008 L ~ 1 fb^{-1}
2009 L ~ 5–10 fb^{-1}

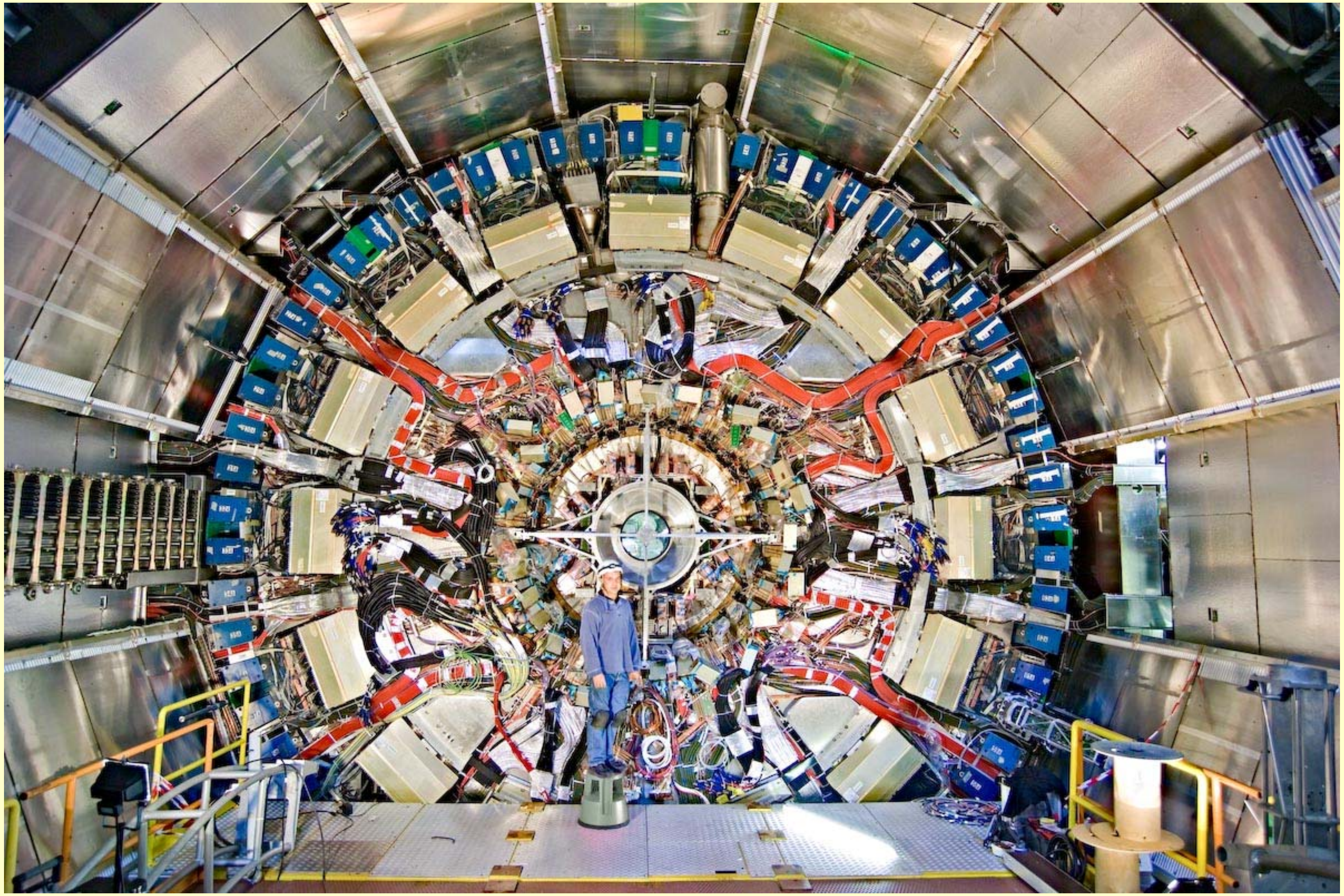
ATLAS Installation

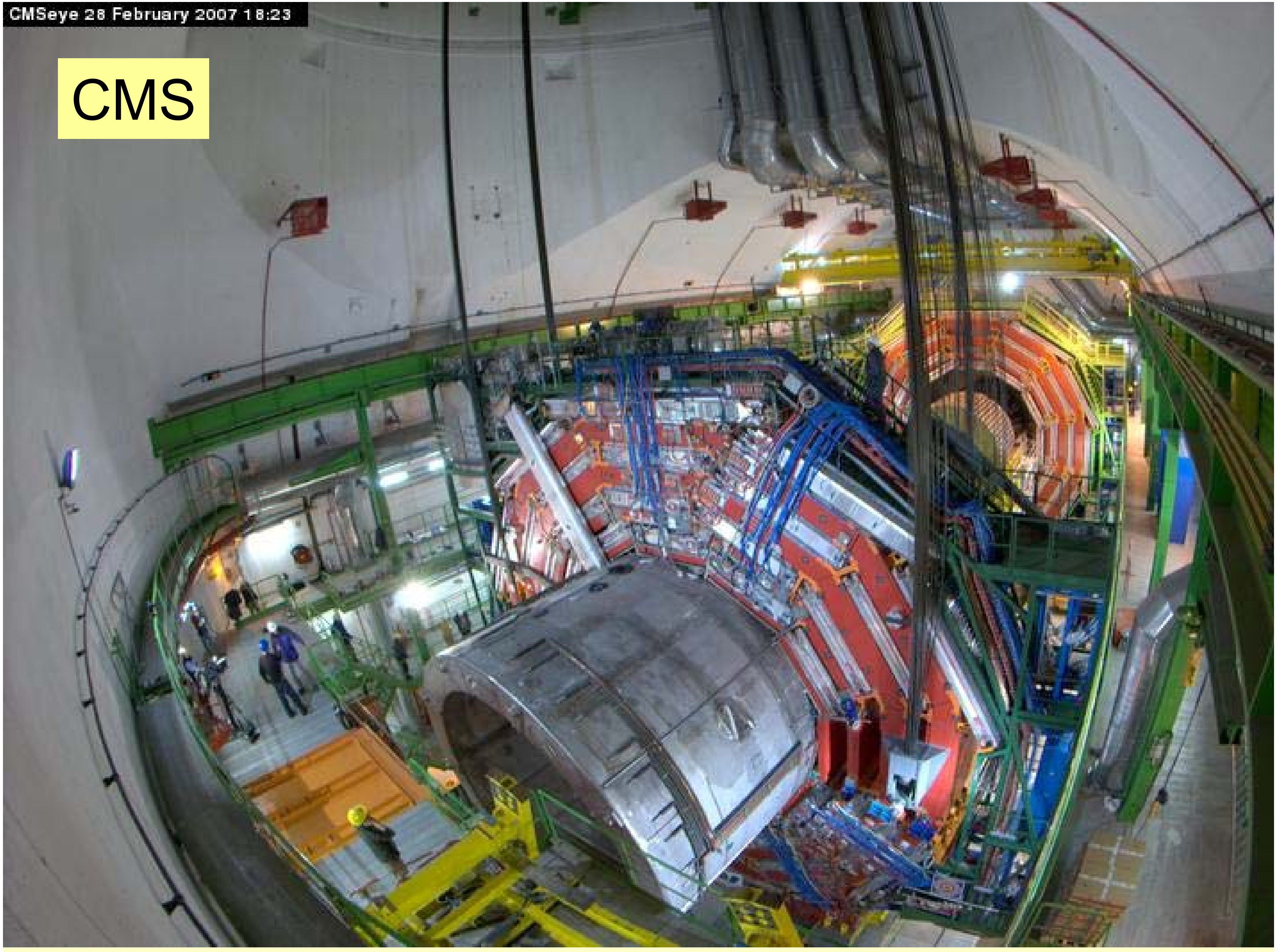


October 2005
January 2007

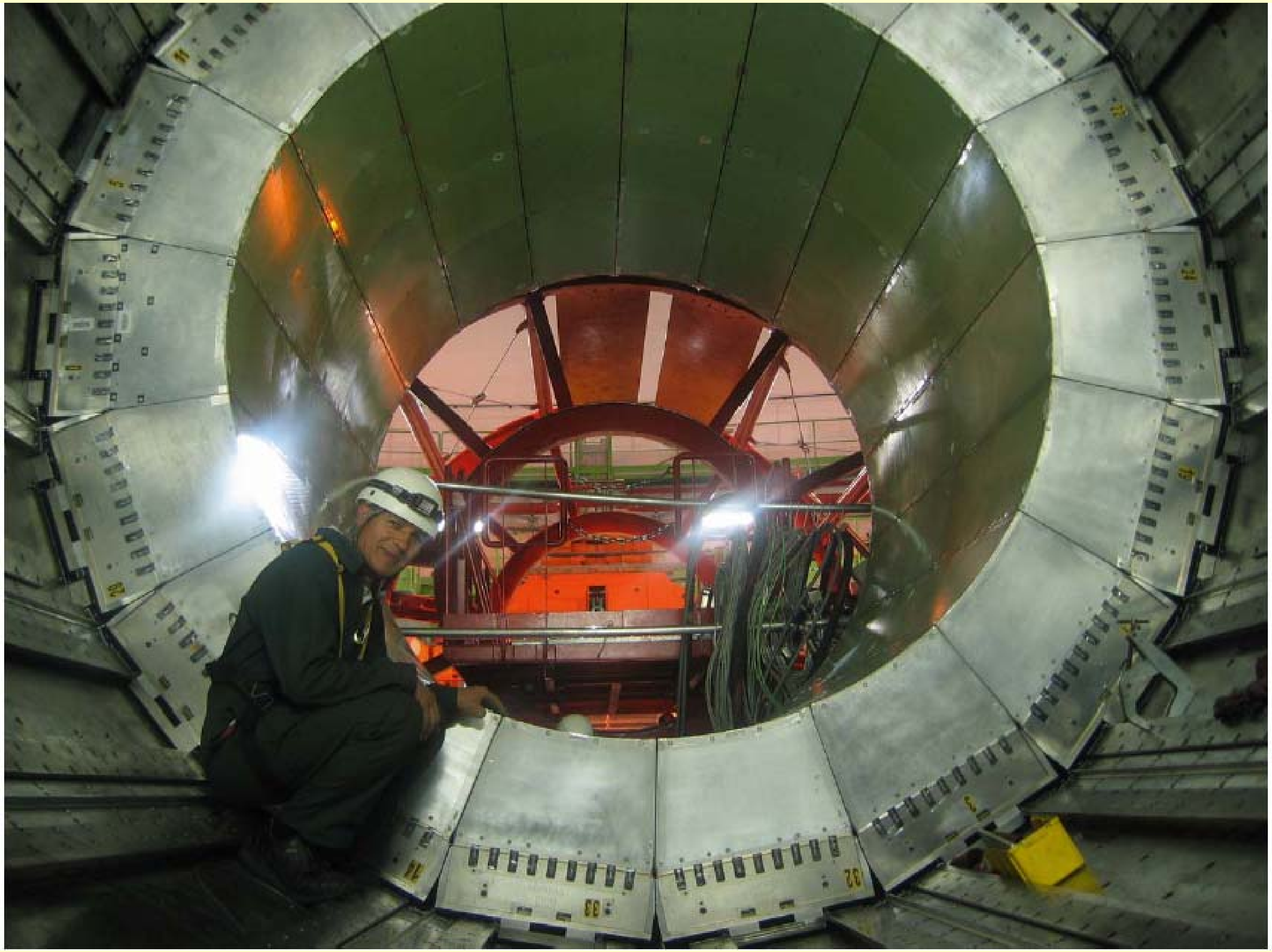
- Construction of the detector component nearly finished
- Installation in full swing
- Ready for first pp collisions end of 2007 or Spring 2008

Installation of the first (out of two) ATLAS Endcap Tracking Detector (completed on 29. May 2007)




CMSeye 28 February 2007 18:23
CMS

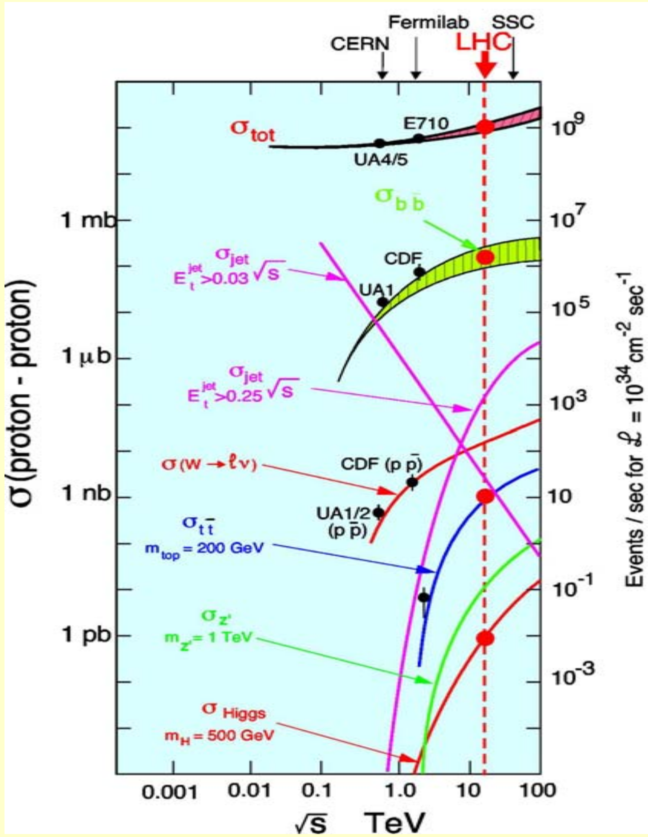
Installation of the CMS Electromagnetic Barrel Calorimeter (completed on 22. May 2007)



Which physics the first year(s) ?

Expected event rates at production in ATLAS and CMS at $L = 10^{33}\ cm^{-2}\ s^{-1}$

Process	Events / sec	Events for 10 fb^{-1}	Total stat. collected at previous machines by 2007
$W \rightarrow e\nu$ $Z \rightarrow ee$	15 1.5	10^8 10^7	10^4 (LEP) 10^7 TeV 10^7 (LEP)
tt bb	1 10^6	10^7 10^{12}-10^{13}	10^4 (Tevatron) 10^9 (BaBar/Belle)
Higgs M_H = 130 GeV	0.02	10^5	?
Squarks, Gluinos M ~ 1 TeV	0.001	10^4	--



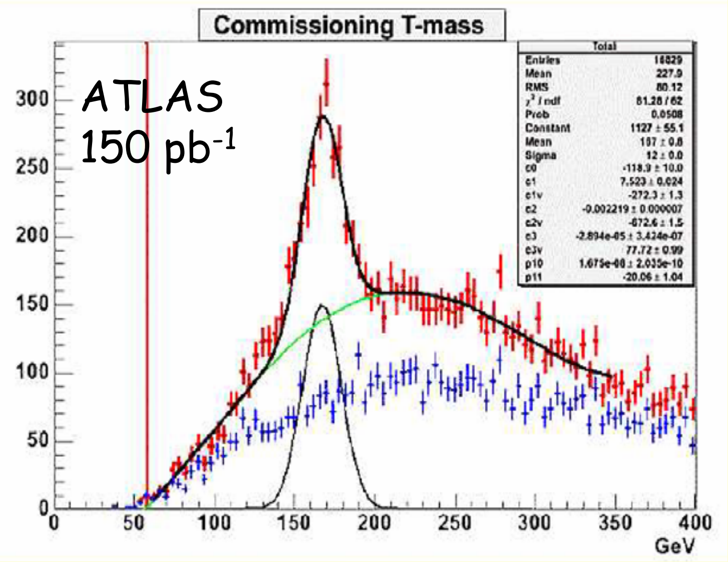
First goals …. (2008) (?)

- Understand and calibrate the detector and trigger system

  in situ using well-known physics samples

e.g.   - $Z \to ee, \mu\mu$ tracker, calorimeter, muon chambers calibration and alignment

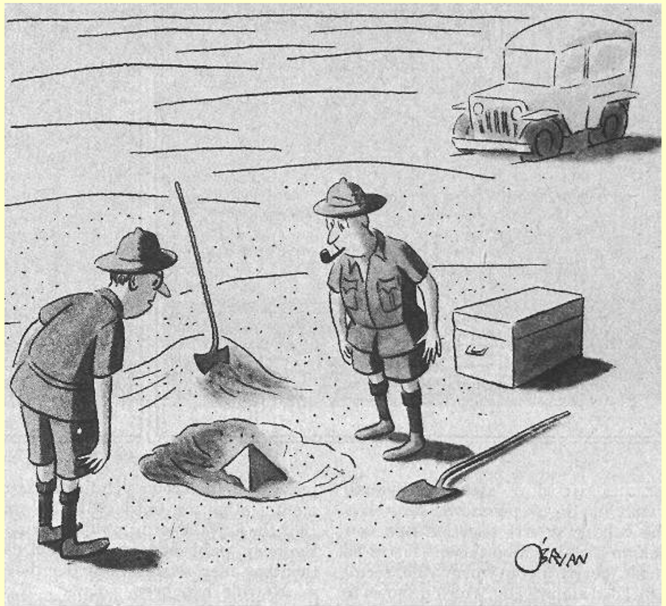
- $tt \to b\ell\nu\ bjj$ 10^4 events / day after cuts
  - $\to$ jet scale from $W \to jj$
  - $\to$ b-tag performance



$\Rightarrow$ defines t_0 !!

......and in parallel.....

....prepare the road for discovery



"This could be the discovery of the century. Depending, of course, on how far down it goes."

• Understand basic SM physics at $\sqrt{s}$ = 14 TeV

e.g. measure cross-sections for W, Z, tt, QCD jets, and events features (P_T spectra etc.)

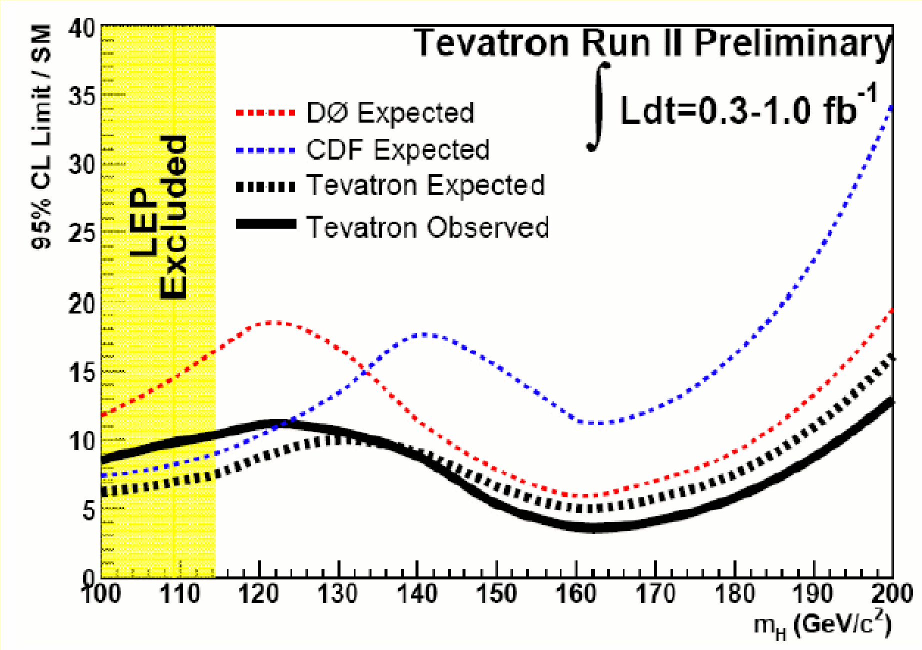
tt and W/Z+ jets are omnipresent in searches for New Physics !

- **Look for New Physics potentially accessible in first year (SUSY, Higgs, …)**

Note: if m_H < 120 GeV : a fast Higgs discovery may be crucial, competition with the Tevatron

Combination of several search channels and both experiments

95% CL Limit / SM value



WH → ℓ ν bb
ZH → ℓ ℓ bb
ZH → νν bb

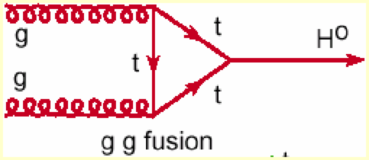
H → WW → ℓν ℓν
WH → WWW → ℓν ℓν + …

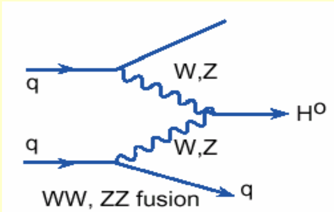
- The expected combined limits are still a factor of 7.5 (m_H=115 GeV/c^2) and 4 (m_H=160 GeV/c^2) away from the Standard Model expectation

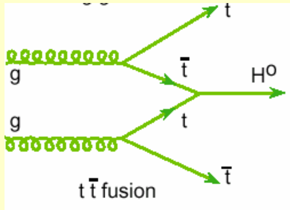
- However, not all results included yet (CDF 1fb^{-1} results at high mass and DØ 1fb^{-1} result at low mass are missing)

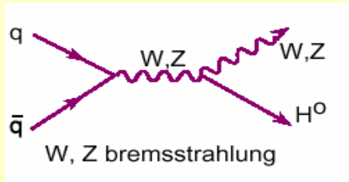
- Many improvements have been made during the past year

Higgs Boson Production at the LHC

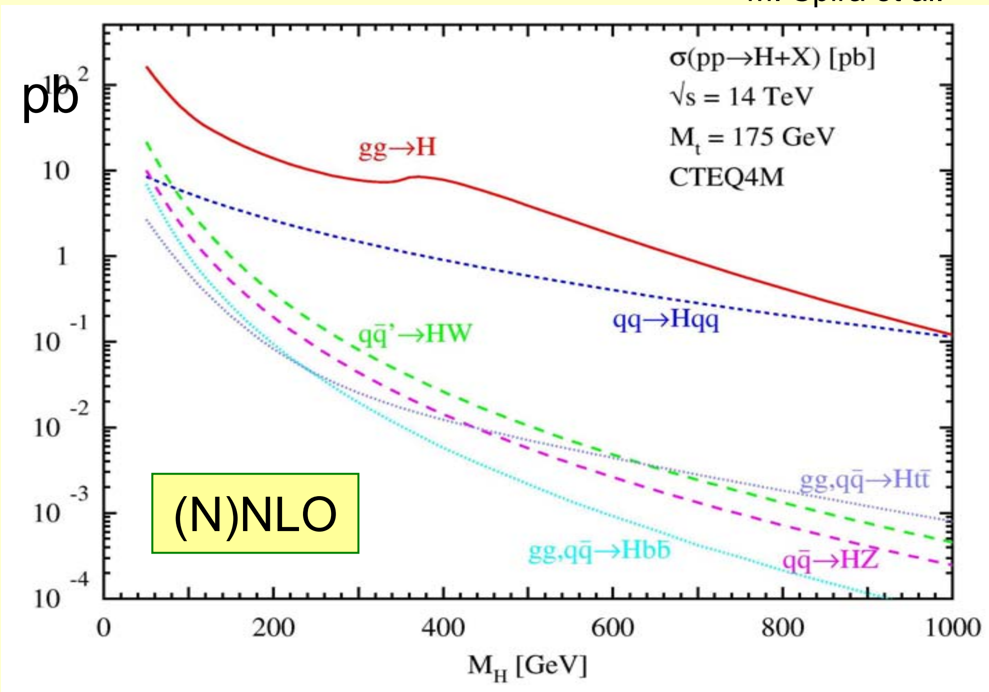








M. Spira et al.



- (N)NLO calculations available for all signal processes
- K factors are large for gg fusion, moderate for the other processes

Gluon fusion: K[1] ~ 1.7–1.8
K [2] ~ 2.0–2.1
[Djouadi, Spira, Zerwas (91)] [Dawson (91)]
[Harlander, Kilgore (02)] [Anastasiou, Melnikov (02)]

qqH production: K ~ 1.1
[Han, Valencia, Willenbrock (92)] [Spira (98)]

WH production: K ~ 1.3
(QCD corrections from Drell-Yan process)

ttH production: K ~ 1.1
[Beenakker, Dittmaier, Krämer, Plümper, Spira, Zerwas [01]
[Dawson, Reina (01)]

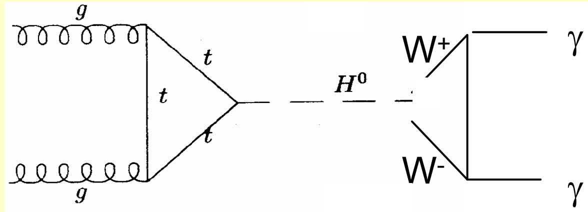
$qq \to W/Z + H$ cross sections ~10 x larger than at the Tevatron
$gg \to H$ ~70-80 x larger than at the Tevatron

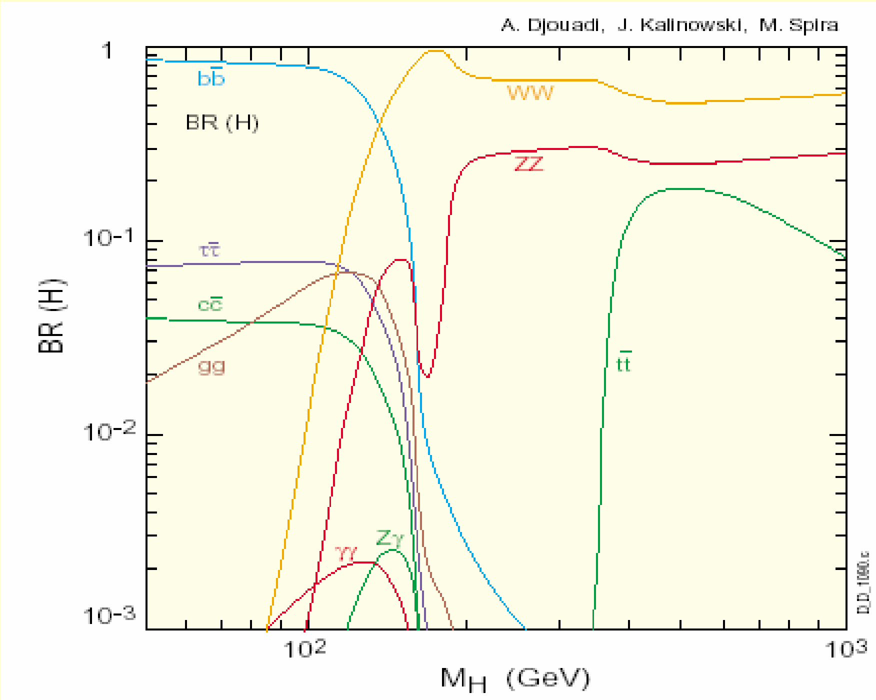
Decays of the Higgs Bosons

- Decay characteristics are known, as soon as the mass is known:

H → W^+, Z, t, b, c, τ^+,..........., g, γ

H → W^-, Z, t, b, c, τ^- ,..........., g, γ





Useful Decays at Hadron Colliders:

at high mass:
Lepton final states are essential
(via H → WW , ZZ)

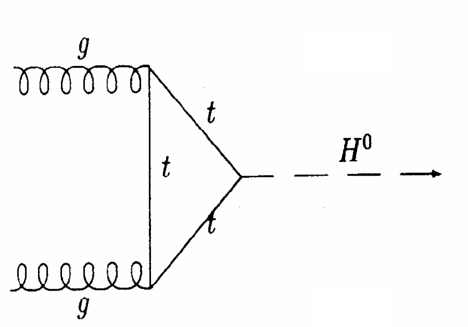
at low mass:
Lepton and Photon final states
(via H → WW*, ZZ* or H → γγ)

The dominant **bb decay mode** is only useable in the associated production mode (ttH, WH, ZH)
(due to the huge background from jet production via QCD processes)

Higgs boson searches in the

gluon fusion

channel at the LHC



No accompanying particles (except high-P_T Higgs + jet production)

$\rightarrow$ Lepton or photon final states (the “classical“ channels)

$H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\,\ell\ell$

$H \rightarrow \gamma\gamma$

$H \rightarrow WW^{(*)} \rightarrow \ell\nu\,\ell\nu$

H → ZZ* → ℓℓ ℓℓ

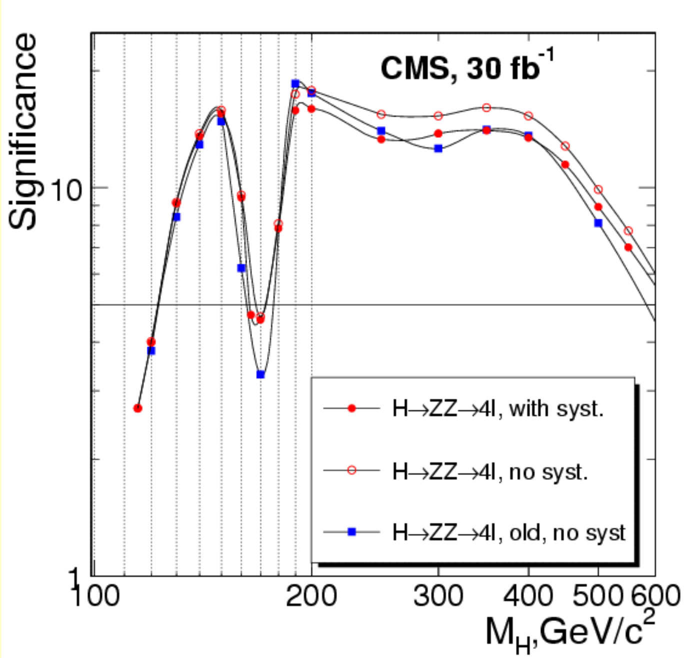
- Main backgrounds: ZZ (irreducible), tt, Zbb (reducible)

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

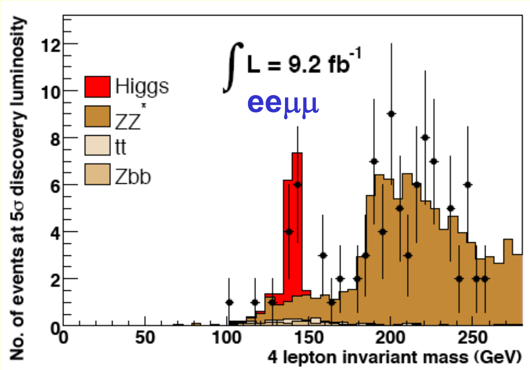
Updated CMS study:

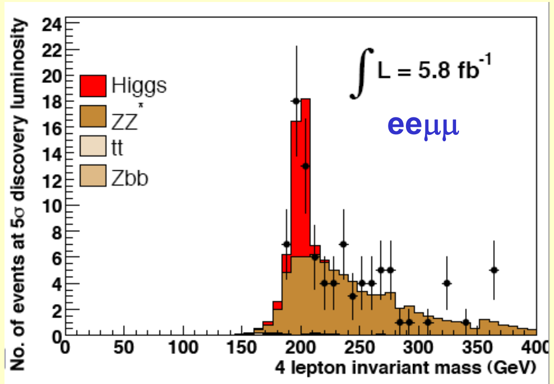
- ZZ background: NLO K factor used
- background from side bands

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

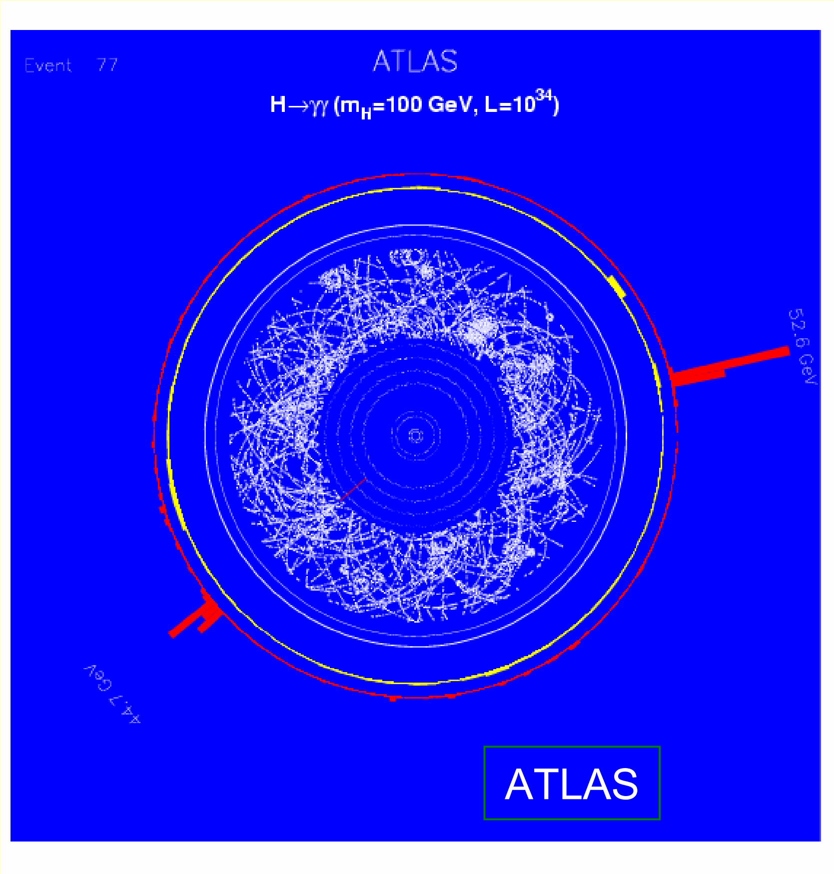


Signal and background at 5 σ discovery



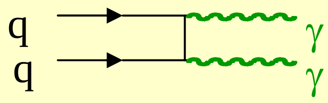


$H \to \gamma\gamma$

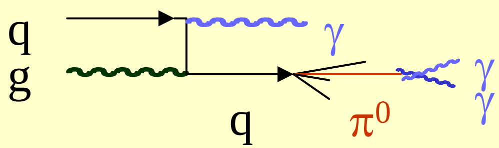


Main backgrounds:

$\gamma\gamma$ irreducible background



γ-jet and jet-jet (reducible)



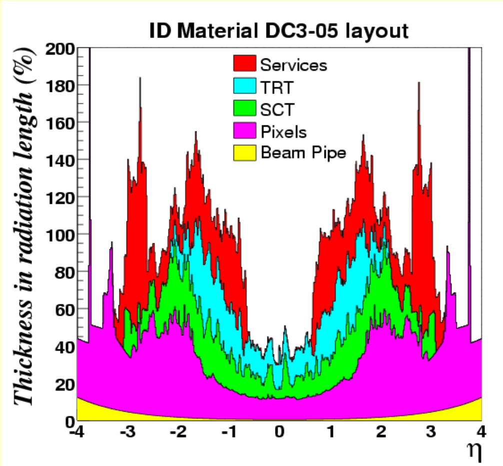
$\sigma_{\gamma j+jj} \sim 10^6\ \sigma_{\gamma\gamma}$ with large uncertainties

$\rightarrow$ need $R_j > 10^3$ for $\varepsilon_\gamma \approx 80\%$ to get $\sigma_{\gamma j+jj} \ll \sigma_{\gamma\gamma}$

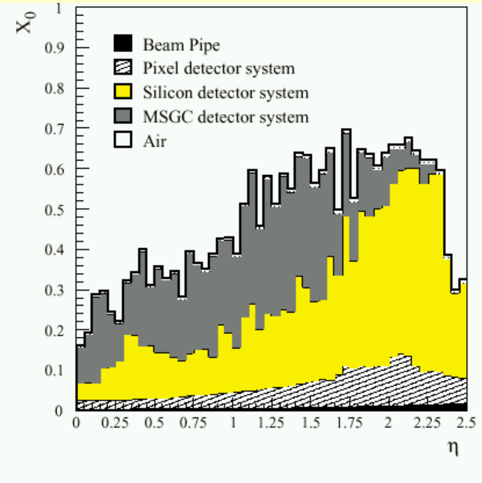
- Main exp. tools for background suppression:
  - photon isolation !
  - γ / jet separation (calorimeter + tracker)
  - note also converted photons need to be reconstructed (large material in LHC silicon trackers)

Material budget in tracking detectors

ATLAS

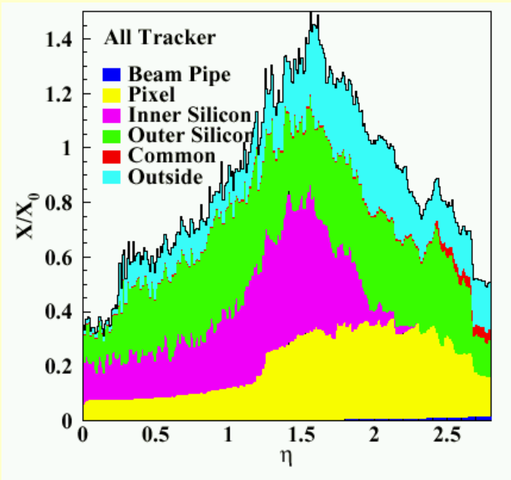


CMS



ECAL TDR (1996)

Micro strip gas chambers



Physics TDR (2006)

Full silicon tracker

Fraction of converted γ s:

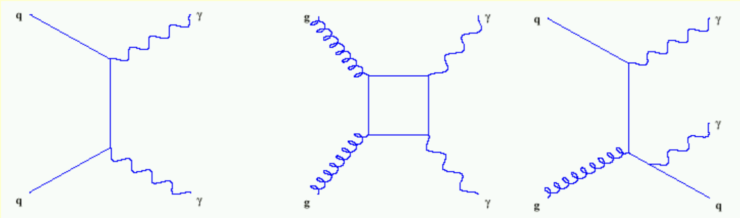
Barrel region: 42.0 %

Endcap region: 59.5 %

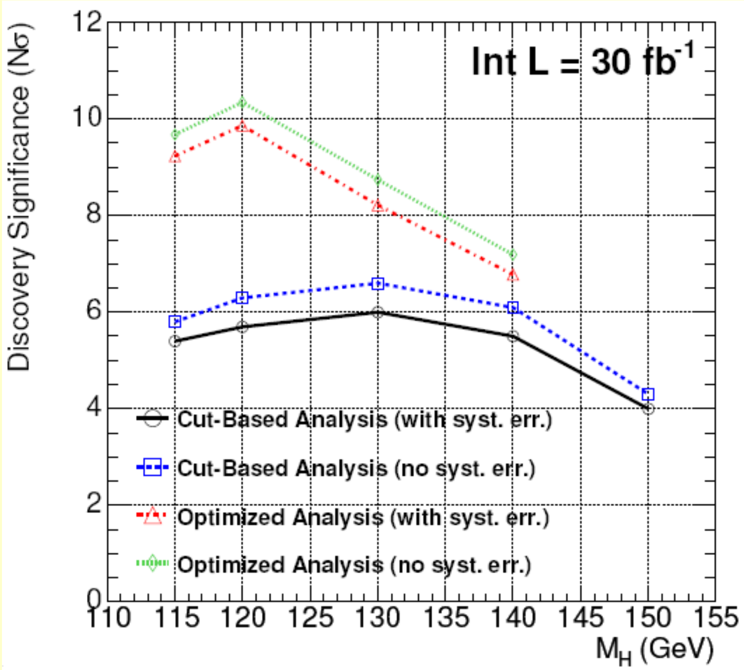
CMS Study: TDR (updated)

New elements of the analysis:

- more contributions to the $\gamma\gamma$ background



- Realistic detector material
- More realistic K factors (for signal and background)
- Reducible backgrounds (γj and jj) considered (unlike in CMS ECAL-TDR)
- Split signal sample acc. to resolution functions

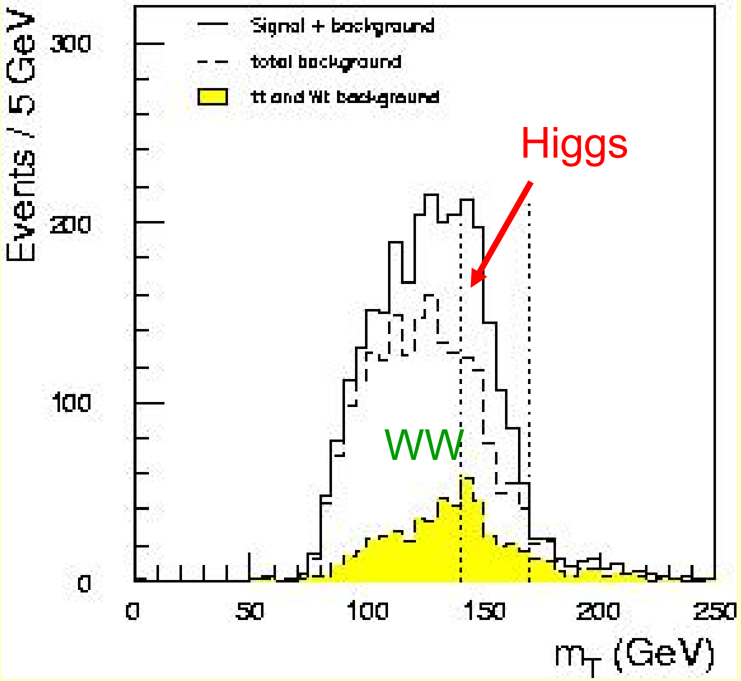


	ECAL TDR K factors	current K factors: DIPHOX(NLO) / PYTHIA
born	1	1.50 , uncertainty 10-20 %
box	1.85	1.20, uncertainty 10-20 % (Dixon et al)
isolated brem	1	1.72, uncertainty 20-30 %
γ+j, j->π^0	not simulated	1.00, uncertainty 30-40 %
j+j, jj->2π^0	not simulated	**1.00, uncertainty 50%**

Comparable results for ATLAS and CMS

H → WW → ℓν ℓν

- Large H → WW BR for m_H ~ 160 GeV/c^2

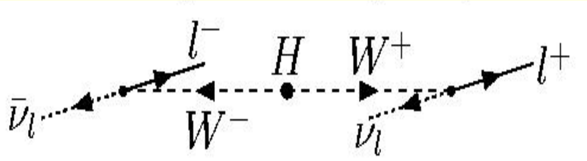


- However: neutrinos in final state,
  use transverse mass
  → no mass peak

- Large backgrounds: WW, Wt, tt

- Two main discriminants:
  (Dittmar & Dreiner, (1997))

  (i) Lepton angular correlation



  (ii) Jet veto: no jet activity
  (P_T > 20 GeV/c, |η| < 3.2)
  in central detector region

Problems:

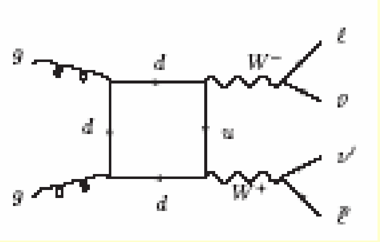
(i) need precise knowledge of the backgrounds, incl. higher order corrections

(ii) need to understand jet veto efficiencies

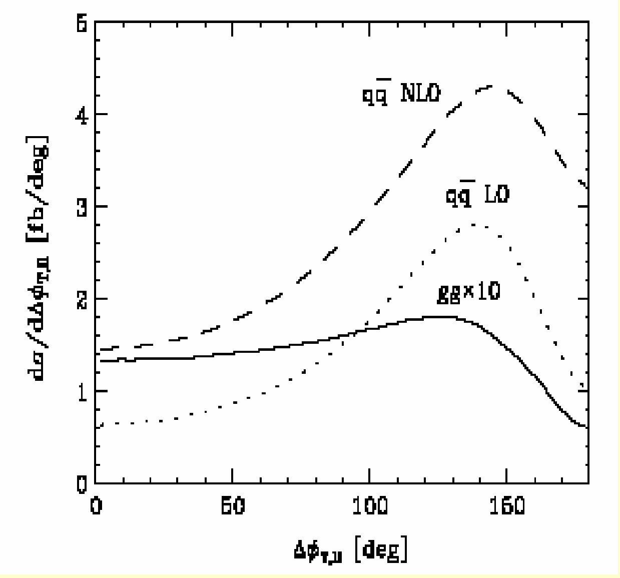
→ reliable Monte Carlo generators, e.g. MC@NLO, validation of ALPGEN/SHERPA at the Tevatron

more work on backgrounds.....

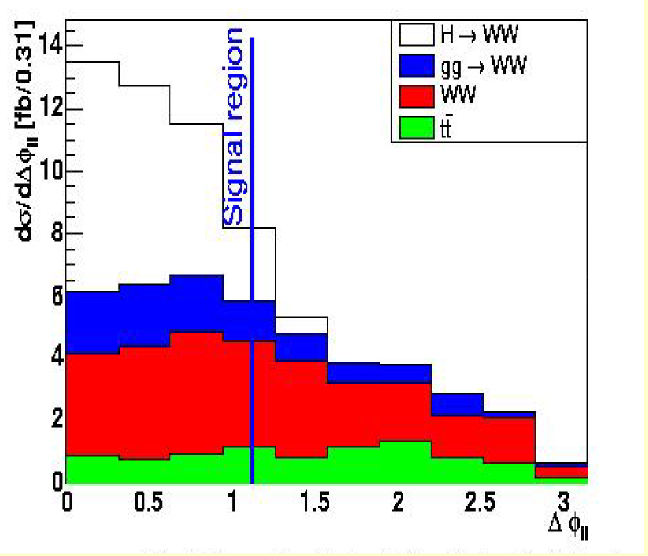
Main theoretical challenge: - shape of the WW background,
- contributions from higher orders, *e.g.*, $gg \to WW$



$\sigma(gg \to WW)$: only 5% of $\sigma(WW)$ before cuts,
but ~ 30% of $\sigma(WW)$ after cuts



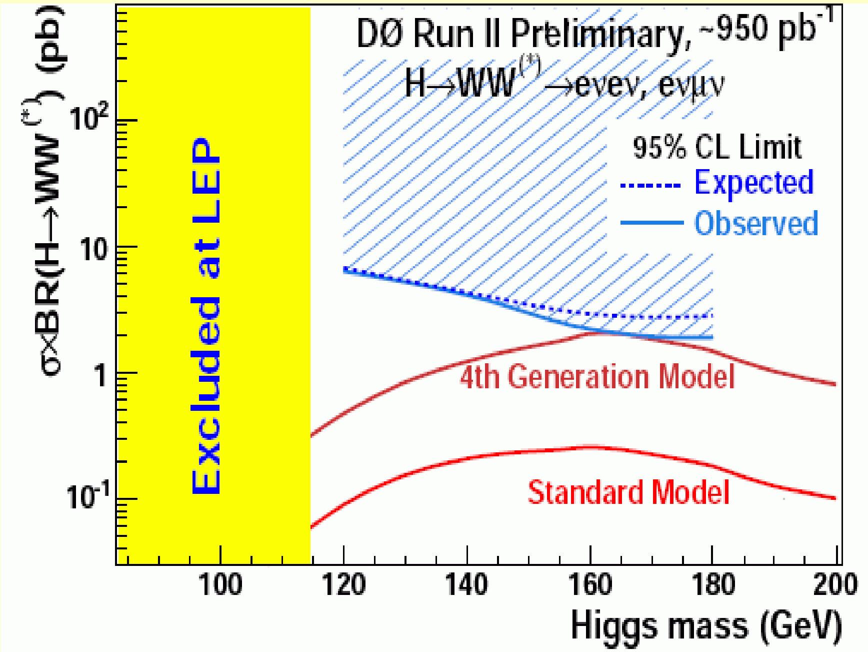
T. Binoth, M. Cicciolini, N. Kauer. M. Krämer
hep-ph/0503094

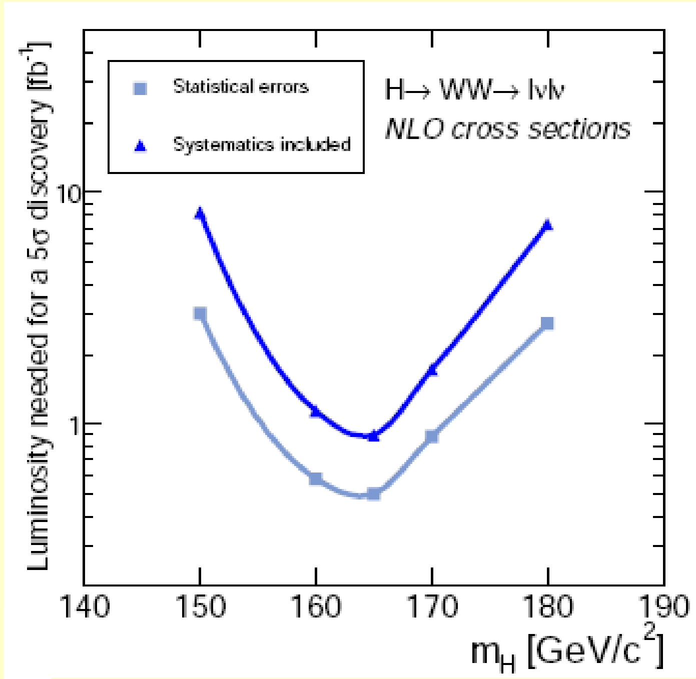


M. Dührssen, K. Jakobs, P. Marquardt, JJ. van der Bij,
hep-ph/0504006

Discovery reach in H → WW →ℓν ℓν

CMS Phys. TDR 2006





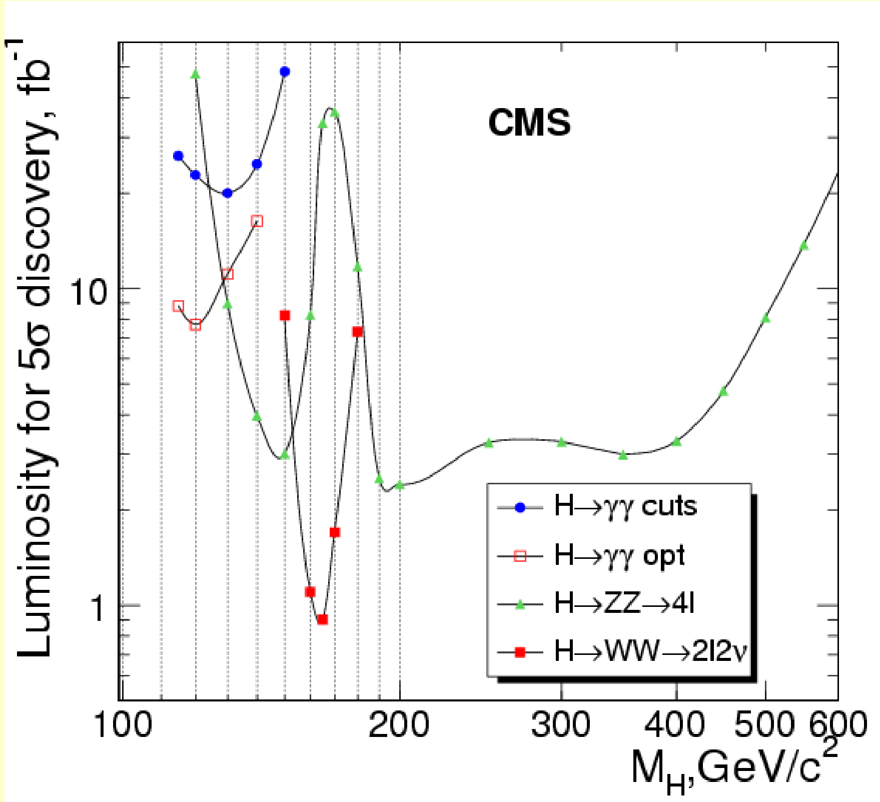
Tevatron:
Excluded σ x BR at 95% C.L.

LHC:
luminosity needed for a 5σ discovery

Estimated background uncertainties:

- tt from data: ±16% at 5 fb^{-1}
- WW from data: ±17% at 5 fb^{-1}
- Wt from theory: ± 22%
- gg → WW from theory: ± 30%

Discovery potential in gluon-fusion channels

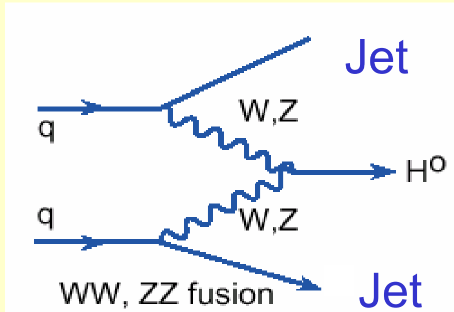


Note: 95% C.L. exclusion limits will need much less luminosity (0.2 – 2 fb^{-1}), but also need an understood and calibrated detector

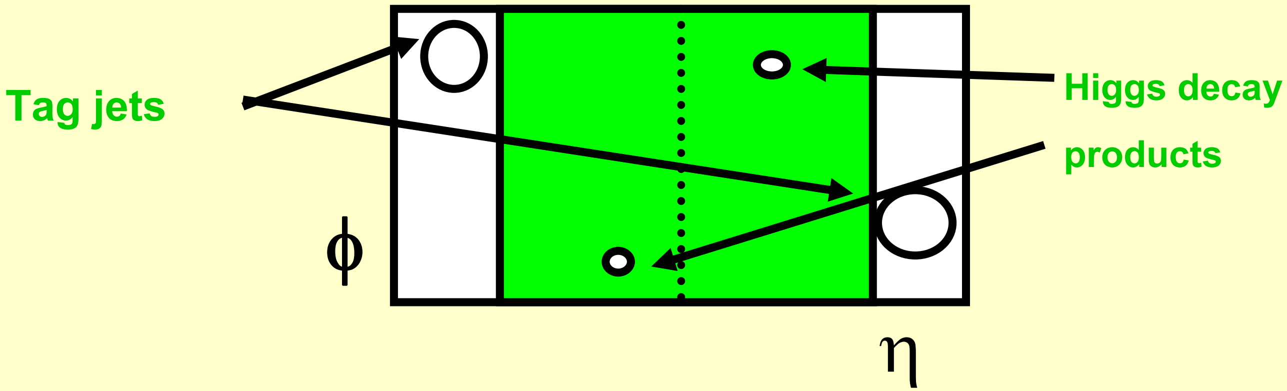
Vector Boson Fusion qq H

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

Established by D. Zeppenfeld et al. (1997/98)
Earlier studies: Kleiss & Stirling (1988);
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



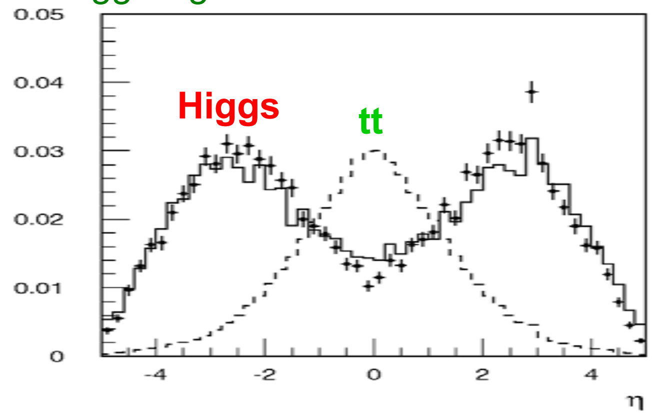
⇒ Experimental Issues:

- Forward jet reconstruction

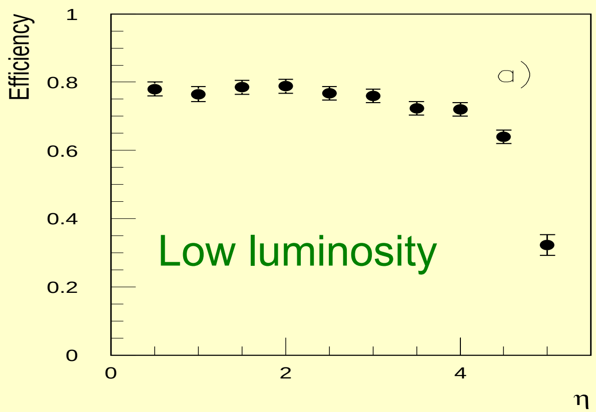
- Jets from pile-up in the central / forward region

- Preliminary ATLAS studies (CSC update)
- CMS studies in TDR (full simulation)

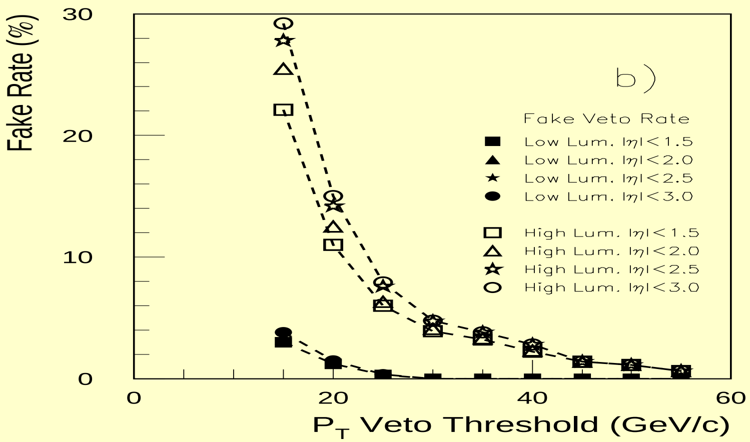
Rapidity distribution of jets in tt and Higgs signal events:



Efficiency of forward jet reconstruction



Fraction of events with jet in central region



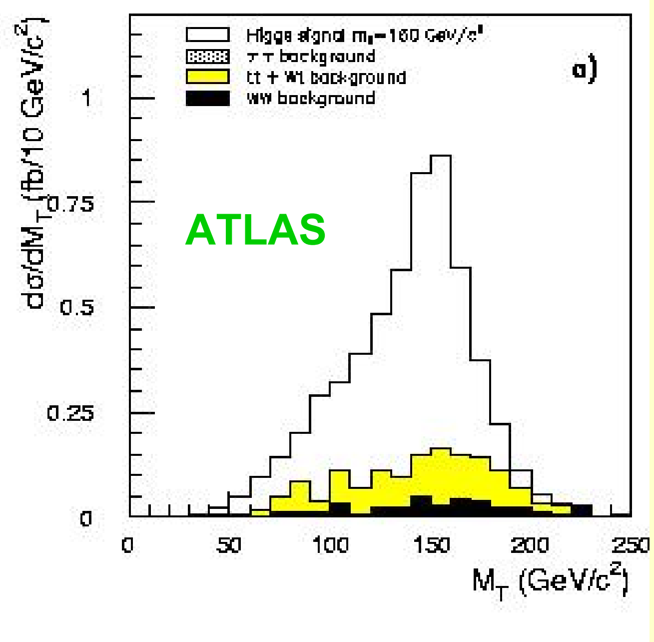
- Looks feasible at low luminosity, higher tag jet P_T- thresholds needed at high luminosity (PYTHIA result, might be too optimistic)

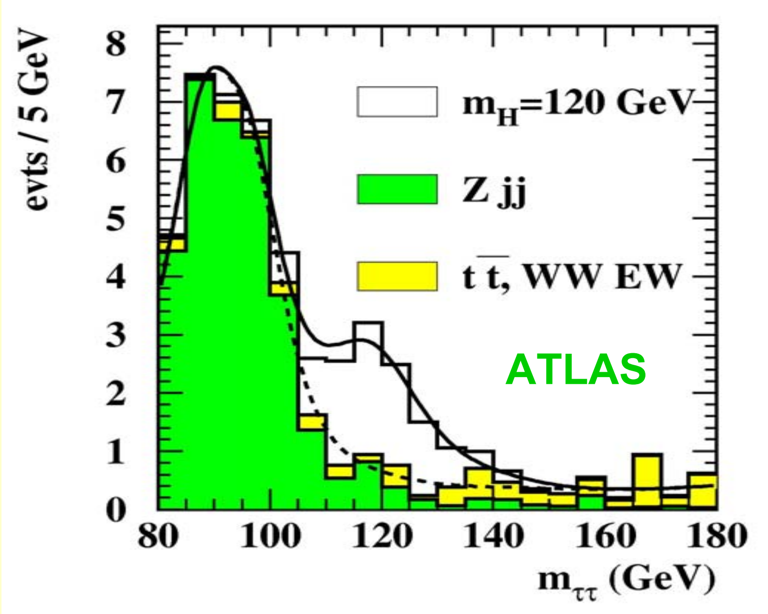
Two search channels at the LHC:

qq H → qq W W*
→ qq ℓν ℓν

qq H → qq τ τ
→ qq l ν ν l ν ν
→ qq l ν ν h ν

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





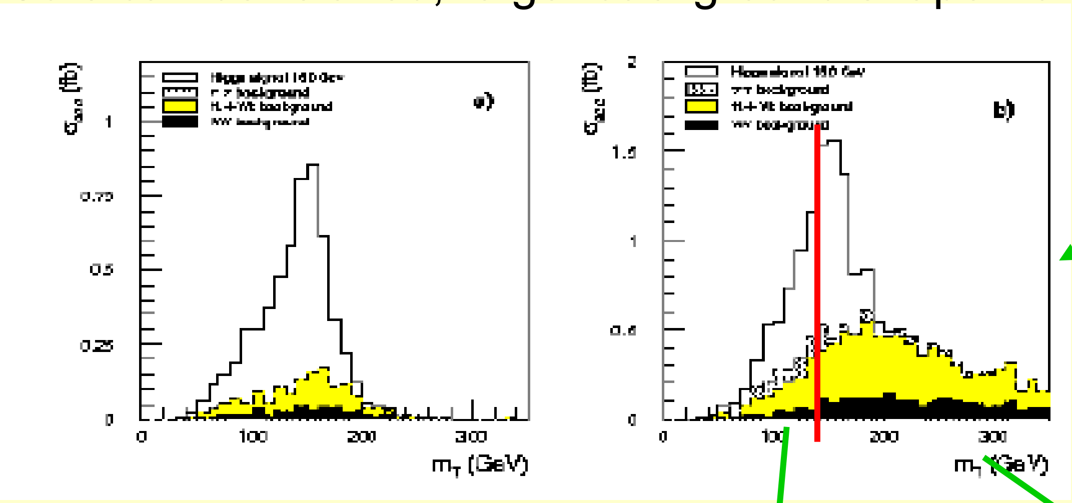
Selection criteria:

- Lepton P_T cuts and tag jet requirements ($\Delta\eta$, P_T)
- Require large mass of tag jet system
- Jet veto (important)
- Lepton angular and mass cuts

How reliable are these signals ?

(i) background shape (the experimental approach)

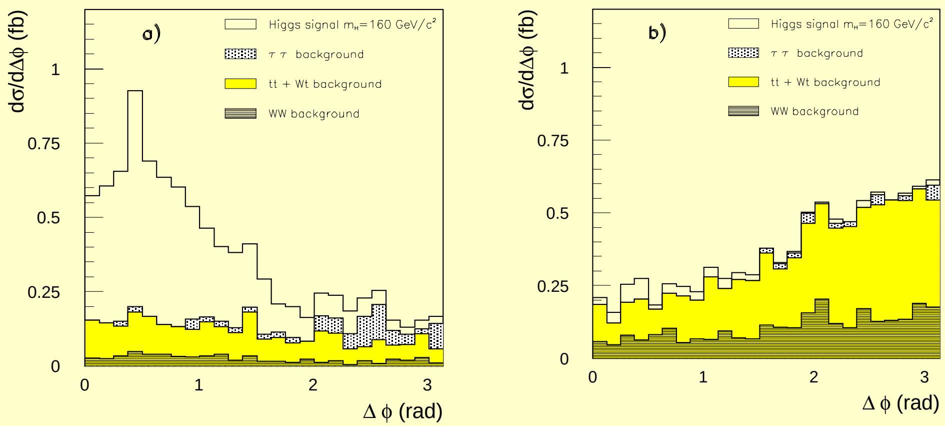
Cuts can be relaxed, to get background shape from the data:



No kinematical cuts on leptons applied: (ATLAS study)

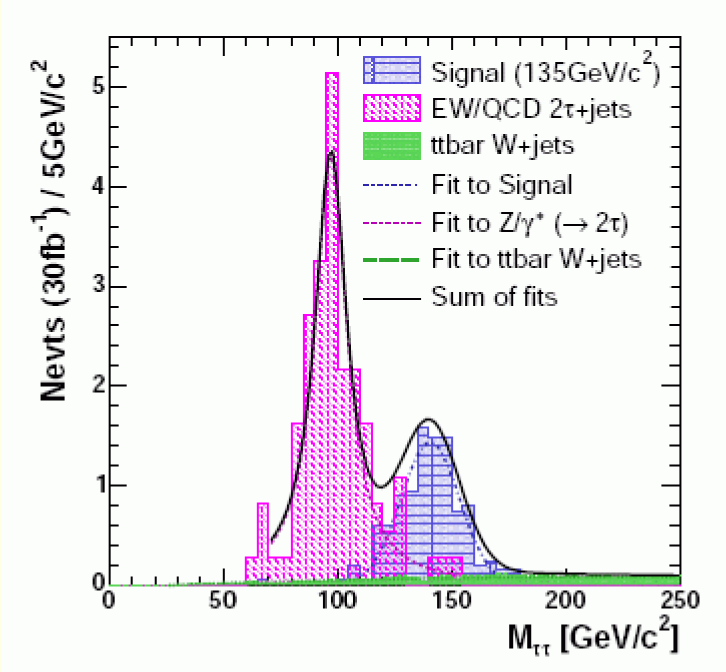
Evidence for spin-0 of the Higgs boson
$\Delta\phi$ distribution

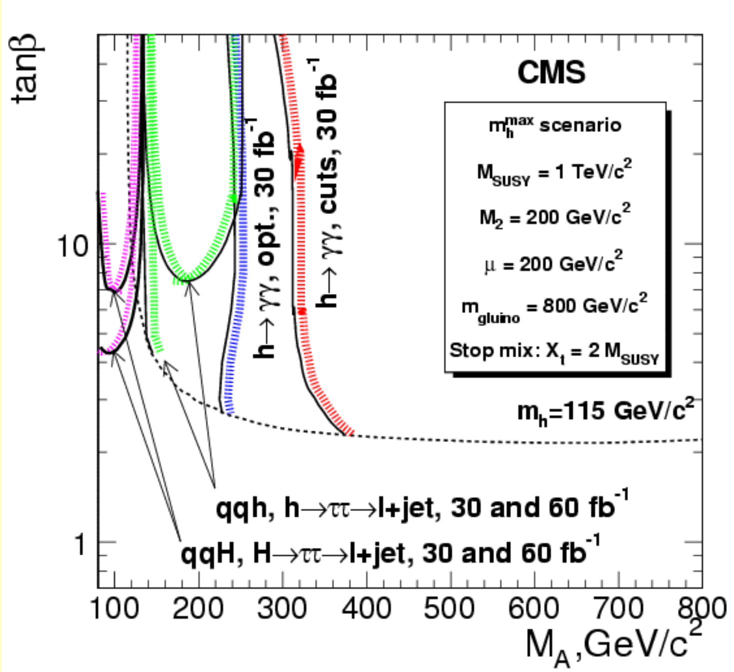
Spin-0 → WW → ℓνℓν expect leptons to be close by in space



- Similar approach (extract background from data) possible for the $Z \to \tau\tau$ background in qq $H \to$ qq $\tau\tau$

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



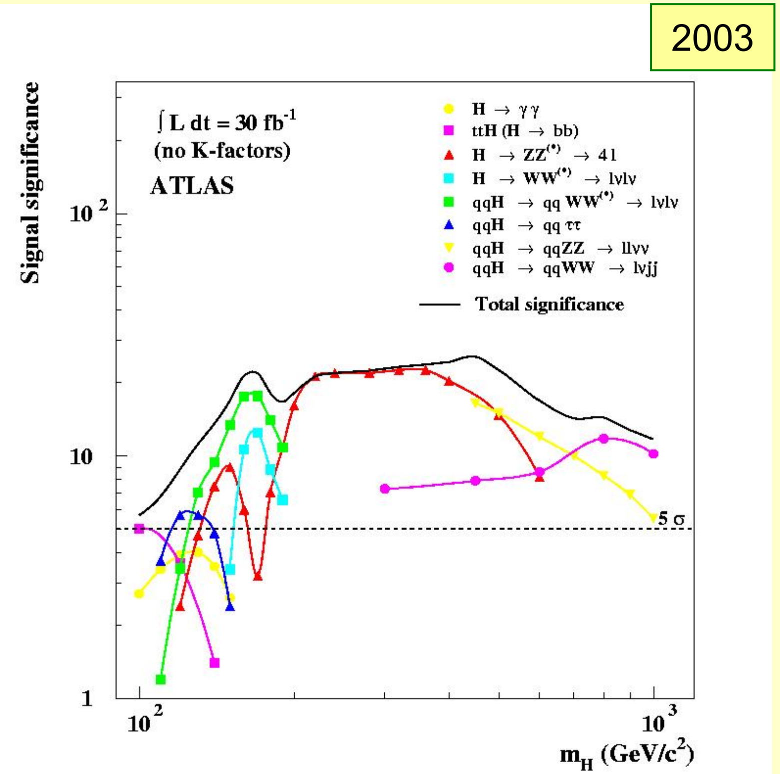


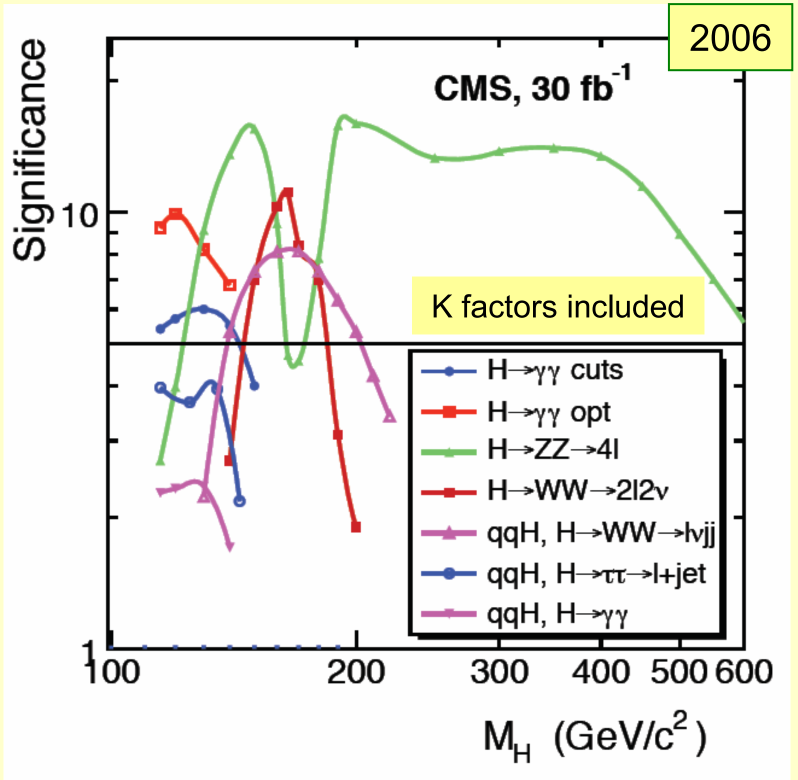
discovery region in the MSSM

Signal and background numbers, signal significance

M_H [GeV]	115	125	135	145
Production σ [fb]	4.65×10^3	4.30×10^3	3.98×10^3	3.70×10^3
$\sigma\times BR(H\rightarrow\tau\tau\rightarrow lj)$ [fb]	157.3	112.9	82.38	45.37
N_S at 30 fb^{-1}	10.5	7.8	7.9	3.6
N_B at 30 fb^{-1}	3.7	2.2	1.8	1.4
Significance at 30 fb^{-1} ($\sigma_B = 7.8\%$)	3.97	3.67	3.94	2.18
Significance at 60 fb^{-1} ($\sigma_B = 5.9\%$)	5.67	5.26	5.64	3.19

LHC discovery potential for 30 fb^{-1}





- Full mass range can already be covered after a few years at low luminosity
- Several channels available over a large range of masses

  Vector boson fusion channels play an important role at low mass !

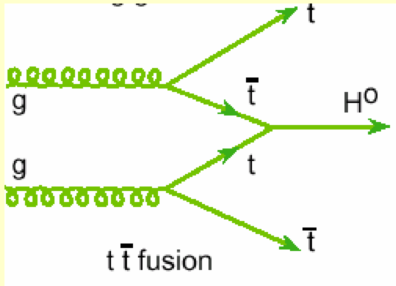
Important changes w.r.t. previous studies:

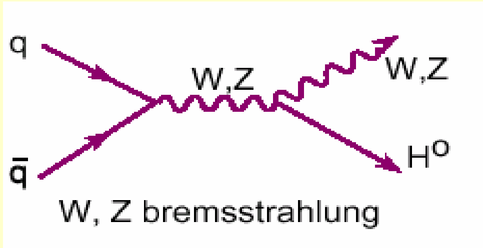
- **H → γγ** sensitivity of ATLAS and CMS comparable
- **ttH → tt bb** disappeared in CMS study (more realistic background estimates, under study in ATLAS)

How much can the

associated production modes
ttH, WH with H → bb

contribute ?





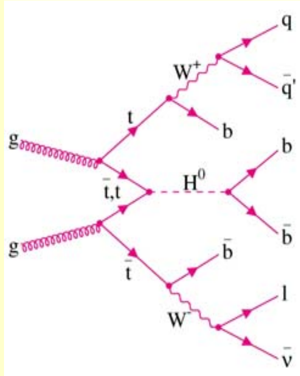
difficult, main problem is
large background from signal itself
(combinatorial background)
and from QCD processes

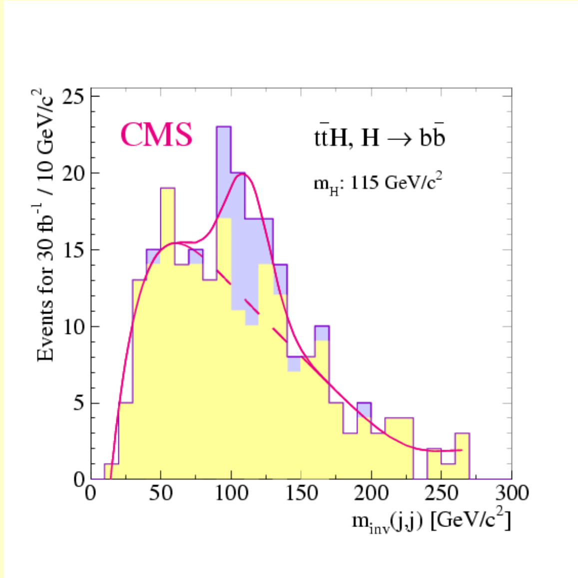
….. has not been re-surrected by CMS

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

ASPEN 2004

σ x BR ≈ 300 fb
Complex final state: H→ bb, t → bjj, t → b$\ell\nu$





- Main backgrounds:
  - combinatorial from signal (4b in final state)
  - Wjjjjjj, WWbbjj, etc.
  - ttjj (dominant, non-resonant)

- b-tagging performance is crucial
  ATLAS results for 2D-b-tag from full simulation
  (ε_b =60% R_j (uds)~ 100 at low L)

S = 38 events
B = 52 events
S/B ~ 0.73

S/ √B = 3.5
for K = 1.0

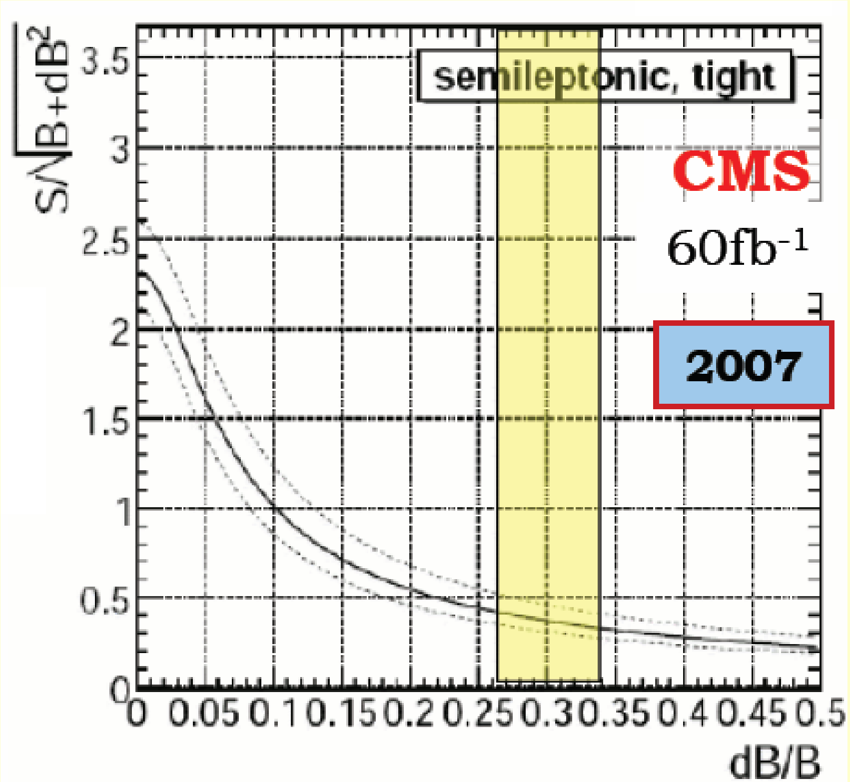
- Shape of background must be known; 60% (from ttbb)

- LHC experiments need a better understanding of signal and backgrounds (K factors for backgrounds)

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

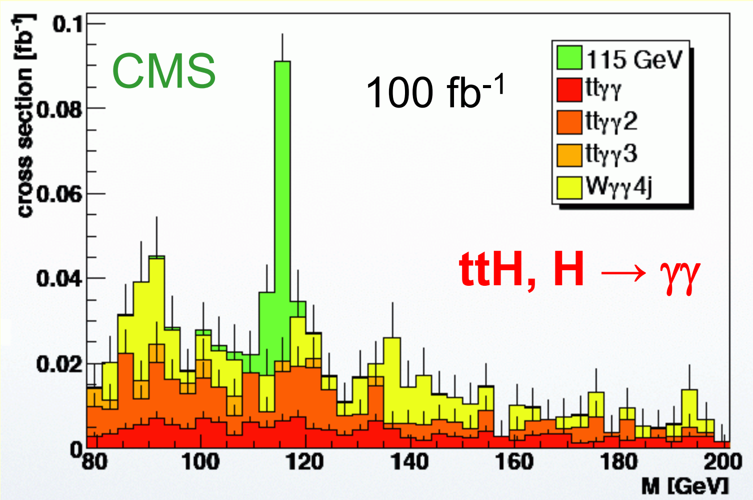
- CMS 2006: COMPHEP and ALPGEN matrix element calculations used
  $\rightarrow$ larger backgrounds,
  uncertainties on backgrounds, exp. normalization seems difficult…..

Signal significance as function of the background uncertainty:



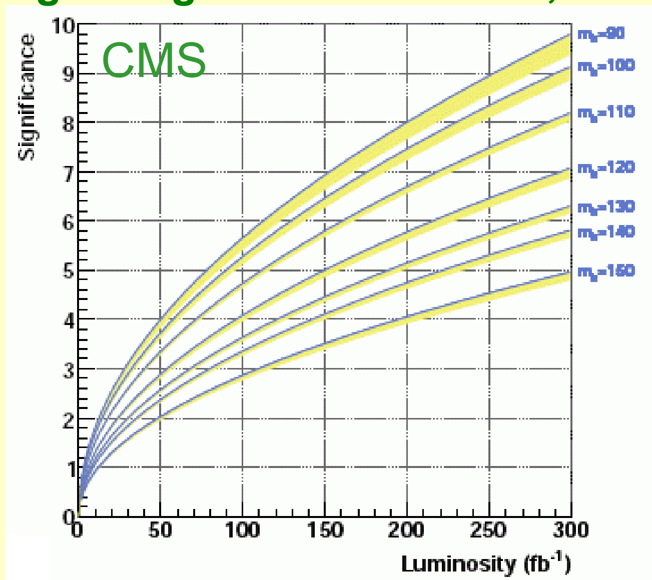
… needs more studies….
($\rightarrow$ ATLAS CSC notes)

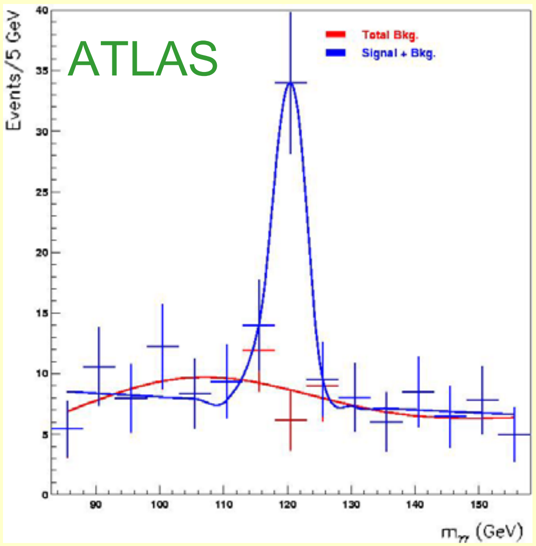
….rare decay modes visible at high luminosity



m_H = 120 GeV/c^2 Sig = 3.5 σ (incl. syst)

Signal significance for WH, H →$\gamma\gamma$

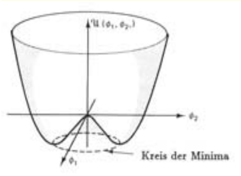




ttH + WH + ZH → $\gamma\gamma$ + P_T^{miss}
(ATLAS fast simulation, prel.)

For 100 fb^{-1}: expect **20.9 signal events (mass peak)**
5.4 background (flat)

Not discovery channels,
but will contribute to Higgs parameter determination



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 $ZZ \rightarrow 4\ell$ resonances, el.magn. calo. scale uncertainty assumed to be ± 0.01%)

2. Couplings to bosons and fermions **(→ D. Zeppenfeld's talk)**

3. Spin

Angular distributions in the decay channel $H \rightarrow ZZ^{(*)} \rightarrow 4\,\ell$ 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.
+ new studies using VBF (CP from tagging jets) in ATLAS and CMS **(→ D. Zeppenfeld's talk)**

4. Higgs self coupling

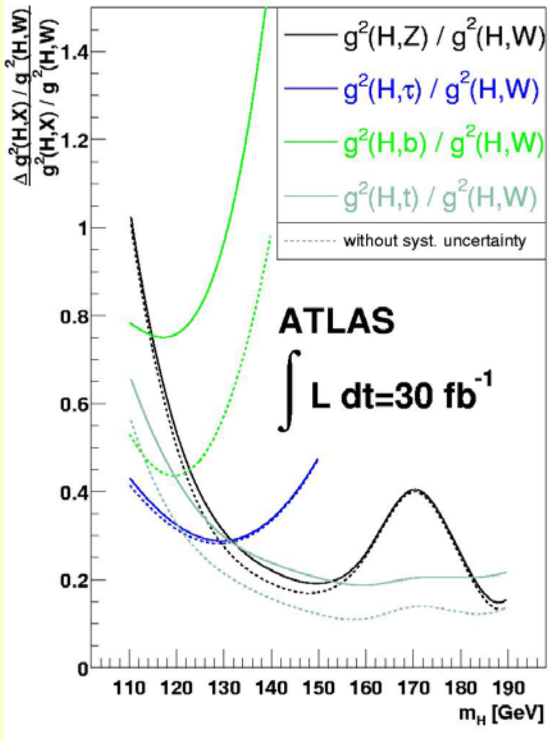
Possible channel: **$gg \rightarrow HH \rightarrow WW\,WW \rightarrow \ell\nu\,jj\;\;\ell\nu\,jj$** (like sign leptons)
Small signal cross sections, large backgrounds from tt, WW, WZ, WWW, tttt, Wtt,...

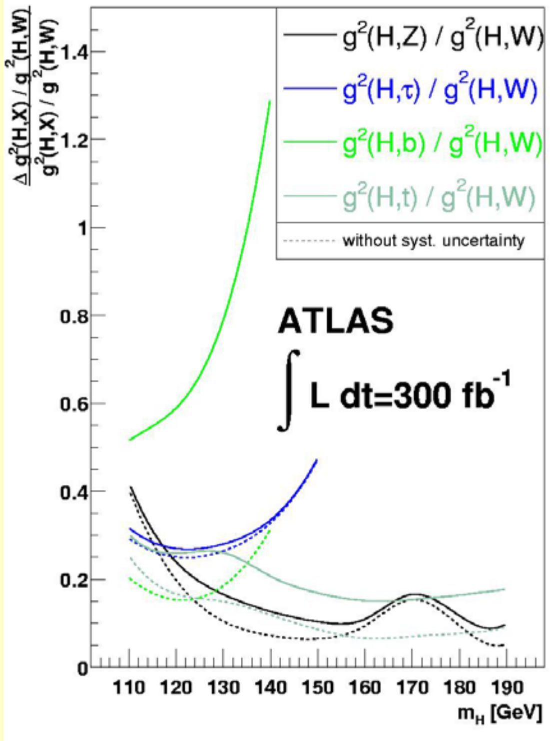
$\Rightarrow$ no significant measurement possible at the LHC
very difficult at a possible SLHC (6000 fb^{-1})
limited to mass region around 160 GeV/c^2 (update will appear soon)

Measurement of Higgs Boson Couplings

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

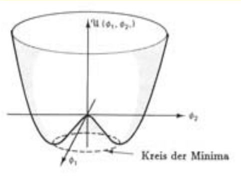
Output: Higgs boson couplings, normalized to the WW-coupling





Relative couplings can be measured with a precision of 10-20% (for 300 fb^{-1})

M. Dührssen, ATL-PHYS-2003-030;
M. Dührssen et al., Phys. Rev. D70 (2004) 113009.



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⇒ no significant measurement possible at the LHC
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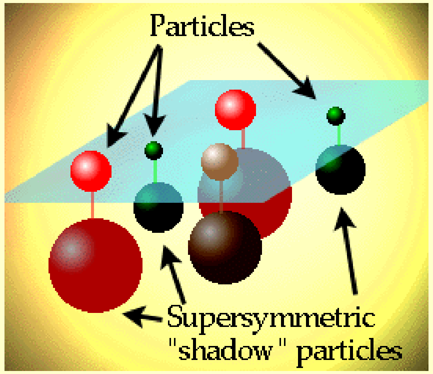
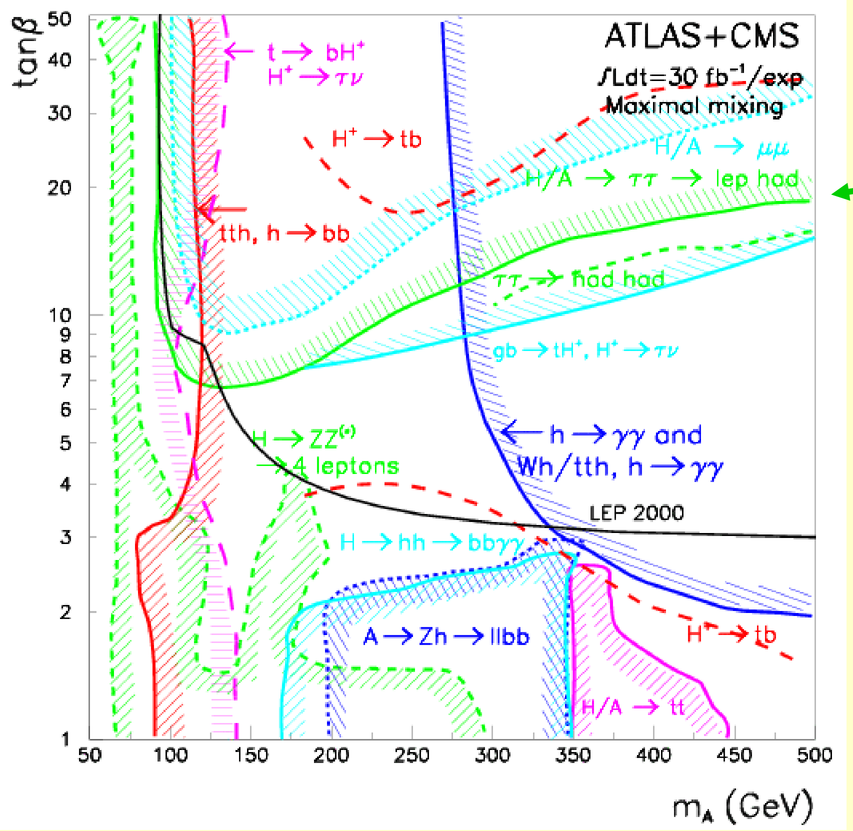
The Higgs Sector

in the MSSM



MSSM Higgs bosons h, H, A, $H^{\pm}$

m_h < 135 GeV
$m_A \approx m_H \approx m_{H\pm}$ at large m_A



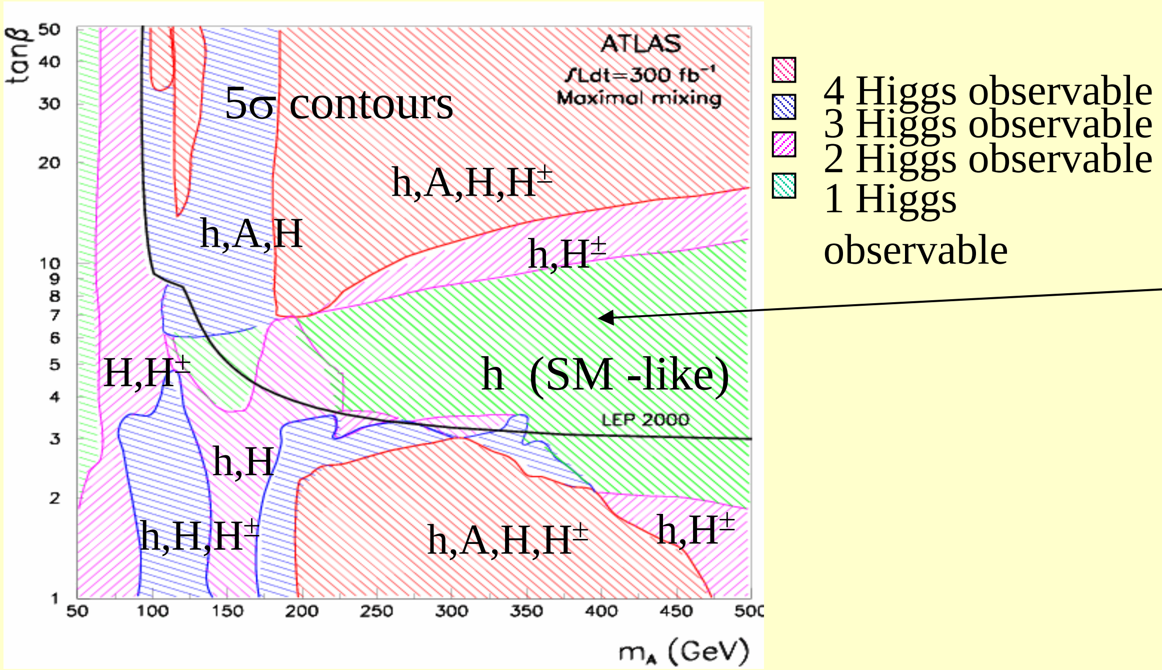
A, H, H± cross-section ~ $\tan^2\beta$

- best sensitivity from A/H $\rightarrow \tau\tau$, H± $\rightarrow \tau\nu$

- A/H → $\mu\mu$ experimentally easier

* Validated by CMS TDR full simulation studies *

LHC discovery potential for SUSY Higgs bosons



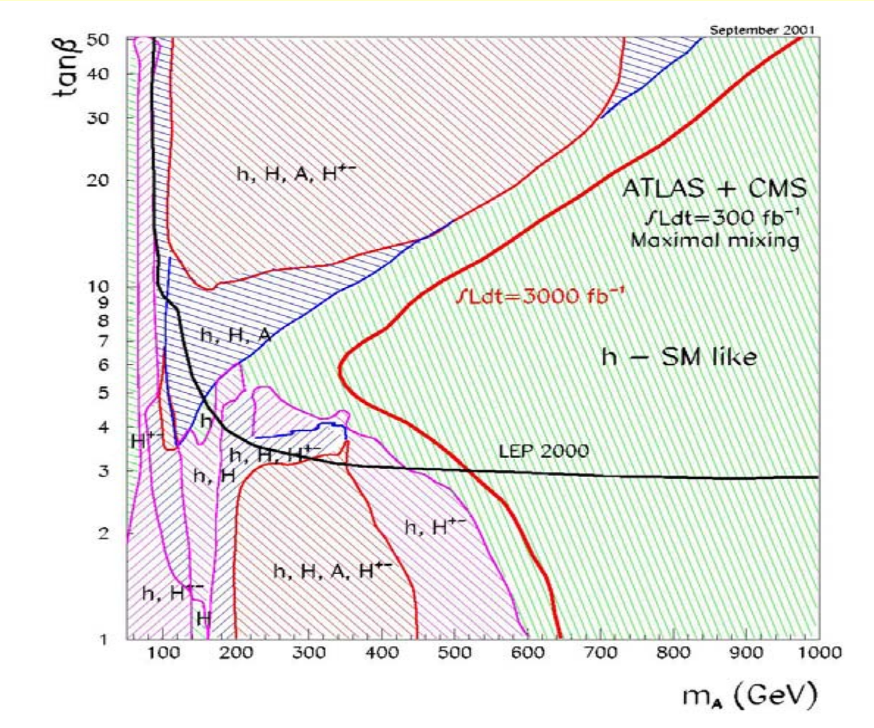
Here only SM-like h observable if SUSY particles neglected.

What can be done in the large m_A wedge region ??

- Higher luminosity ? SLHC
- Additional SUSY decay modes

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 ....

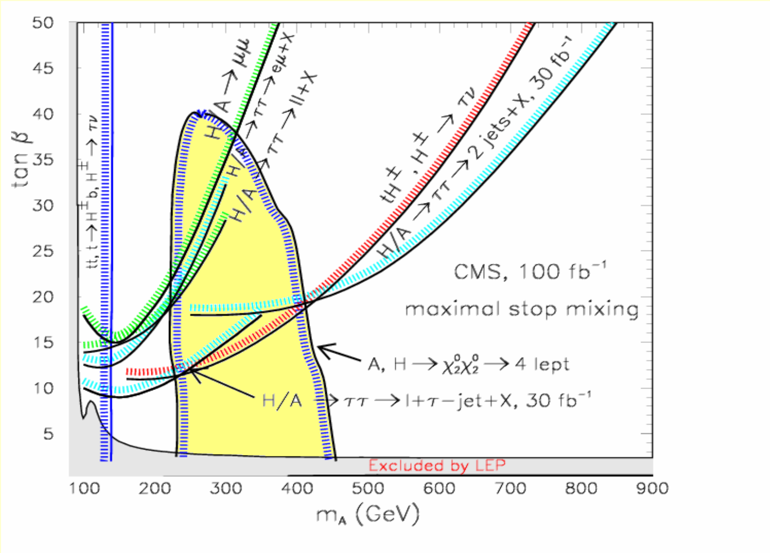
...... although the observation of sparticles will clearly indicate that additional Higgs bosons should exist.

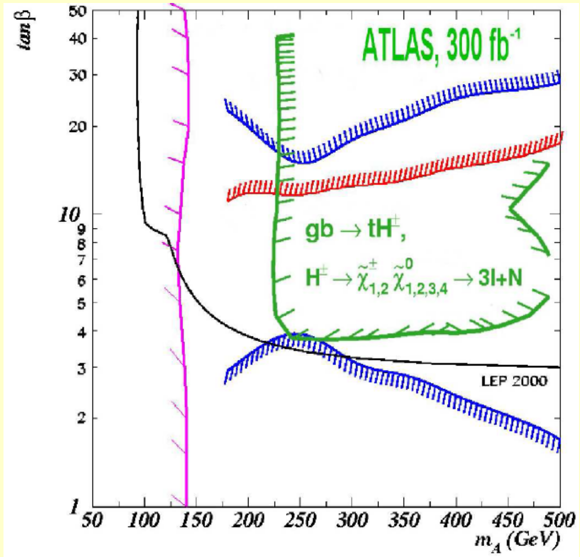
Higgs decays via SUSY particles

If SUSY exists : search for

$H/A \to \chi^0_2\chi^0_2 \to \ell\ell\chi^0_1\ \ell\ell\chi^0_1$

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





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

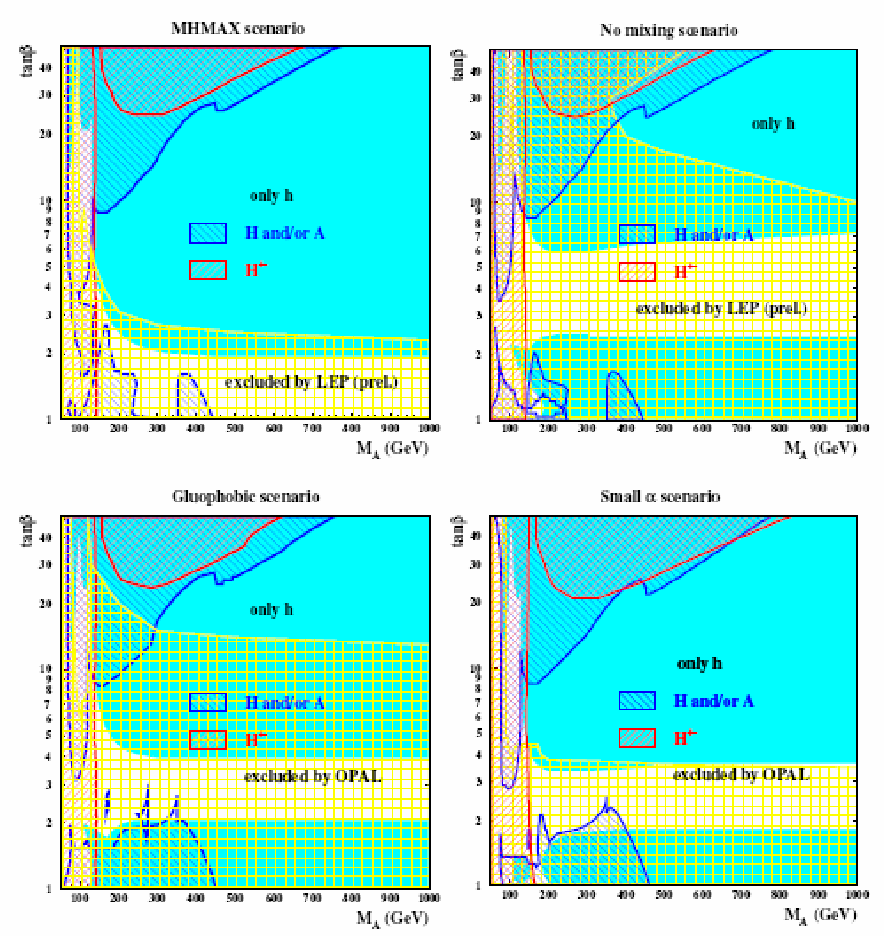
m(s-τ_R) = 210 GeV/c^2

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

Updated MSSM scan for different benchmark scenarios

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

ATLAS, 30 fb^{-1}, 5σ discovery



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

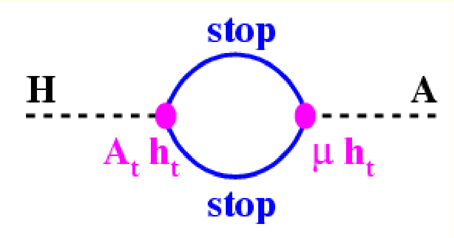
Nomixing scenario (M_{SUSY}= 2TeV)
(1TeV almost excl. by LEP)
small m_h → difficult for LHC

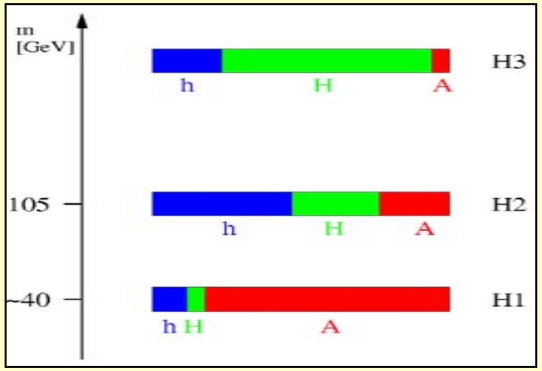
Gluophobic scenario (M_{SUSY} = 350 GeV)
coupling to gluons suppressed
(cancellation of top + stop loops)
small rate for g g → H, H→ $\gamma\gamma$ and Z→4 ℓ

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

Higgs search at the LHC in CPX scenarios

- CP conservation at Born level, but CP violation via complex $\mathbf{A_t}$, $\mathbf{A_b}$, **M....**





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

- Effect maximized in a defined CPX benchmark scenario

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

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

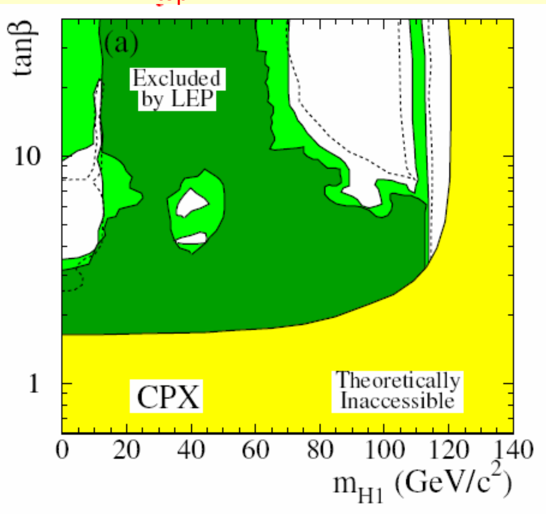
- No lower mass limit for H_1 from LEP !

(decoupling from the Z)

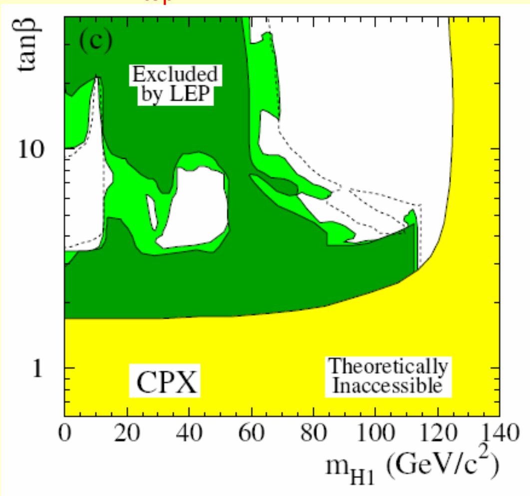
details depend on m_{top} and on theory model

(FeynHiggs vs. CPHiggs)

m_{top} = 169.3 GeV/c²

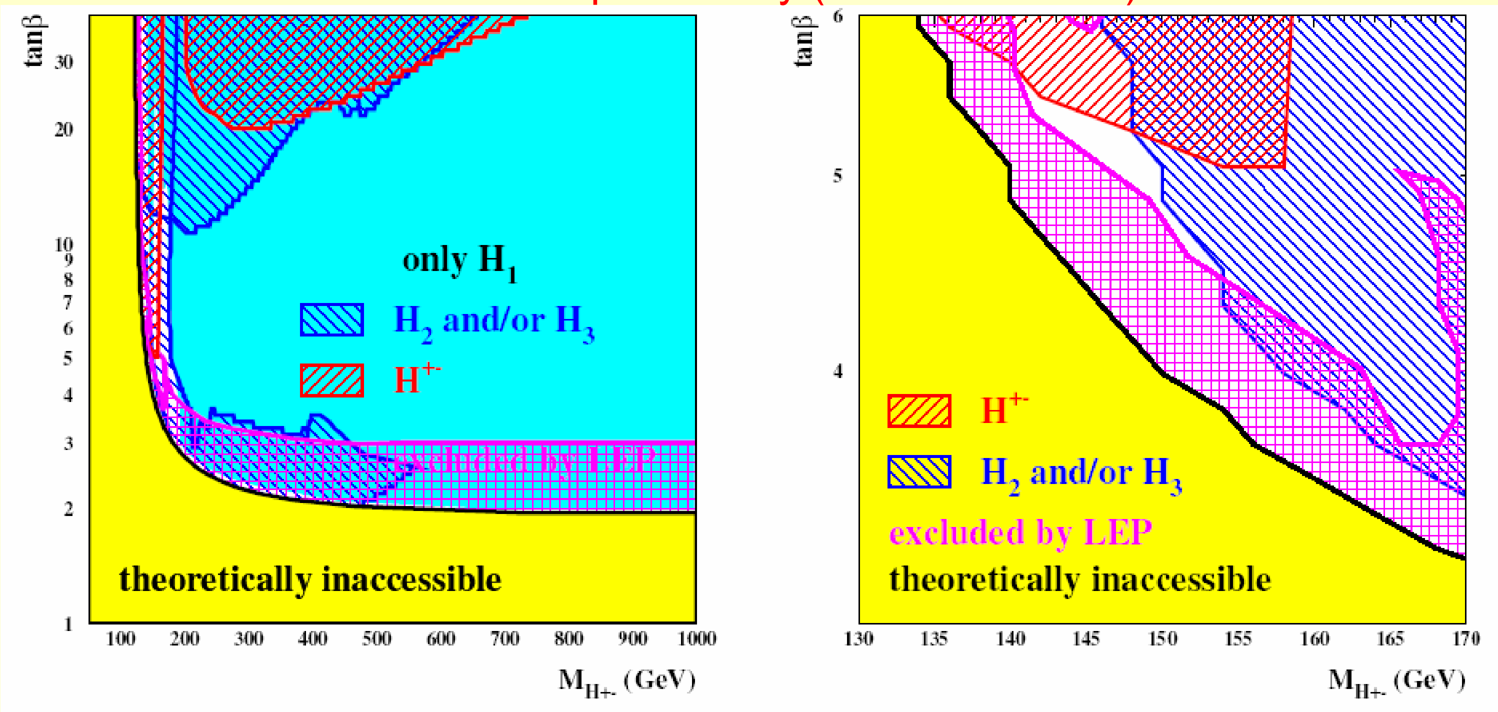


m_{top} = 174.3 GeV/c²



MSSM discovery potential for a CPX benchmark point

ATLAS preliminary (M. Schumacher)

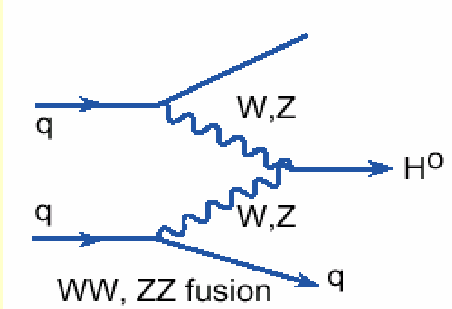


- Large fraction of the parameter range can be covered, however, small hole at (intermediate tanβ , low m_{H+}) corresponding to low m_{H_1}

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

Invisible Higgs decays ?

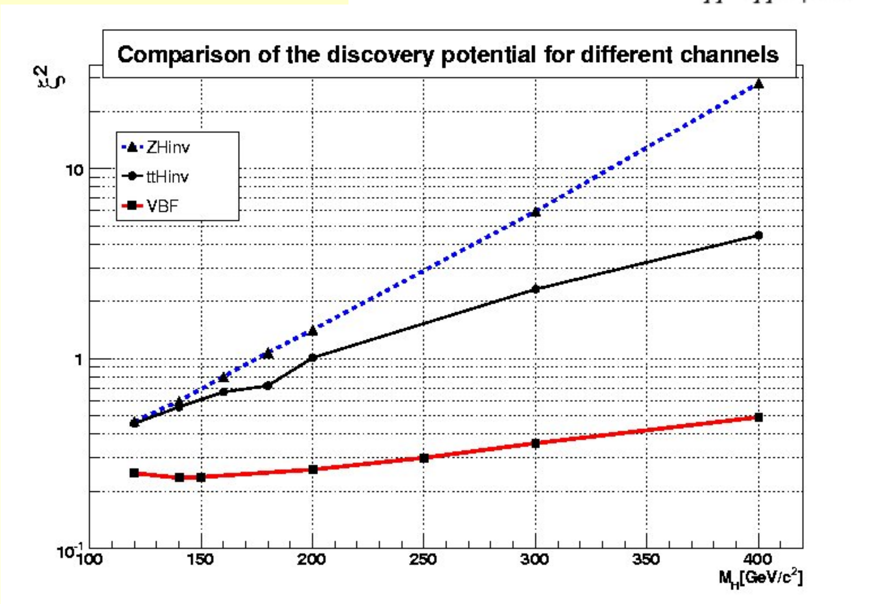
Possible searches: tt H $\rightarrow$ ℓνb qqb + P_T^{miss}
Z H $\rightarrow$ $\ell\ell$ + P_T^{miss}
qq H $\rightarrow$ qq + P_T^{miss}



P_T^{miss}

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

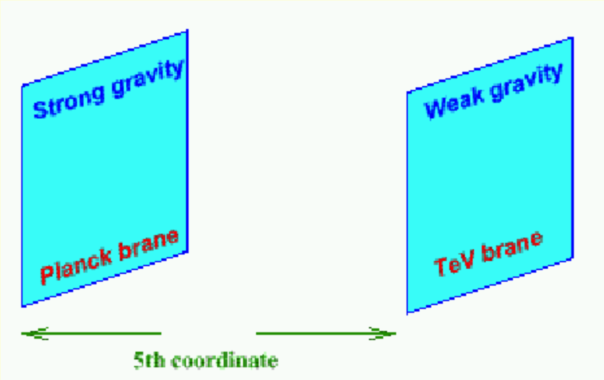
Sensitivity: $$\xi^2 = Br(H \rightarrow Inv.)\frac{\sigma_{qq\rightarrow qqH}}{\sigma_{qq\rightarrow qqH}|_{SM}}$$



Problems / ongoing work:

- ttH and ZH channels have low rates
- 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

Higgs in a 5-dim. Randall-Sundrum Model



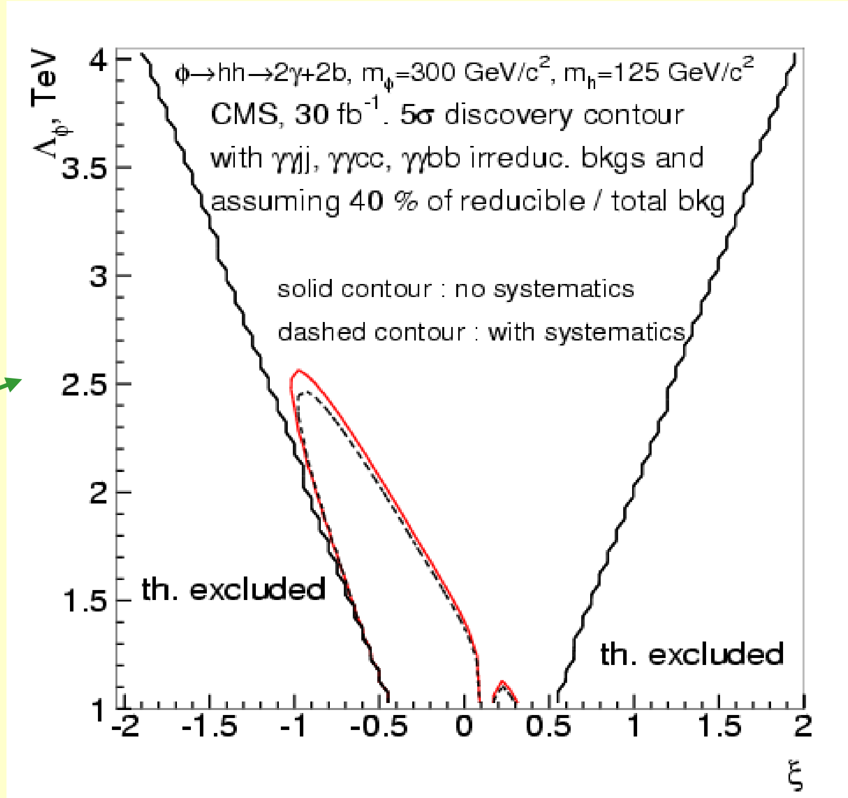
Scalar sector of the theory includes:

Higgs h, radion ϕ

Parameters: m_h, m_ϕ, Λ_ϕ, ξ (h-ϕ mixing parameter)

CMS search for $\phi \to hh \to \gamma\gamma\, bb$
$\to \tau\tau\, bb$

Scan in (Λ_ϕ, ξ) plane for
m_ϕ=300 GeV/c^2, m_h=125 GeV/c^2



Where do we go from here ?

- Data taking is only ~1 year away !

- Need to get ready for first data

→ Commissioning, alignment, calibration activities;
Development of computing tools,… reconstruction software, data challenges, GRID, **e.g. ATLAS CSC studies**
Development of analysis tools, e.g. Tau tagging
b tagging;
Development / improvement of methods to extract background from data;

→ Get familiar with new, improved Monte Carlo Generators
(e.g. MC@NLO, SHERPA, …..)

Test and validate them at the Tevatron
(nice synergy between LHC and Tevatron activities)

Changing Prospects for Higgs and SUSY ?

1985: No – Lose theorem
LHC will discover a Higgs boson and/or a Supersymmetric World

1995: Maybe SUSY will not be realized in its minimal version ….
(maybe there is NMSSM, no h with m_h below 130 GeV)

…. but we believe in SUSY (see e.g. J. Ellis, hep-ph 9503426)

negligible in this range. Similar sensitivity is to be expected in the CMS experiment [14]. Thus essentially all the parameter space of the MSSM allowed by naturalness arguments will be covered. If the LHC does not discover supersymmetry, we theorists will have to eat our collective hat.

2006: No discoveries at LEP-II and Tevatron (so far), Standard Model still rules !
Maybe SUSY is not realized as a *Low Energy SUSY* …..

"The SUSY train is already a bit late….." (G. Altarelli)

New models: extra space time dimensions, …… including **Dark Higgs** scenarios !
(e.g. J.van der Bij et al., Higgs boson coupled to a higher dimensional singlet scalar, hep-ph/0605008)

in the range $s^{1/2} > 100\,\mathrm{GeV}$. The data show a slight preference for a five-dimensional over a six-dimensional field. This Higgs boson cannot be seen at the LHC, but can be studied at the ILC.

Conclusions

- The LHC experiments are well set up to explore the existence of a Standard Model or MSSM Higgs bosons
  …. and are well prepared for unexpected scenarios

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

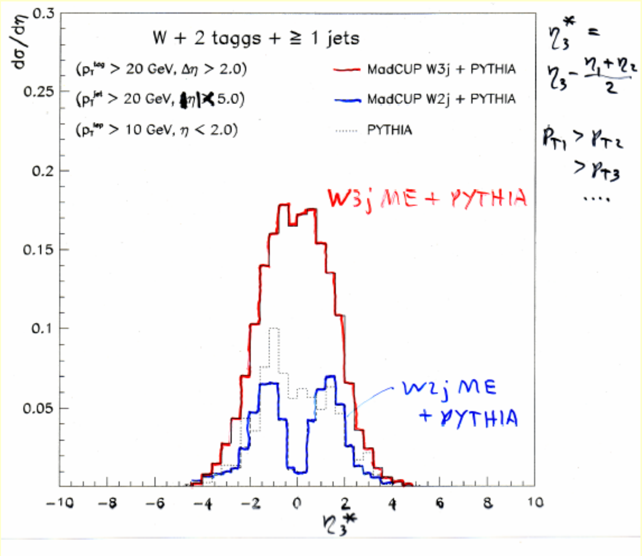
  in addition: important parameter measurements (mass, spin, ratio of couplings) can be performed, vector boson fusion channels are important;

  more difficult: invisible Higgs boson decays
  measurement of Higgs boson self coupling

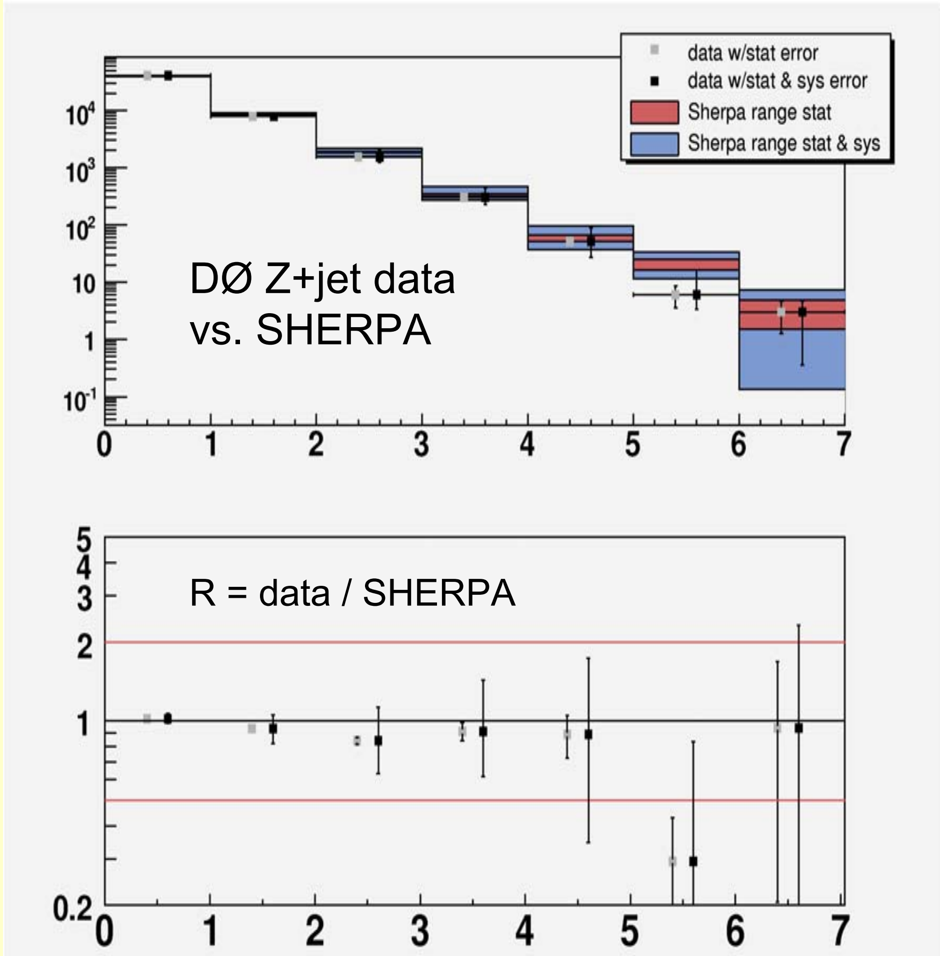
- Hopefully LHC data will soon give guidance to theory and to future experiments

(ii) jet veto

• Comparison between explicit matrix element calculations and shower Monte Carlos for W + jj production



$$\eta_3^* = \eta_3 - \tfrac{1}{2}(\eta_1 + \eta_2)$$

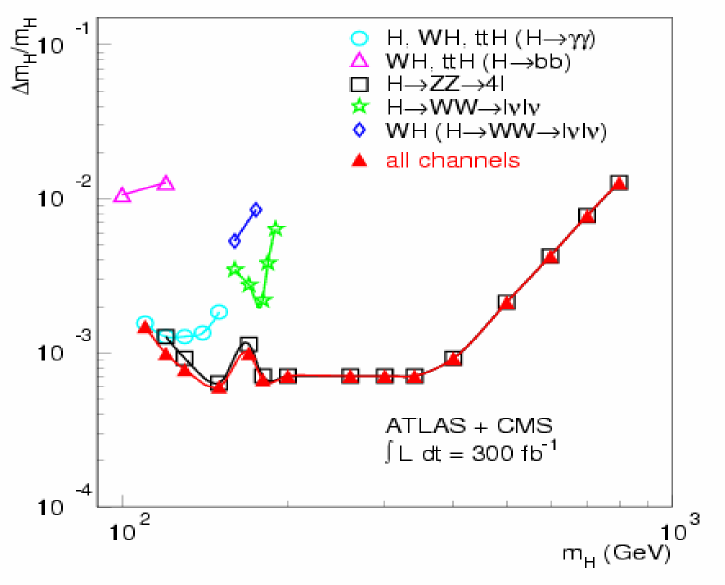


arlos

:

jet multiplicity

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)

What do we need from theory ?

- Friendly cooperation

- NLO calculations, reliable Monte Carlo event generators

  Urgent exp. wish list for MC@NLO: tt (spin correlations)
  Zbb, ttbb,….
  bb H/A
  W/Z + jet (if possible)
  VBF H signal production
  …….

- Cooperation in validation of matrix element + parton shower matching

  (started already, Tevatron data)

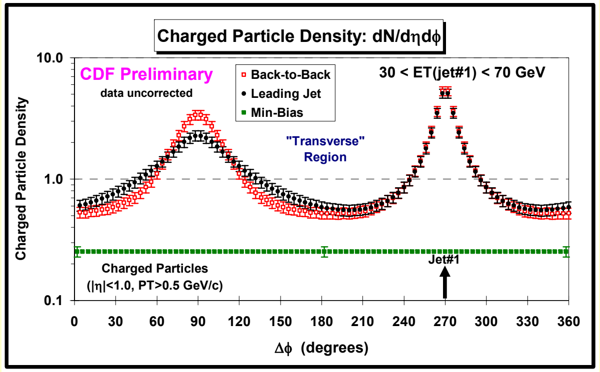
- More validation and tuning of Monte Carlo generators

  important examples:

  - underlying event in PYTHIA, MC@NLO, SHERPA,…

    (comparison with Tevatron data, studies a la R. Field)

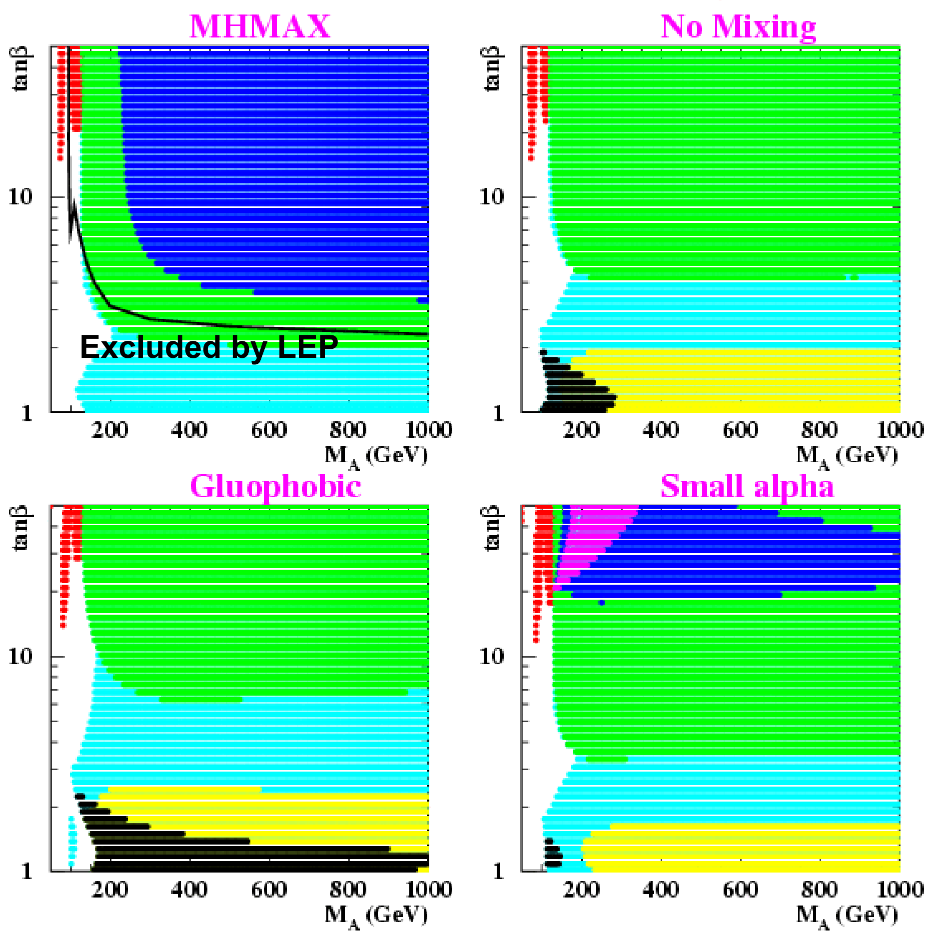
  - parton shower parameters



Updated MSSM scan for different benchmark scenarios

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

ATLAS, 30 fb^{-1}, 5σ coverage for h



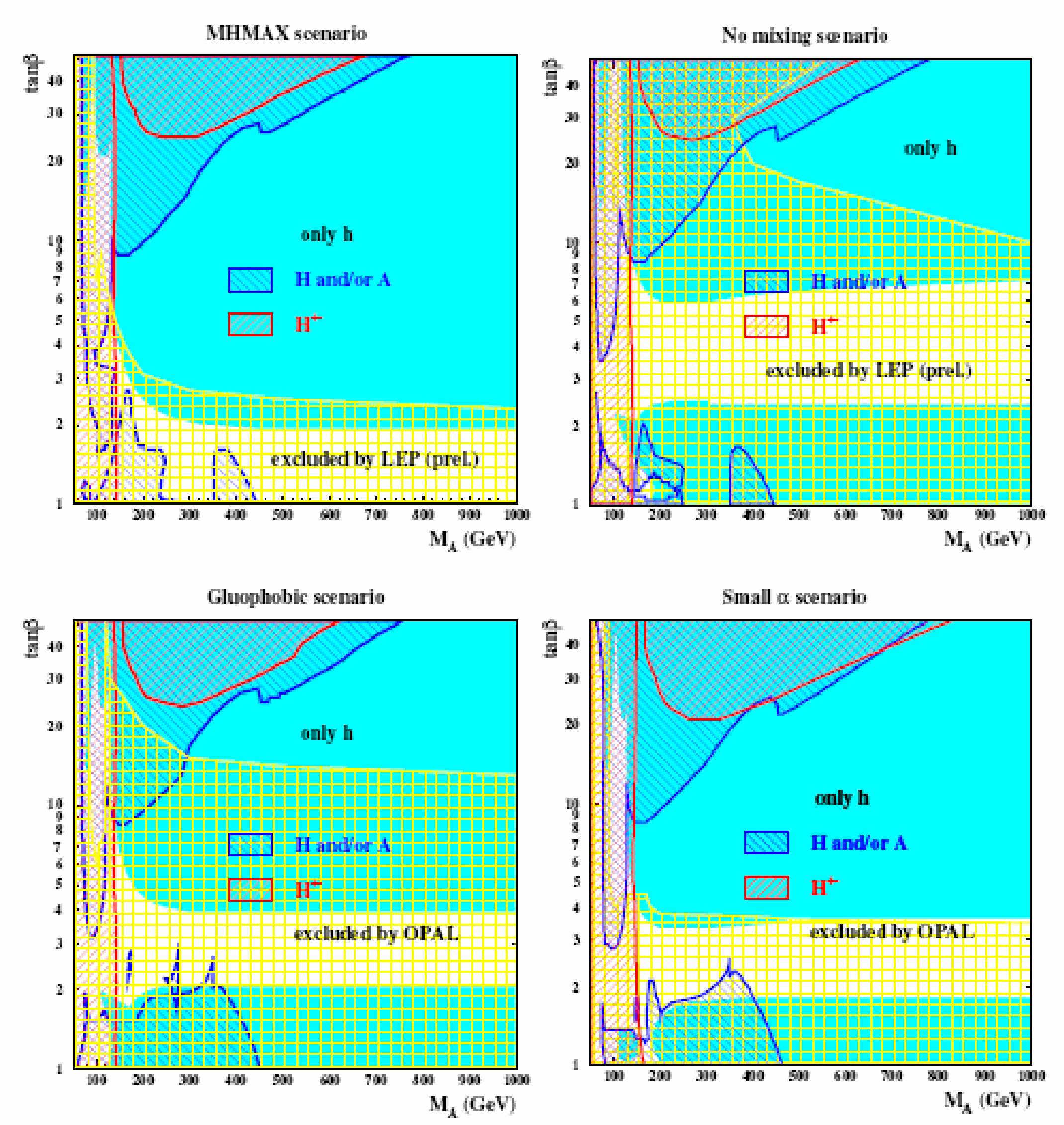
MHMAX scenario (M_{SUSY}=1 TeV)
maximal theoretically allowed region for m_h

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

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

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

MSSM discovery potential for various benchmark scenarios



- Full parameter range can be covered with modest luminosity, 30 fb^{-1}, for all benchmark scenarios !

- Only one Higgs boson, h, in some regions
  (moderate tanβ – large m_A wedge)

  valid if CP is conserved !!

Different in CP violating scenarios