Standard Model Higgs searches with the CMS detector

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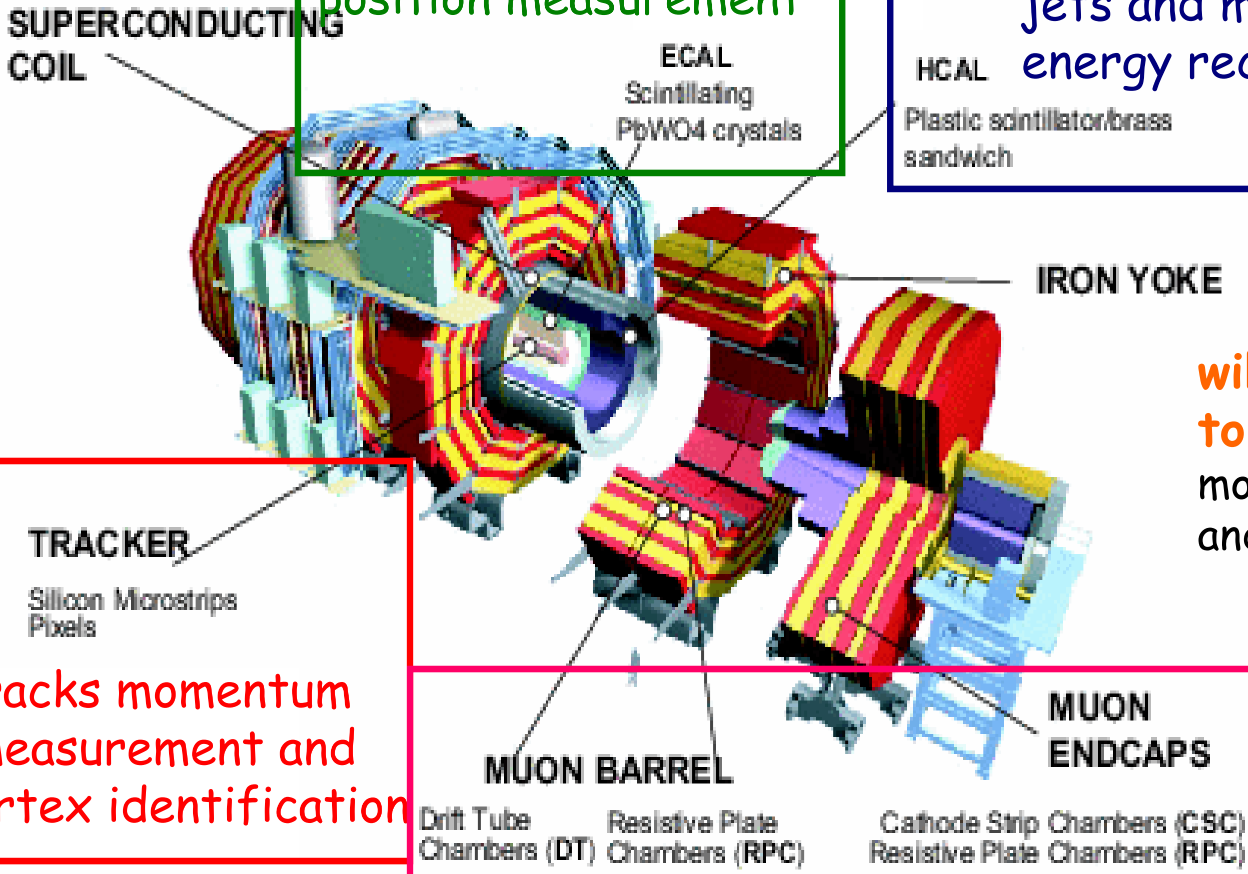
on behalf of the CMS Collaboration

EPS, Manchester – July 19th – 25th

The CMS experiment



e/γ energy and position measurement

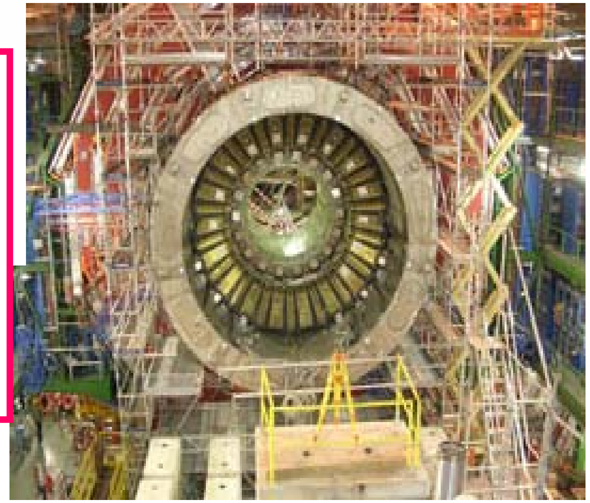
jets and missing energy reconstruction

tracks momentum measurement and vertex identification

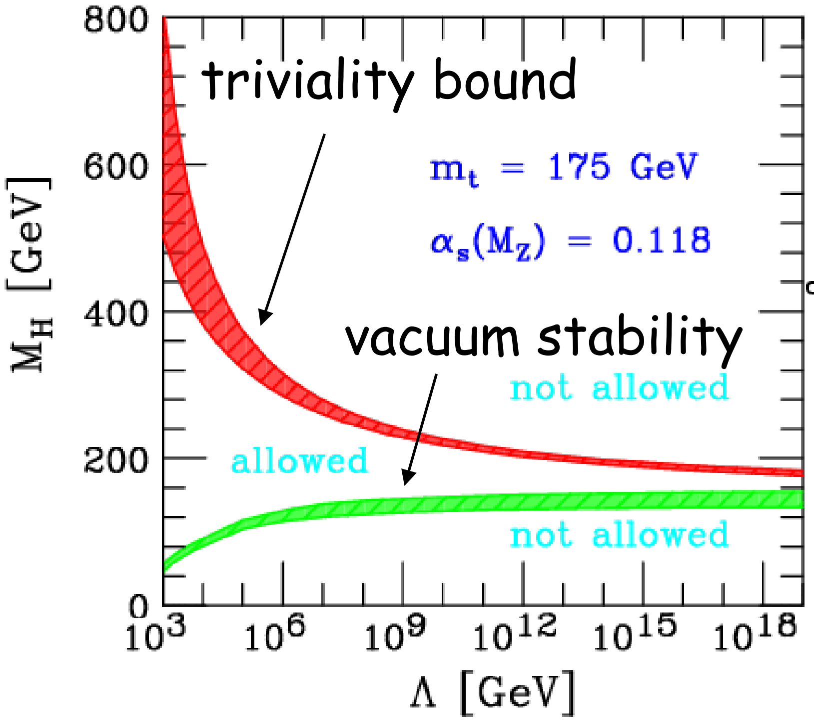
muon tracks reconstruction and momentum measurement

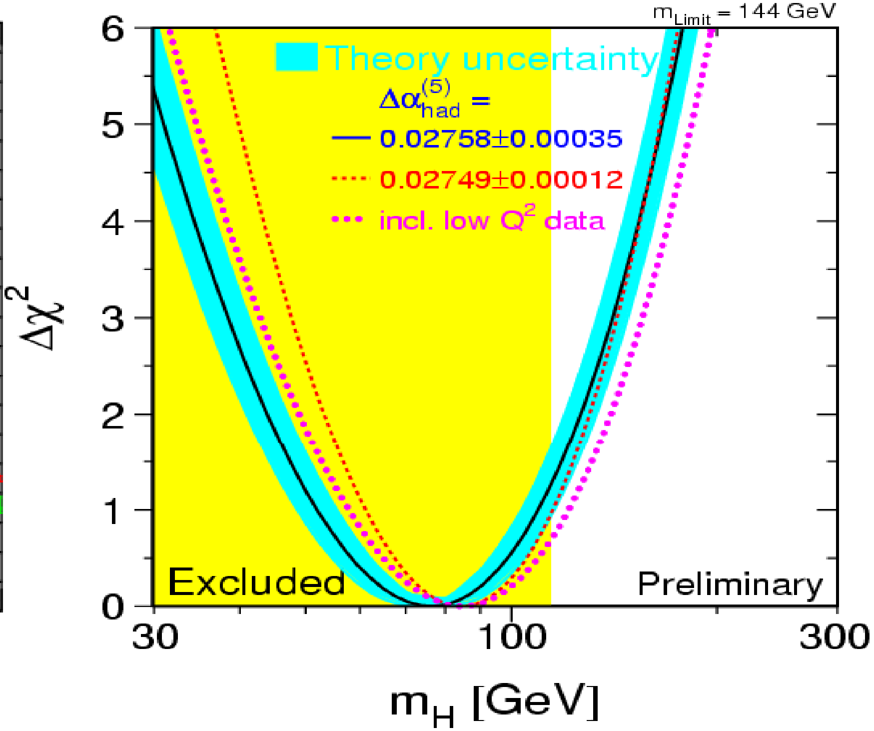
will be ready according to new LHC schedule

more details in `Detectors and Data Handling' session



SM Higgs mass constraints





theoretical limits: finite and positive Higgs couplings

experimental limits:

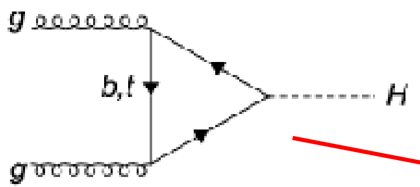
direct (from LEP): m_H > 114.4 GeV/c^2 Phys.Lett.B 565 (2003) 61

indirect (from EW data): m_H < 144 GeV/c^2 @ 95% CL

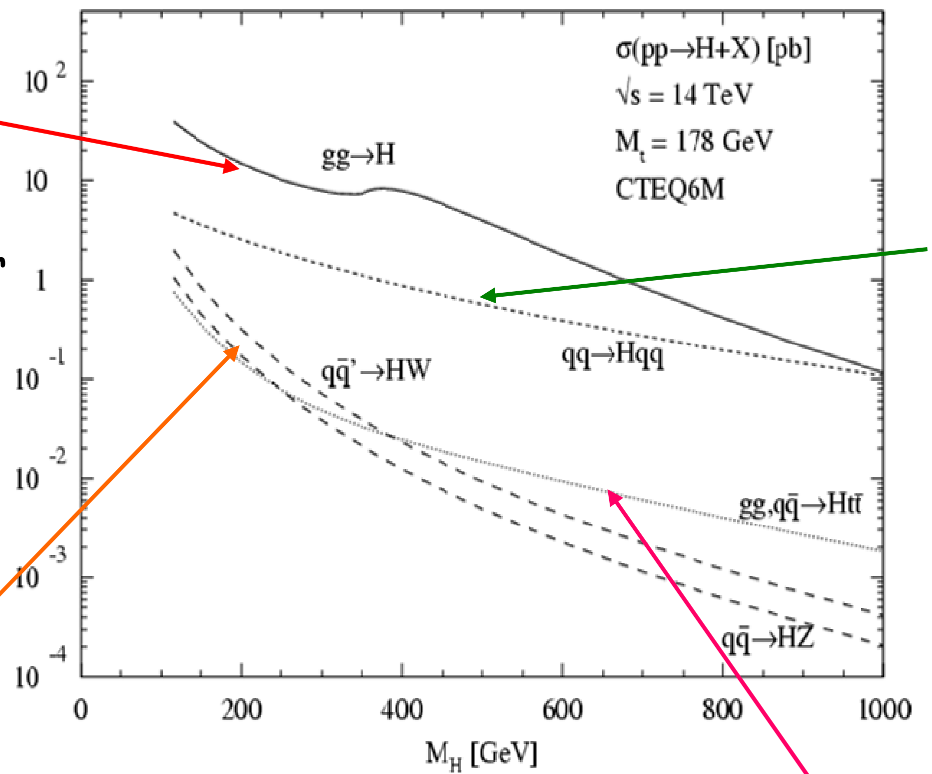
m_H < 182 GeV/c^2 including LEP results } LEP EW WG home page

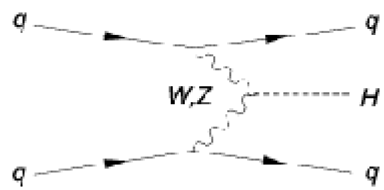
(using latest measurement of m_{top}= 170.9 GeV/c^2)

SM Higgs production at LHC



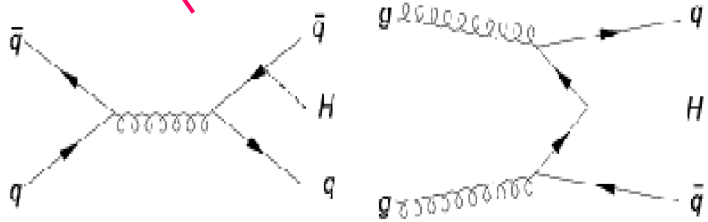
gluon-gluon fusion:
dominant process over entire mass range





vector bosons fusion (VBF):
forward jets in final state

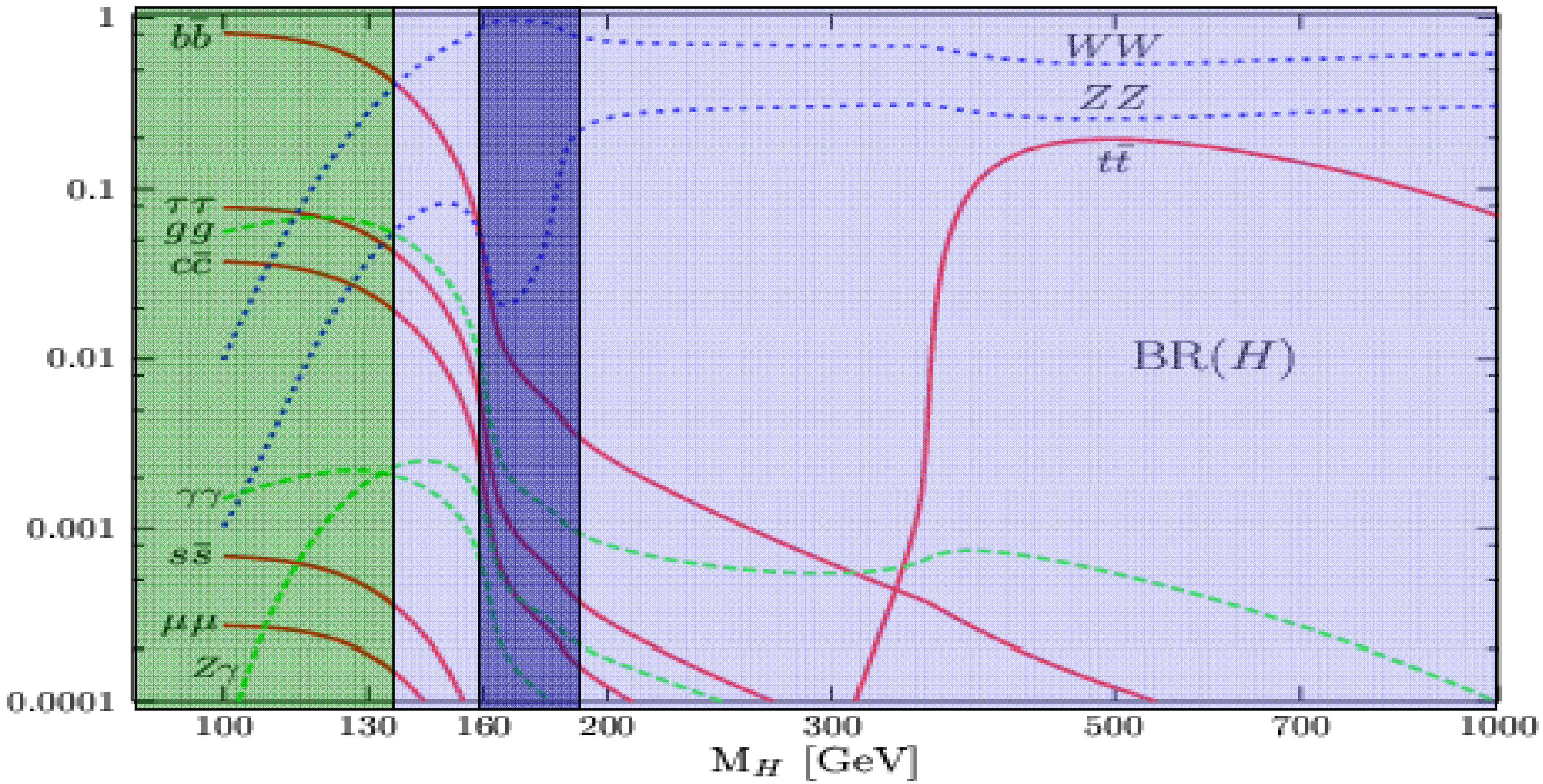
associated production with quarks or bosons:
additional leptons or jets in final state



SM Higgs decays

m_H<140 GeV/c^2
$b\bar{b}$ dominates but hidden by QCD background,
$H \to \gamma\gamma$ main discovery channel

m_H>140 GeV/c^2
$H \to VV$ dominates
$H \to WW$ main channel if $2m_W < m_H < 2m_Z$



$H \to \gamma\gamma$

very clean signature in m_H<140GeV/c^2 region
low branching ratio (0.002)

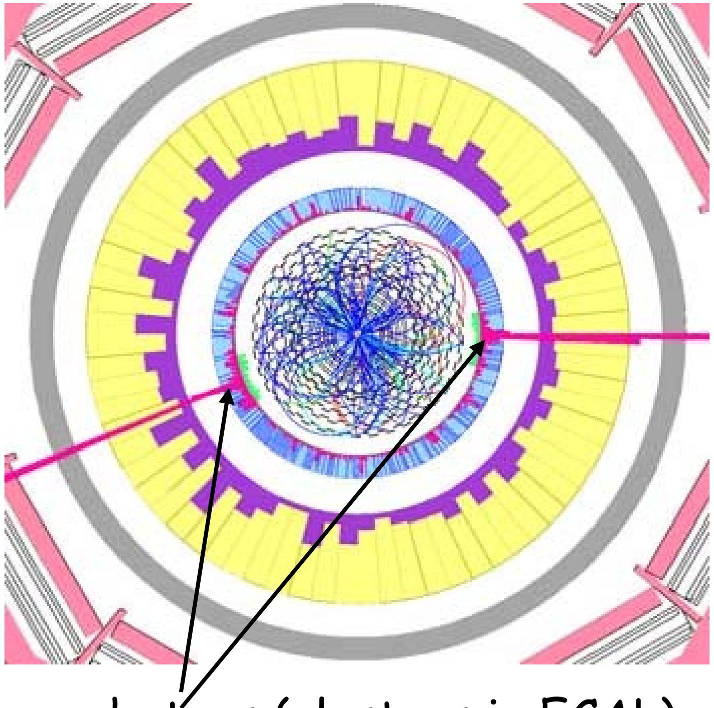
- signature:
  two isolated high p_T photons
  narrow peak in di-photon invariant mass
- backgrounds: $pp \to \gamma\gamma$ (irreducible)
  $pp \to \gamma$+jets, $pp \to$ jets (reducible)
- experimental requirements:
  very good γ identification and isolation
  aiming at 0.5% ECAL energy resolution

signal:

m_H = 115 GeV/c^2	σxBR = 99.3fb
m_H = 140 GeV/c^2	σxBR = 65.5fb

backgrounds:

$pp \to \gamma\gamma$	σ = 82pb
$pp \to \gamma$+jets	σ = 5x10^4pb
$pp \to$ jets	σ = 2.8x10^7pb



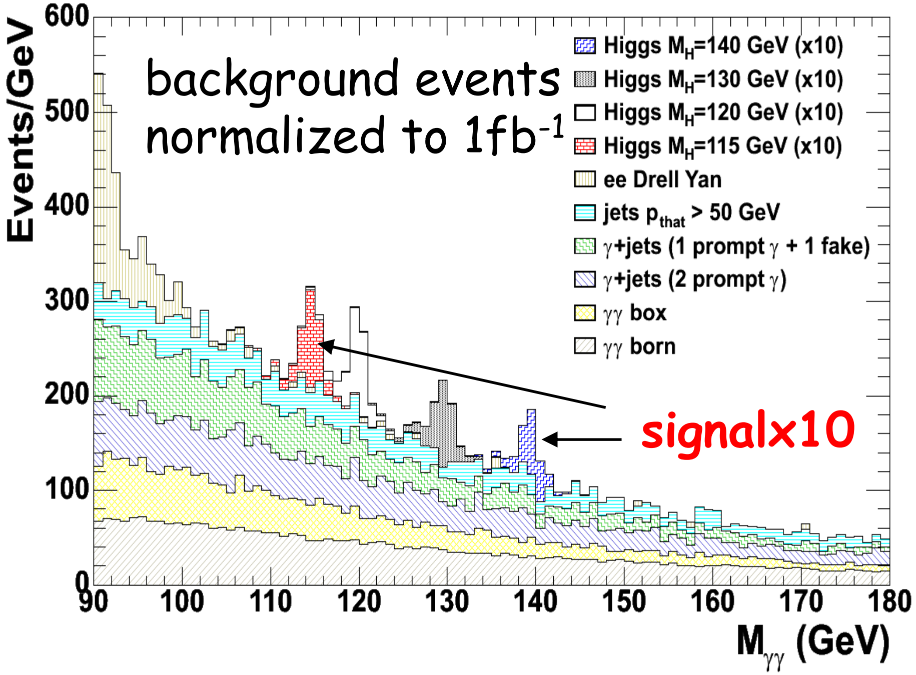
photons (clusters in ECAL)

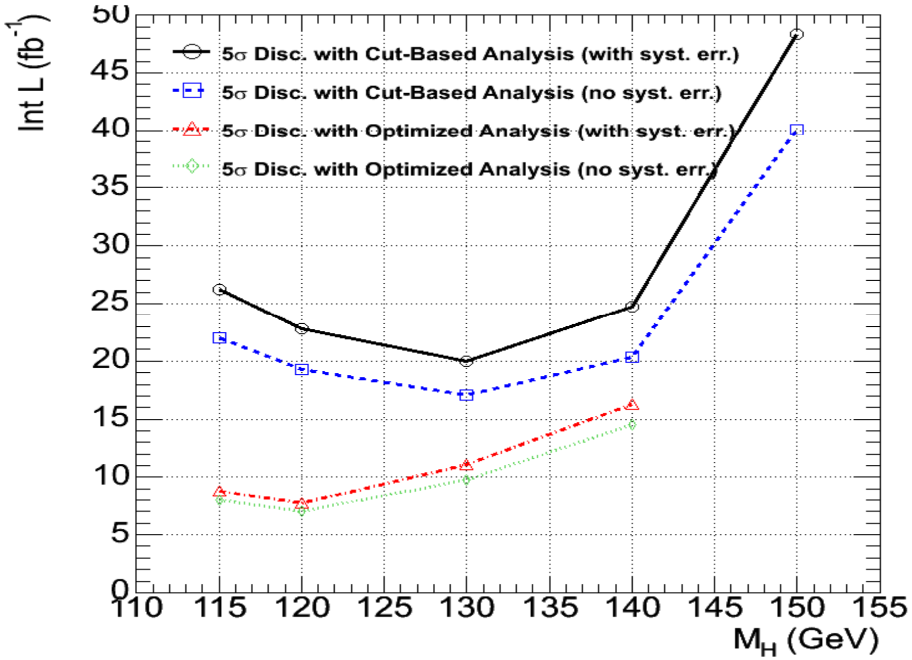
H→γγ: results

two approaches:
cuts based analysis and
neural network analysis

signal: very small contribution to the total number of events
(signal efficiency at 120 GeV/c² ~ 30%)

30fb⁻¹:
discovery possible for masses < 140 GeV/c² using 0.5% resolution



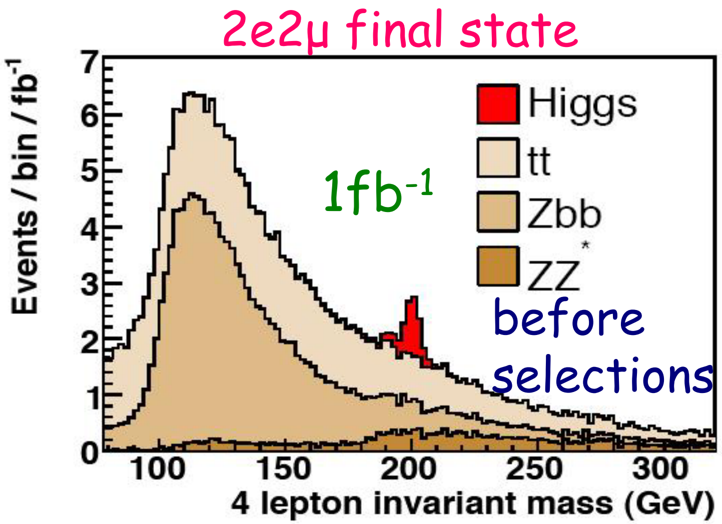


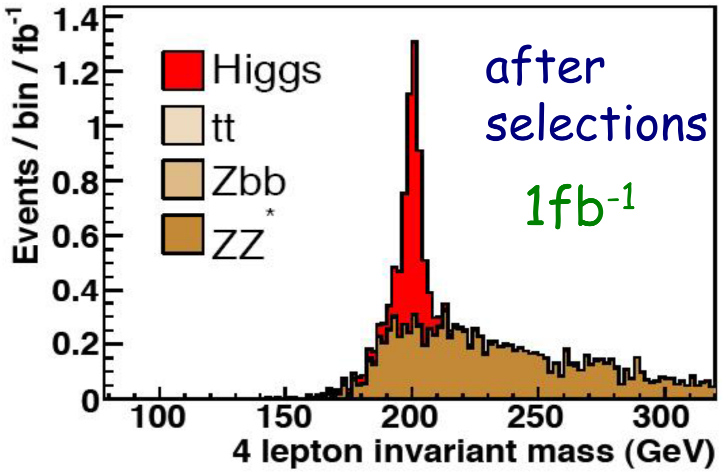
H→ZZ→4 charged leptons

GOLDEN CHANNEL: cleanest discovery channel over m_H>140GeV/c^2 range

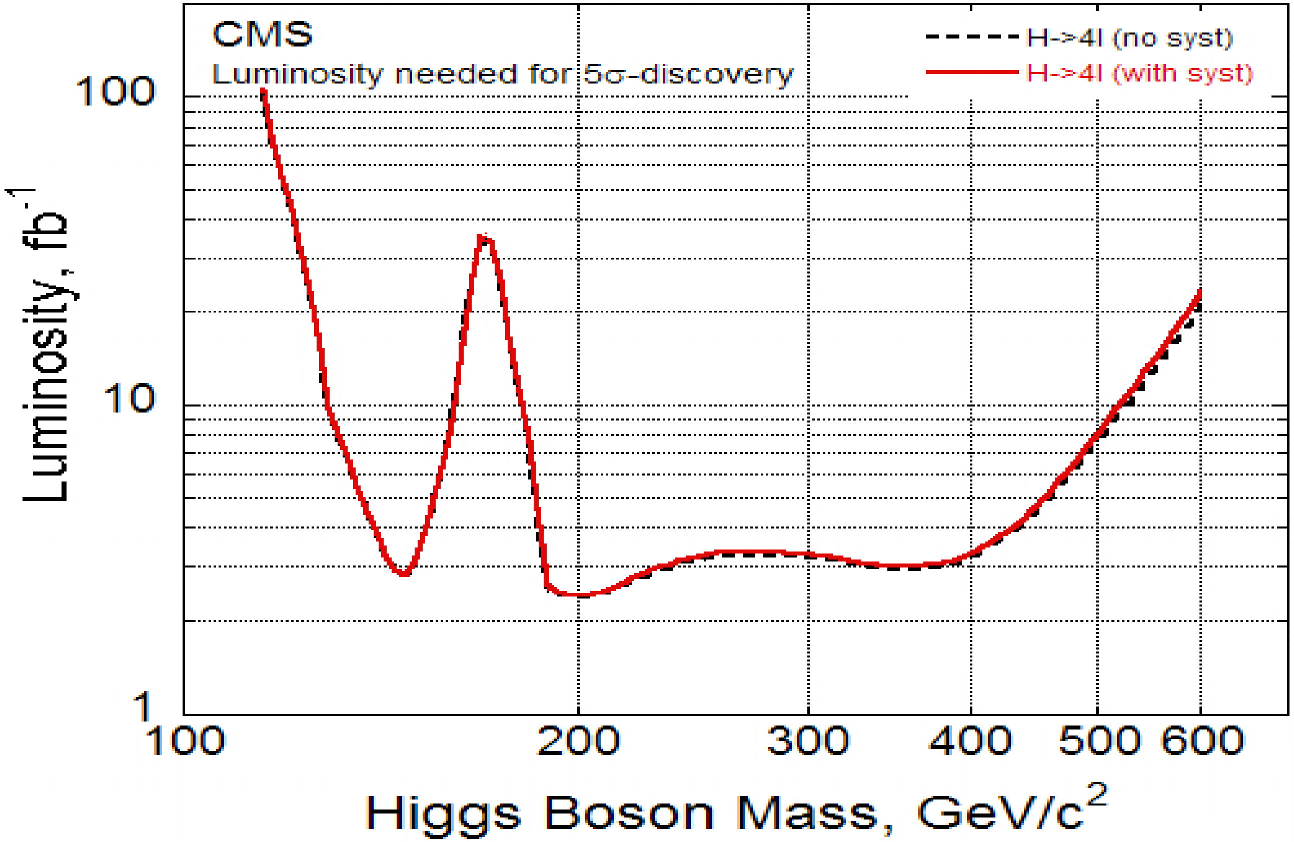
- signature:
  - 2 pairs of opposite-charge, same flavour isolated leptons
  - from primary vertex
  - dileptons invariant mass ~ m_Z
- backgrounds: pp → $ZZ^{(*)}$ (irreducible, dominant)
  pp→$t\bar{t}$, pp→$Zb\bar{b}$ (reducible)
- main experimental challenges:
  lepton identification with
  high efficiency and resolution
  down to low (~ 5 GeV/c) p_T

selection criteria:
requirements on vertex, p_T(l), isolation, m(ll)





H→ZZ→4 charged leptons: significance



4e, 2e2μ, 4μ combined channels

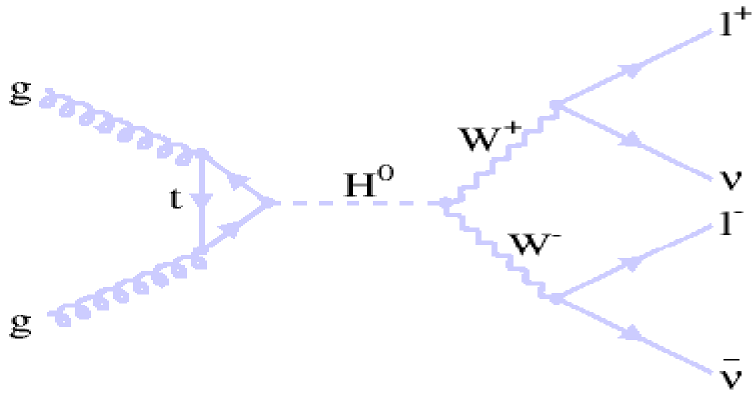
5σ with L < 20 fb^{-1}, 130< m_H<600GeV/c^2

5σ with L < 3 fb^{-1}, m_H ~ 200GeV/c^2

$H \to WW \to 2l2\nu$

discovery channel in $2m_W < m_H < 2m_Z$

- signature:
  - 2 charged leptons and missing energy
  - no jet activity in the central region



2 neutrinos in the final state:
no mass peak, counting experiments →
accurate background estimate from data needed

- main backgrounds:

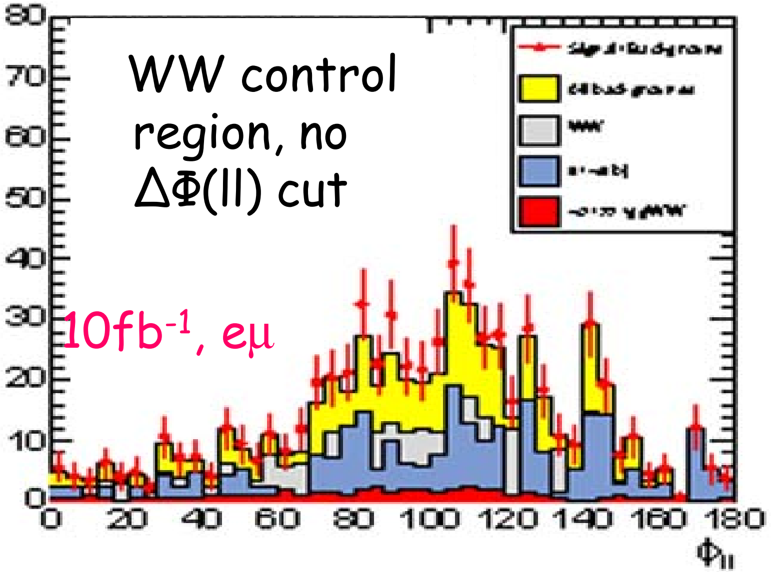
$WW^{(*)}$ (irreducible, dominant)
pp→ $t\bar{t}$, pp→ Wtb
pp→ W+jets, pp→ Z+jets } (reducible)

crucial for the analysis:
reconstruction tools for
charged leptons, missing
energy and jet veto
understanding !!!

2 opposite charge leptons
no jet with $E_T > 15$GeV, $|\eta|<2.5$
MET > 50 GeV
$12 < m(ll) < 40$ GeV
$30 < p_T^{max} < 55$ GeV
$p_T^{min} > 25$ GeV
$\Delta\Phi(ll) < 45°$

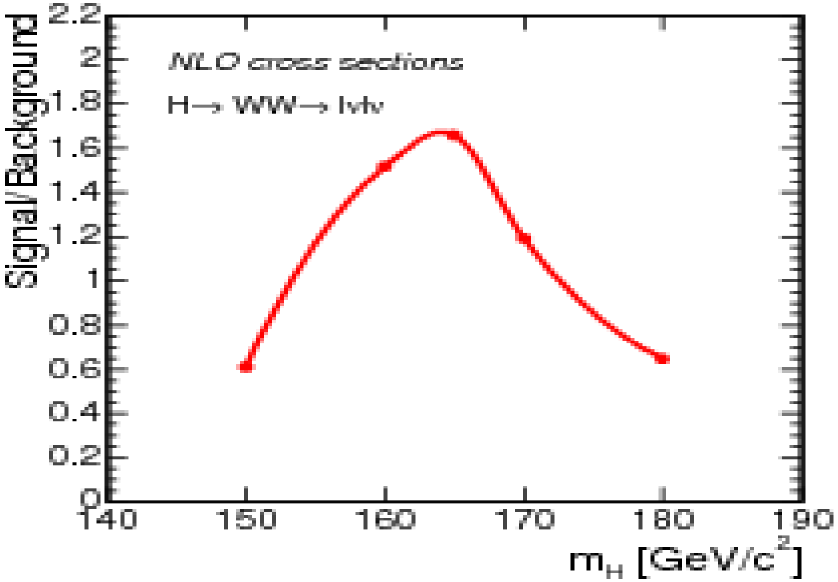
cuts and counts analysis

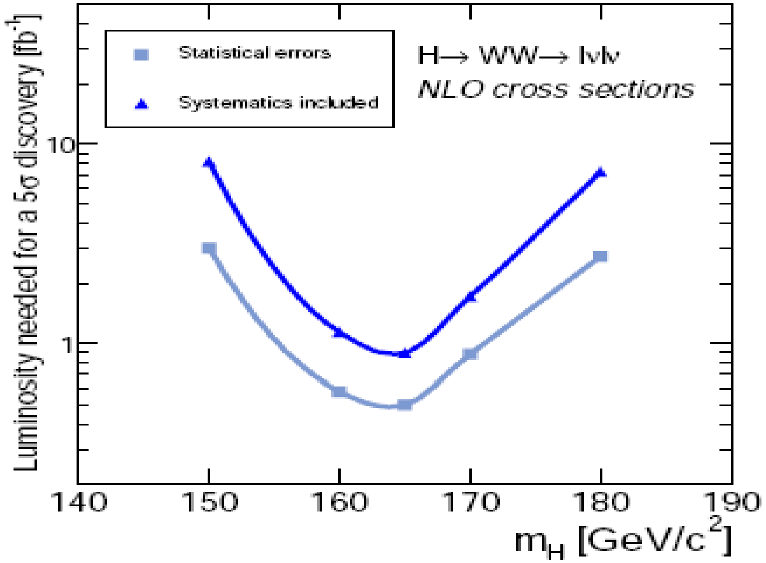
H→WW→2l2ν: results



critical:
precise background knowledge
→ control regions using data
ie. WW: inverted kinematic cuts
on ΔΦ(ll) and m(ll)
ie. $t\bar{t}$: extra b-tagged jets

large S/B,
5σ with L<1fb^{-1} m_H=165 GeV/c^2

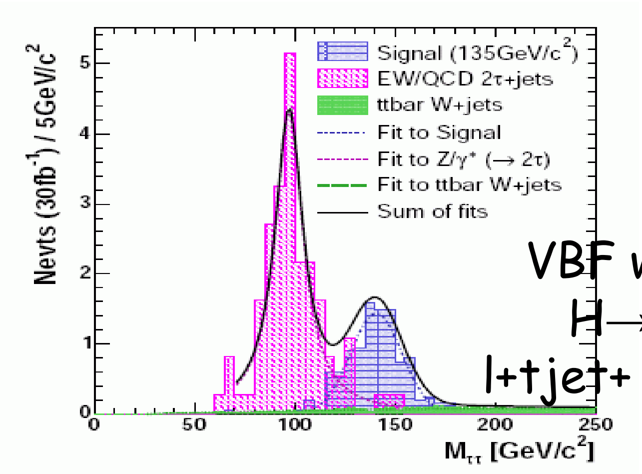




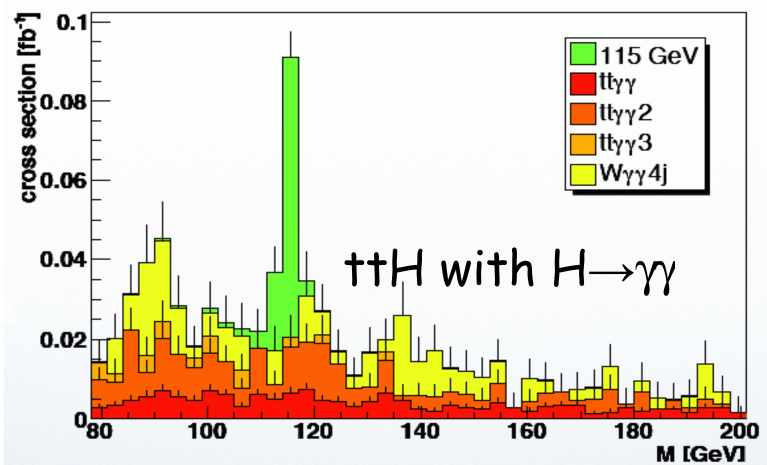
Other Higgs production mechanisms

associated ttH, WH production: additional leptons/jets in the final state
vector boson fusion: two tagging jets, large $\Delta\eta jj$ (>4.5), large m(jj) (>1TeV)

- despite lower cross section wrt gg fusion
  - increased discriminating power against QCD jets background
  - better main vertex reconstruction
- with large statistics: enhance the significance, measure of Higgs couplings
- some examples in CMS:
  - VBF with $H\to\tau\tau \to$ l+tjet+ $E_T$miss (5σ with L=60fb^{-1} if m_H<140GeV/c^2)
  - VBF with $H\to\gamma\gamma$ (3σ with L=60fb^{-1} if m_H<150 GeV/c^2)
  - ttH, WH with $H\to\gamma\gamma$ (3σ with L=100fb^{-1} if m_H<150 GeV/c^2)



VBF with $H\to\tau\tau \to$ l+tjet+ ETmiss



ttH with $H\to\gamma\gamma$

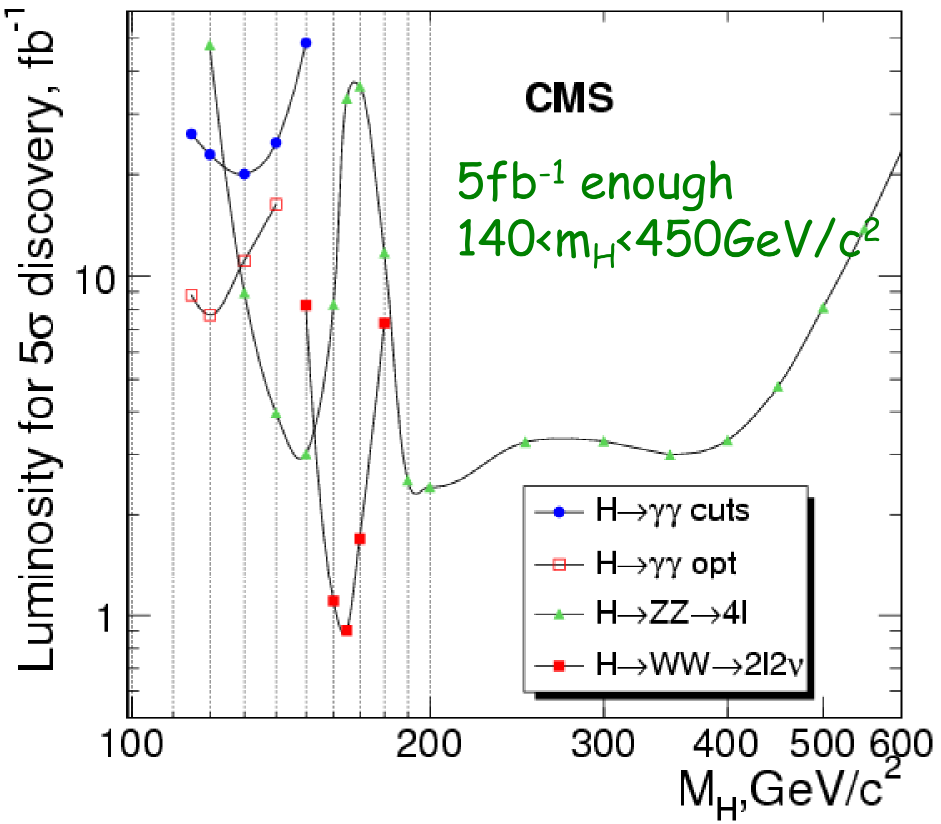
Analyses common aspects

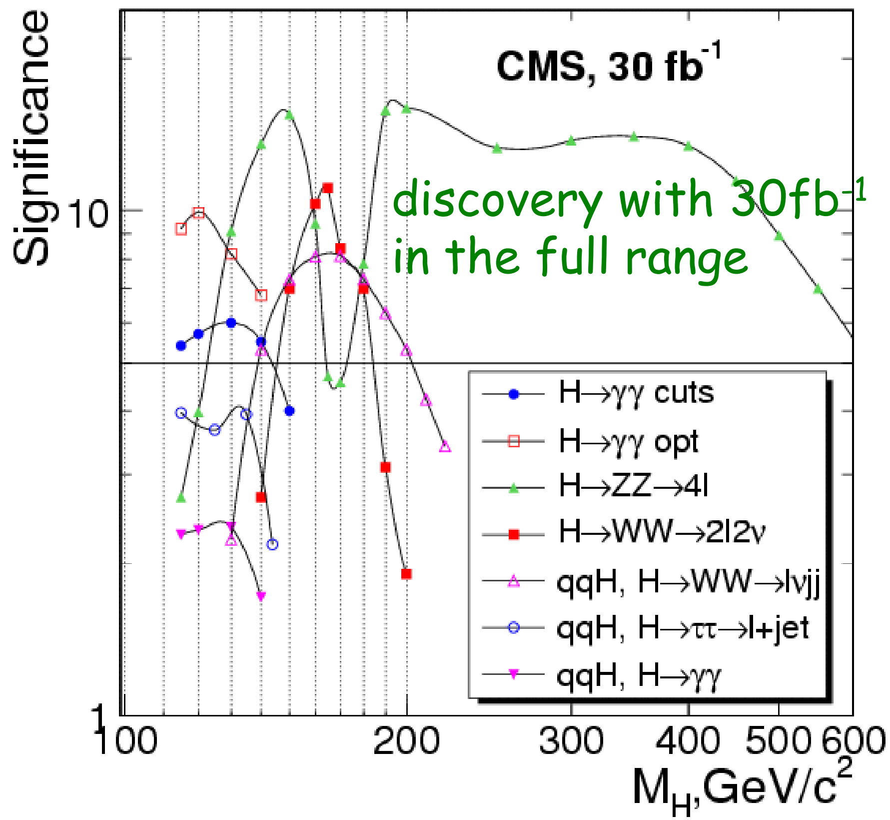
- Event generation and simulation:
  - NLO, NNLO: K factors for σ and events re-weighting
  - MC used: PYTHIA, CompHEP, Alpgen, TopReX, MC@NLO....
  - full detector simulation and reconstruction

- uncertainties taken into account:
  - theoretical:
    - pdf, N(N)LO corrections, factorization/renormalization scale
  - experimental:
    - lepton reconstruction efficiency and energy scale
    - jets/MET scale
    - misalineament, miscalibration, geometry description (ie. tracker material budget)
  - data driven estimate
    - background shape and cross-section in signal region
    - leptons energy scale (via Z,W -> ll)

recently published analyses
(CMS Physics TDR, vol II: http://cmsdoc.cern.ch/cms/cpt/tdr)

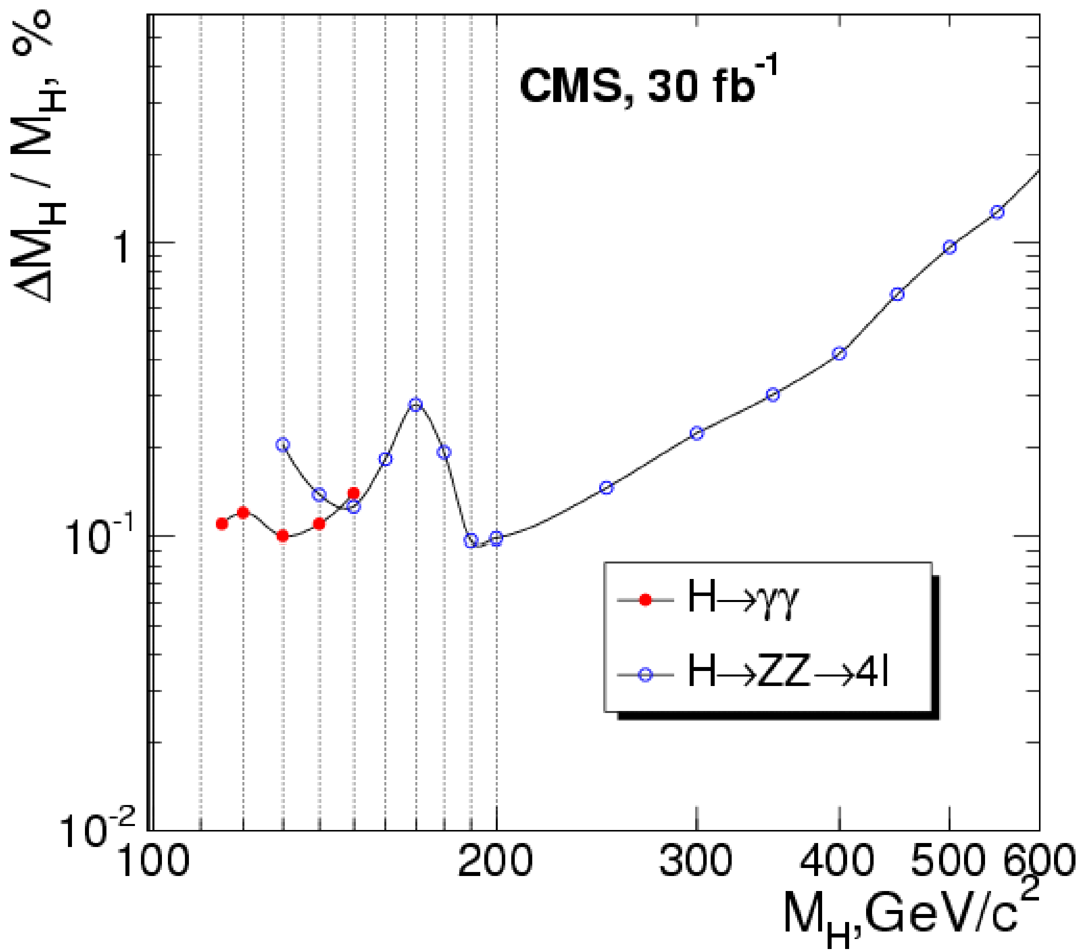
Summary of SM Higgs discovery





all Higgs mass range: significance larger than 5σ with 30 fb^{-1}
m_H < 140 GeV/c^2 discovery with L < 10 fb^{-1}
m_H > 140 GeV/c^2 discovery with L < 5 fb^{-1}

Higgs mass and width



- Higgs mass precision:
  - better than 0.1% if m_H<200 GeV/c^2
  - better than 2% up to 600 GeV/c^2

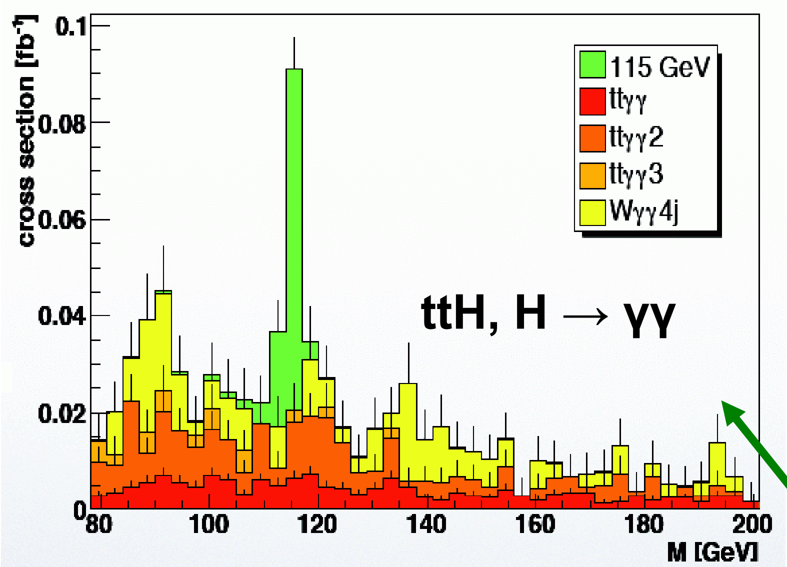
- Higgs width precision:
  - detector effects dominate if m_H < 200 GeV/c^2
  - if m_H > 200 GeV/c^2 possible measurement with precision better 30% in ZZ channel

Summary

- CMS discovery potential for the SM Higgs boson recently evaluated with full detector simulation
- inclusion/development of
  - systematics errors, both theoretical and experimental
  - background estimate procedures using data
  - NLO computation
- CMS discovery reach
  - $L < 10fb^{-1}$ in the $H\rightarrow\gamma\gamma$ channel @ 120 GeV/c^2
  - $L < 3fb^{-1}$ in the $H \rightarrow ZZ$ channel @ 180 GeV/c^2
  - $L < 1fb^{-1}$ in the $H \rightarrow WW$ channel @ 165 GeV/c^2
- significance > 5σ with $L = 30fb^{-1}$ in 120 $GeV/c^2 < m_H <$ 600 GeV/c^2 range
- Higgs mass precision better than
  - 0.1% if $m_H <$ 200 GeV/c^2
  - 2% up to 600 GeV/c^2

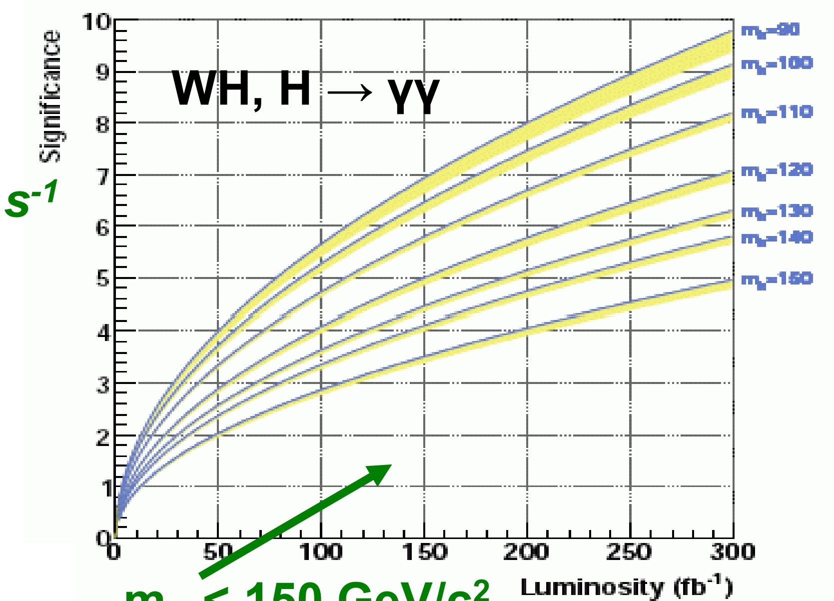
BACKUP SLIDES

VBF and associated production, H->γγ



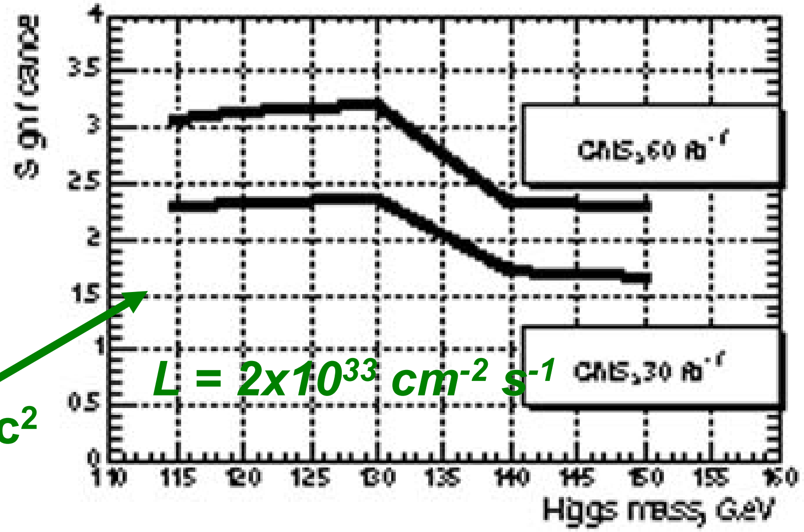
L = 10^{34} cm^{-2} s^{-1}

100fb^{-1}



m_H < 150 GeV/c^2
3σ → 100fb^{-1}

Higgs Boson Mass (GeV)	115	120	130	140
Sig. Selection Eff. (%)	10.7	11.2	11.3	11.3
Number Signal NS	7.42 ±0.33	7.33 ± 0.33	5.96±0.27	4.21±0.19
Total Number Bcgkd	1.61 ±0.53	2.79 ±0.62	1.98±0.66	1.10± 0.51
Total Number Bcgkd from fit w. syst.	2.23±0.34	1.94±0.32	1.60±0.22	1.39±0.22
Signal Significance (ScP)	3.541	3.662	3.257	2.510
Signal Significance (ScP) w. syst.	3.414	3.523	3.184	2.453



L = 2x10^{33} cm^{-2} s^{-1}

additional jets and isolated leptons:
- ✓ larger discrimination power against light QCD background
- ✓ better vertex reconstruction

m_H < 150 GeV/c^2
3σ → 60fb^{-1}

ttbar H, H→bbar

all the possible final states have been investigated:
semileptonic, fully hadronic, fully leptonic

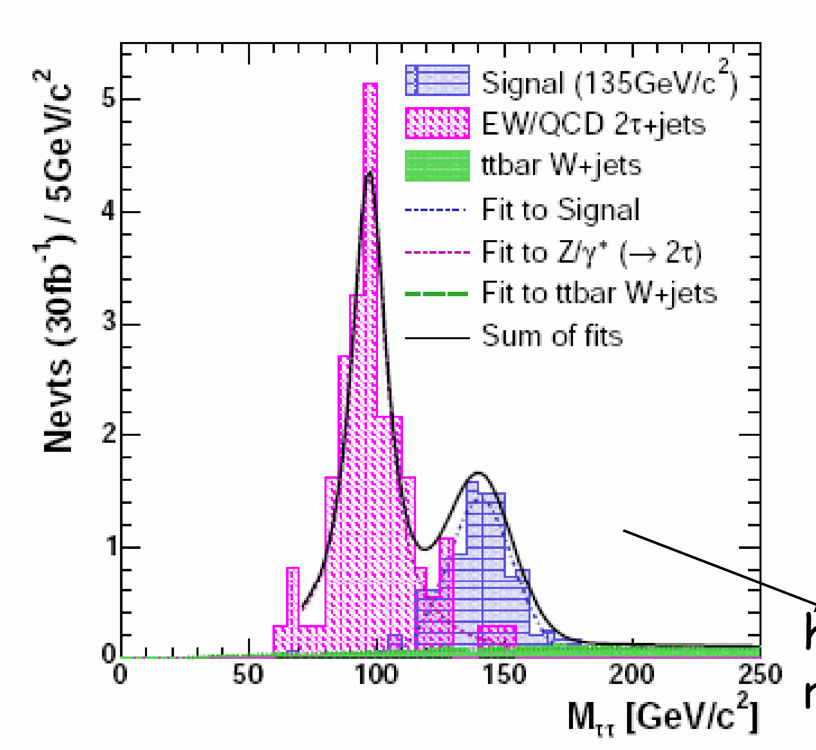
main backgrounds:
ttbarjj, ttbar bbar, Z ttbar with Z →bbar
QCD multi-jets bkg for hadronic final states
W,Z + jets for leptonic final states

main goals: b-jet tagging +
extract the "correct" b-jets
from the combinatorics

channel	S/B	$S/\sqrt{B}$	$S/\sqrt{B+dB^2}$
semileptonic, μ	0.108	2.0	0.44
semileptonic, e	0.086	1.5	0.37
dilepton	0.069	1.4	0.42
hadron	0.087	2.0	0.22

→ full simulation analysis:
H → bbar lost as discovery channel
also with $60fb^{-1}$

VBF with $H \rightarrow \tau\tau \rightarrow l + \tau jet + E_T^{miss}$



VBF: two tagging jets ($\Delta\eta_{jj}$>4.5, M_{jj}>1TeV) which increase the discriminating power with respect to jet backgrounds

main backgrounds:
QCD 2τ + 2or3jets
EW 2τ + 2jets
W+jets, ttbar

higgs mass resolution = 9.1%

5σ with L=60fb^{-1}
If m_H<140 GeV/c^2

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