Discovery Potential for the SM Higgs Boson in the Inclusive Search Channels (CMS and ATLAS)

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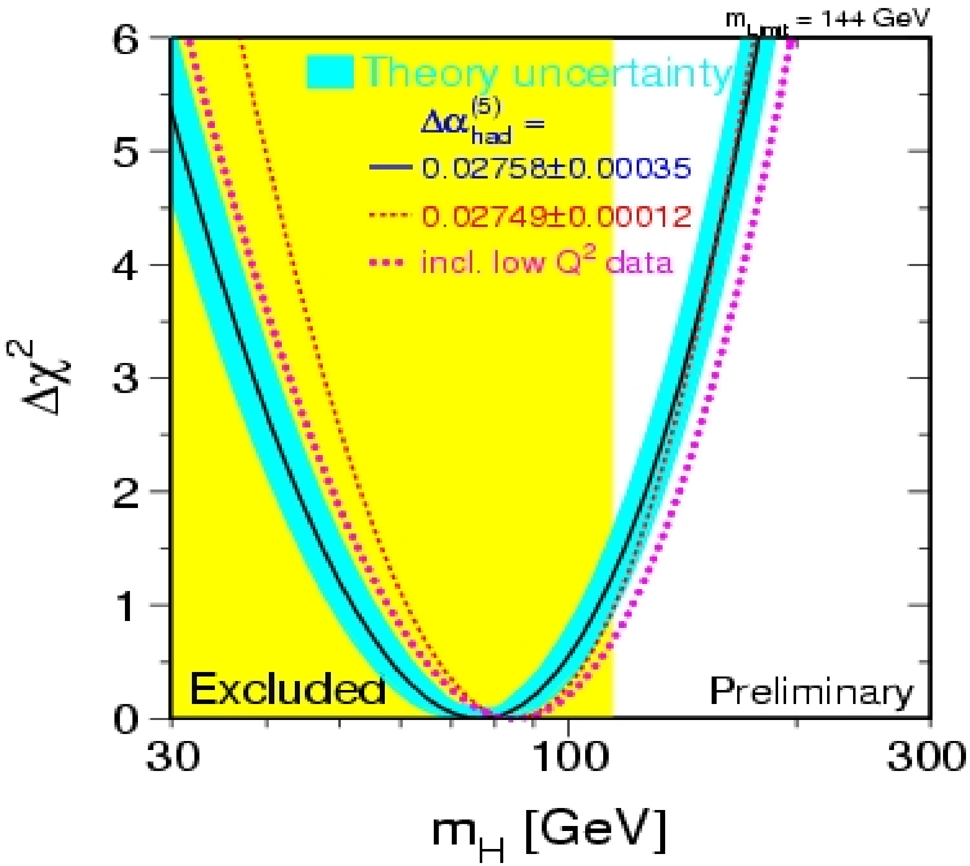
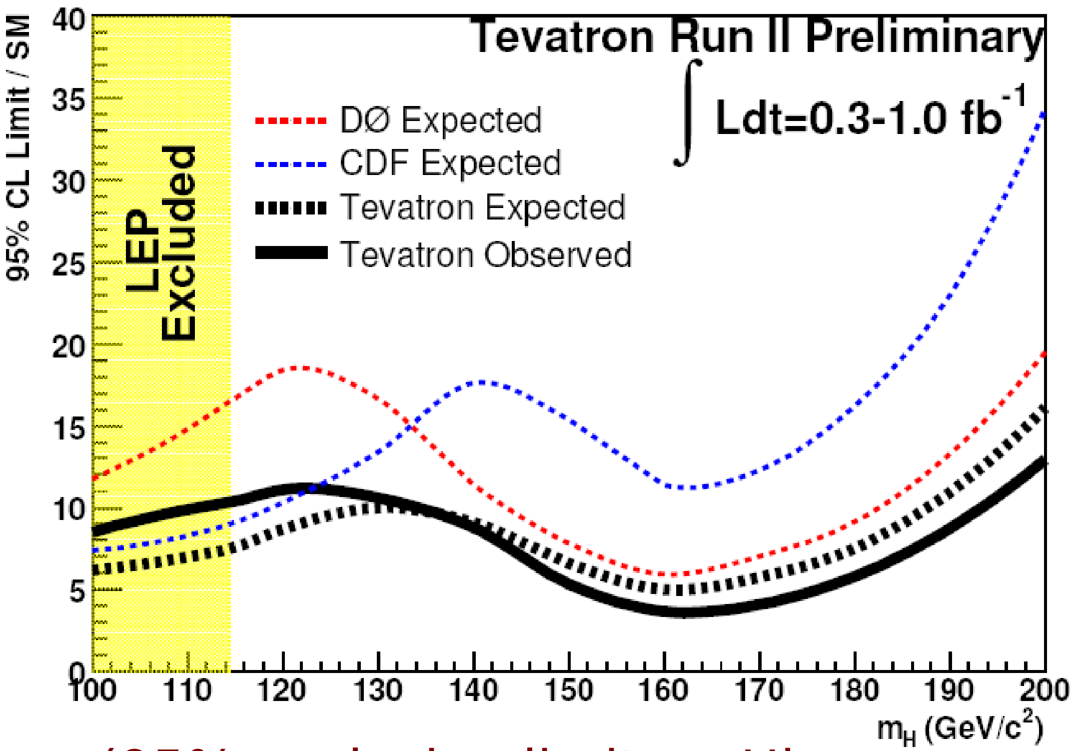
Introduction

masses of top, W, Higgs connected through radiative corrections
global Standard Model fit:

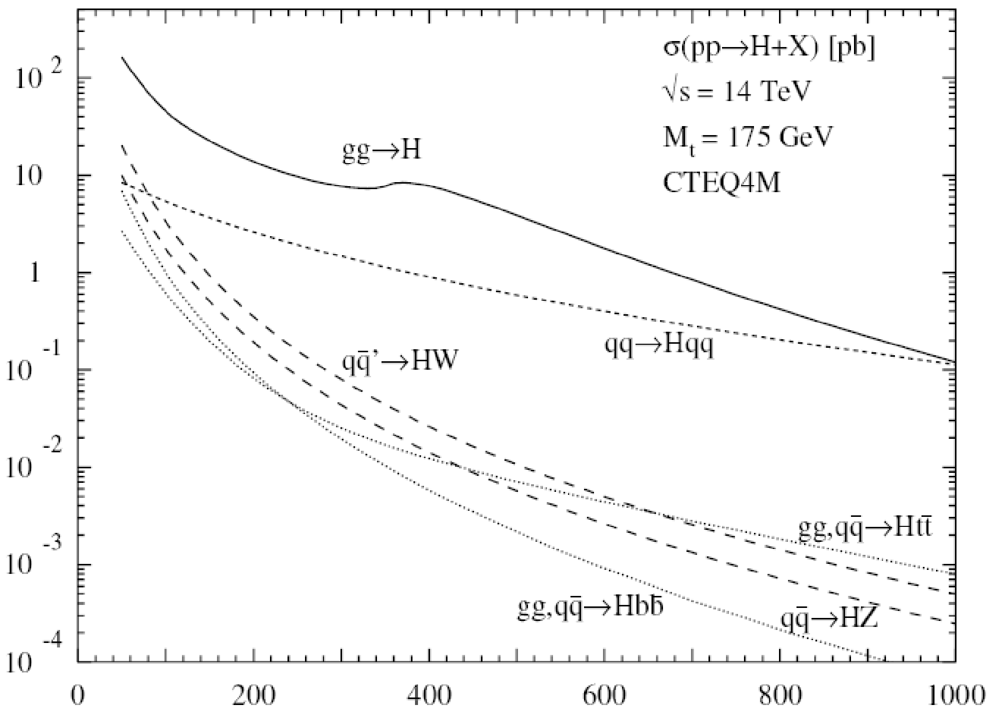


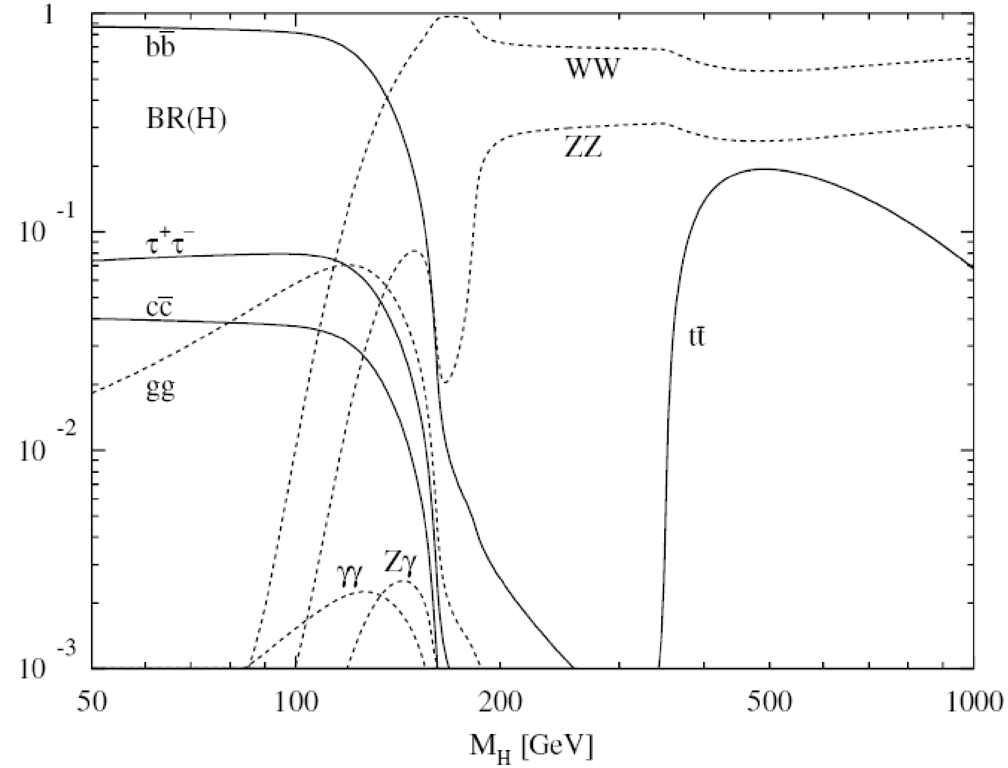
search at Tevatron:
most sensitive around 160 GeV (H->WW)

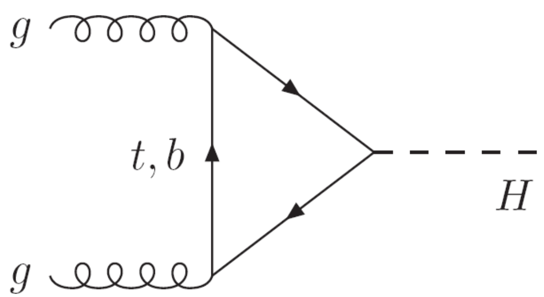


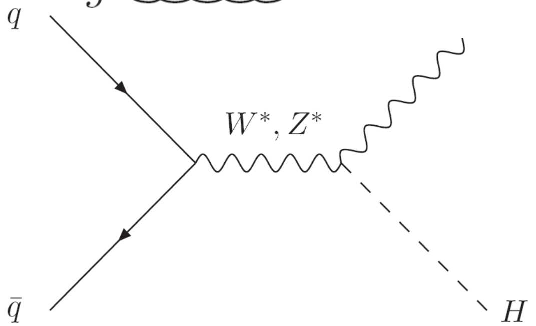
(95% exclusion limit on Higgs production cross section normalized to SM cross section)

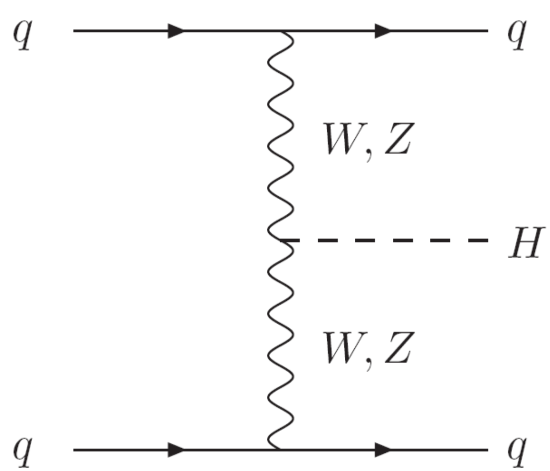
Introduction

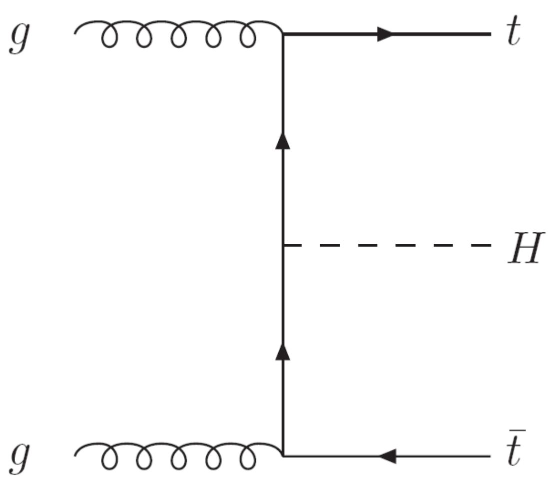








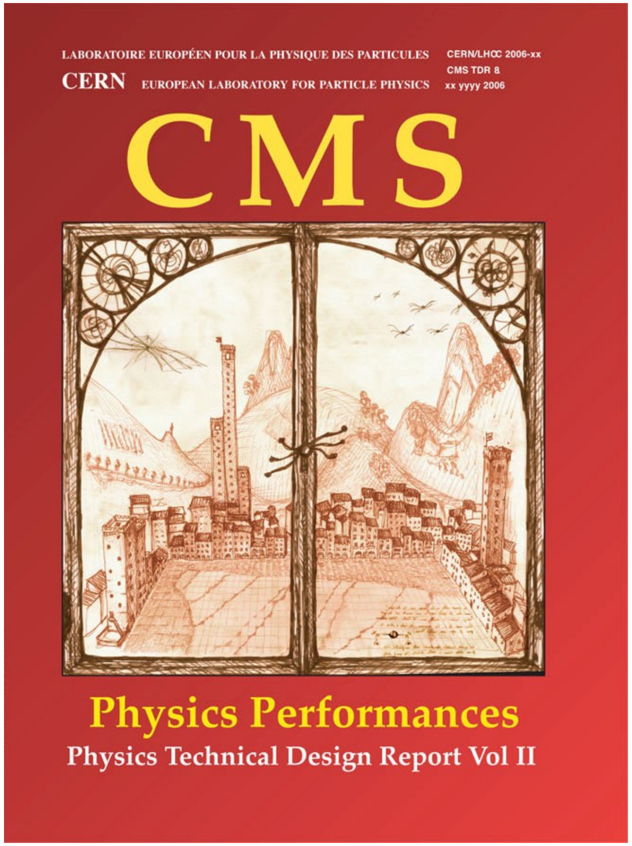




ATLAS and CMS

in 2006 CMS published the
"Physics Technical Design Reports":

- last status of complete physics analyses on SM Higgs Bosons (and much more...)
- all analyses use realistic detector simulation (GEANT4), including Level-1 and High-Level Triggers
- recent NLO calculations, where available



the ATLAS Physics TDR has been published in 1999:

- uses fast simulation and LO calculations
- **analyses are being updated right now!**
- recent updates on H->gamma gamma available
- H->ZZ and H->WW not official yet
  (need to show old results on these)

$$H \rightarrow \gamma\gamma$$

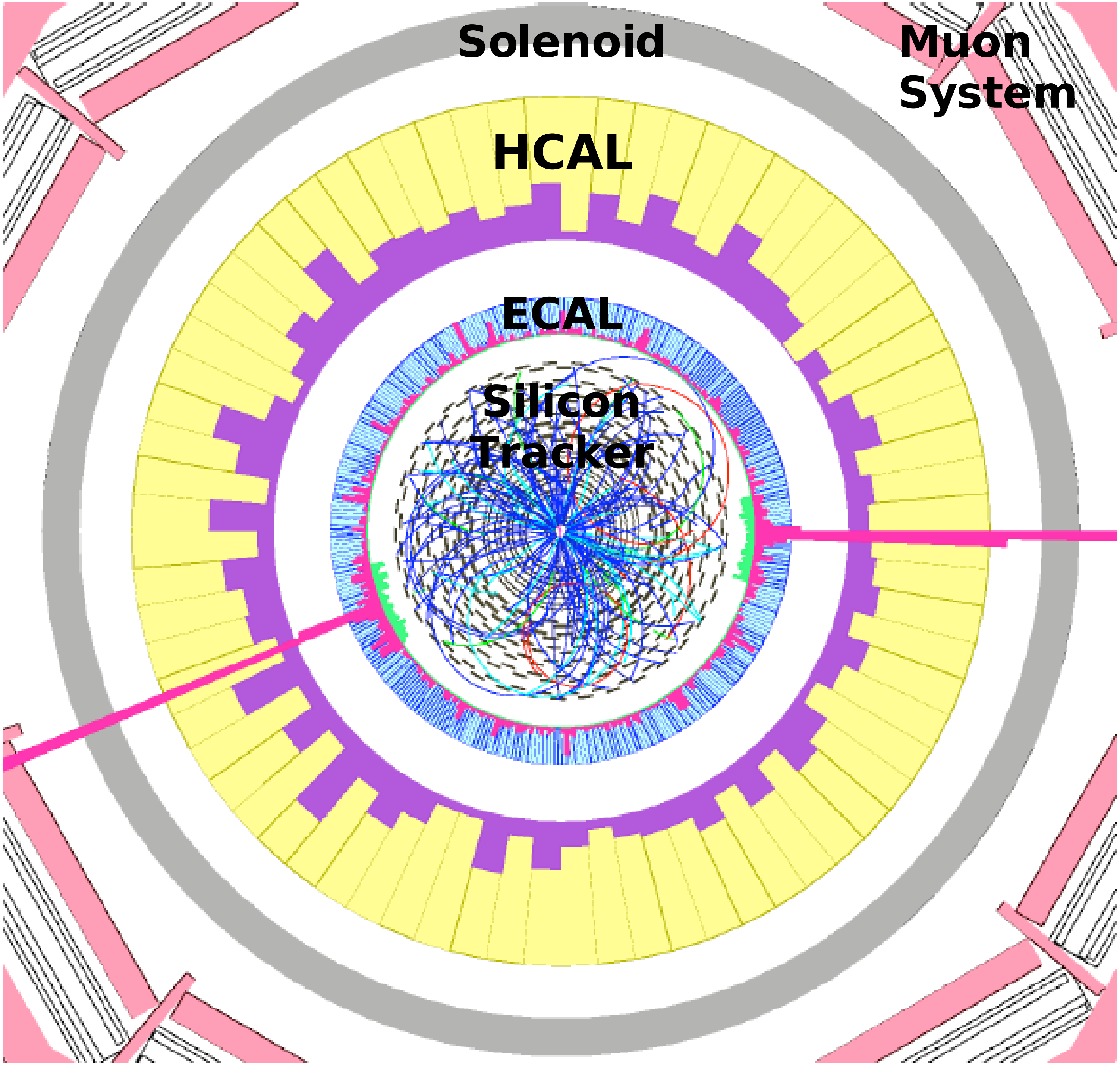
general properties:

- $H \rightarrow \gamma\gamma$ is a rare decay mode: BR ~ 0.002 (m_H ~ 120 GeV)
- visible as narrow peak above a quite flat background
  (e.m. calorimeters have good energy resolution)
- important in low mass range:

NLO signal cross sections:

M_H	115 GeV	120 GeV	130 GeV	140 GeV	150 GeV
σ (gg fusion)	39.2 pb	36.4 pb	31.6 pb	27.7 pb	24.5
σ (WVB fusion)	4.7 pb	4.5 pb	4.1 pb	3.8 pb	3.6
σ (WH, ZH, $t\bar{t}$H)	3.8 pb	3.3 pb	2.6 pb	2.1 pb	1.7
Total σ	47.6 pb	44.2 pb	38.3 pb	33.6 pb	29.7
$H \rightarrow \gamma\gamma$ Branching Ratio	0.00208	0.00220	0.00224	0.00195	0.00140
Inclusive $\sigma \times B.R.$	99.3 fb	97.5 fb	86.0 fb	65.5 fb	41.5 fb

CMS NOTE - 2006/112



CMS event view

CMS NOTE - 2006/112

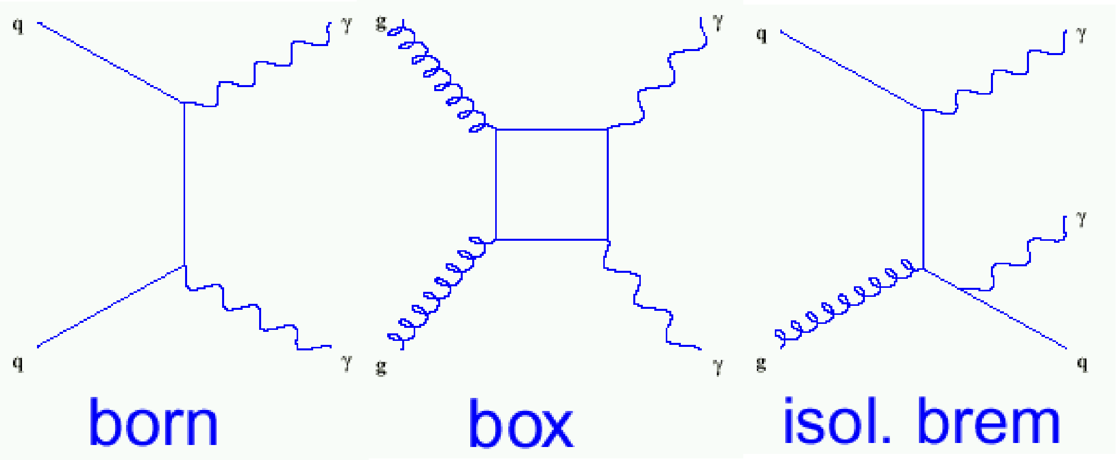
Backgrounds

backgrounds:

irreducible: two real high Et photons (born, box diagrams ~ 80 pb, "isolated brem")

reducible: jet-jet and gamma-jet events with jets misidentified as photons ~ 4000 pb (with generator preselection factor ~6000)

- CMS uses K factors, while ATLAS uses full NLO Events
  => differences in tails

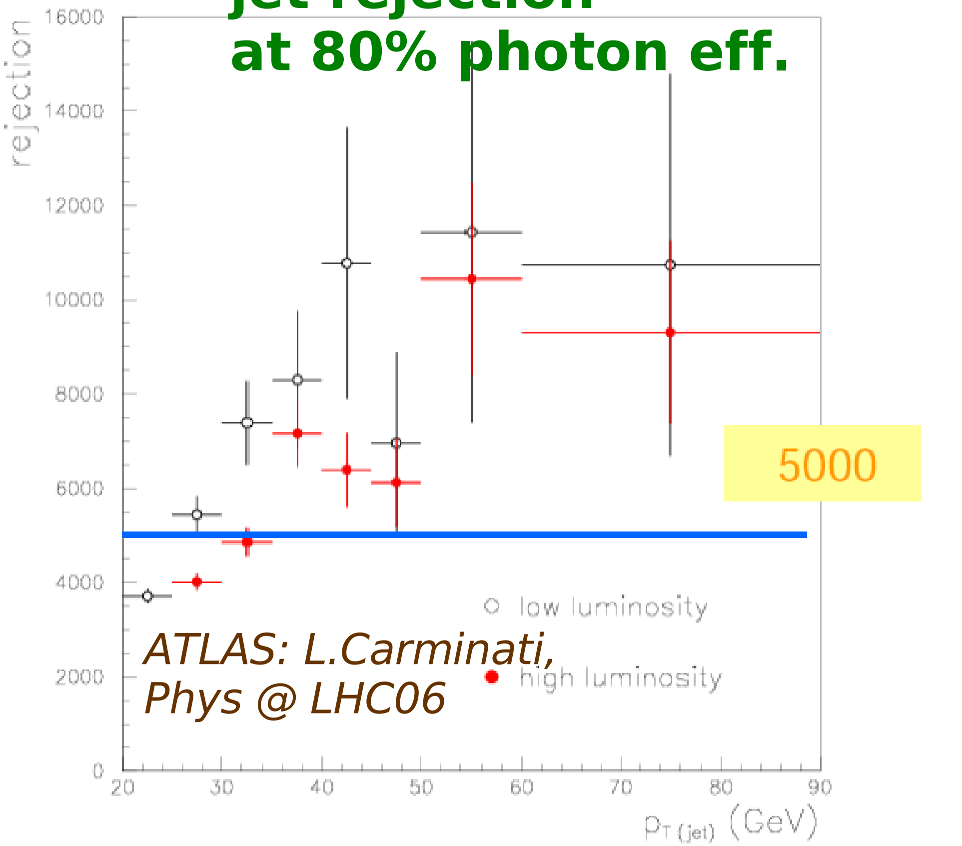


important tool to suppress bkg.:

photon ID and isolation:

misidentified jets are accompanied by particles measured in tracker, e.m. and had. calorimeters

jet rejection at 80% photon eff.



Analysis Concept

primary vertex:

- e.m. energy measurement precise, but not the direction
- longitudinal spread of interaction vertices ~53 mm
  => m_H smeared by 1.5 GeV if average vertex position is used
- real PV can be determined from tracks from e.g. underlying event and initial state gluon radiation

analysis strategies:

CMS: **1.** cut based analysis, events separated into quality categories based on shower shape and pseudo-rapidity

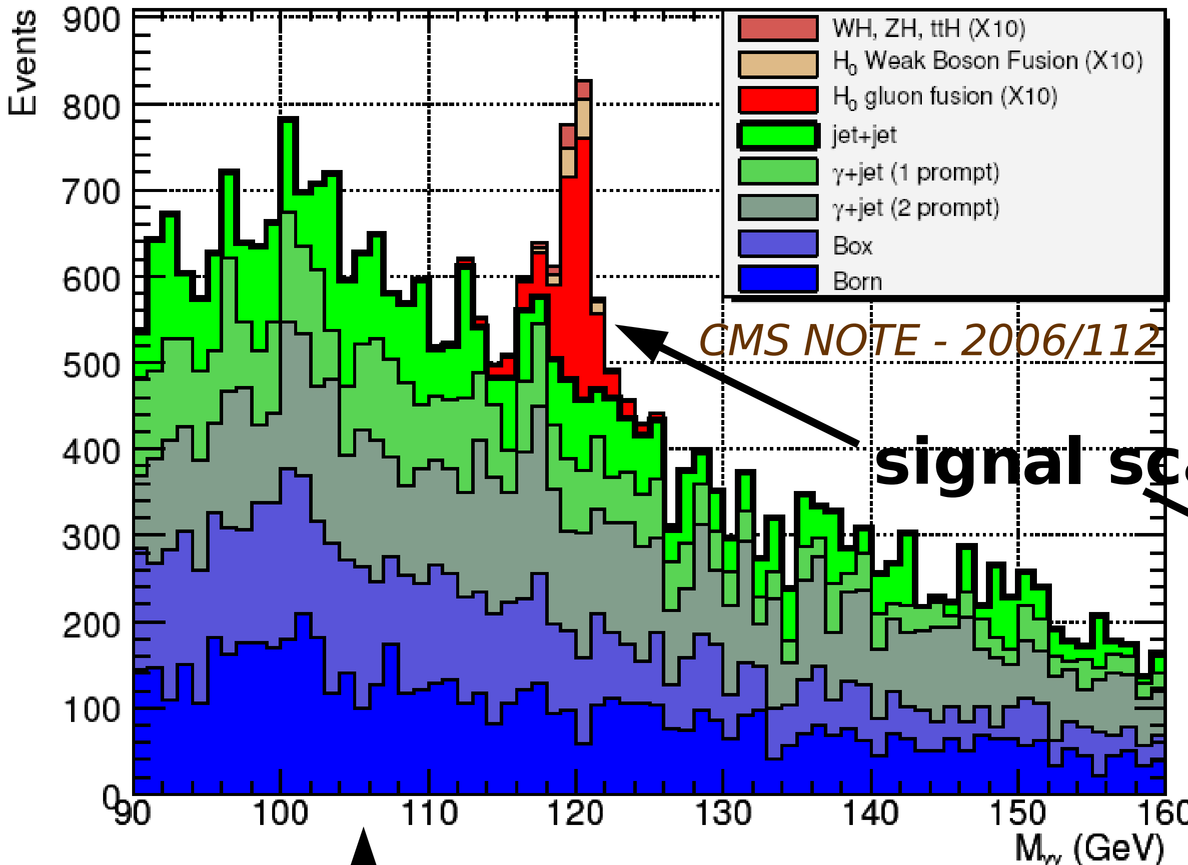
2. more optimized analysis using neural network:
- kinematic observables in addition to isolation
- kin. observables insensitive to mass !
- NN trained on sidebands of background
  (background can be determined from data this way)

ATLAS: 1. cut based analysis (but not the same observables as CMS)

2. likelihood exploiting shape of kinematical variables
   (30 - 40% improvement over cut based analysis)

$H \rightarrow \gamma\gamma$ CMS Results

invariant photon-photon mass distributions

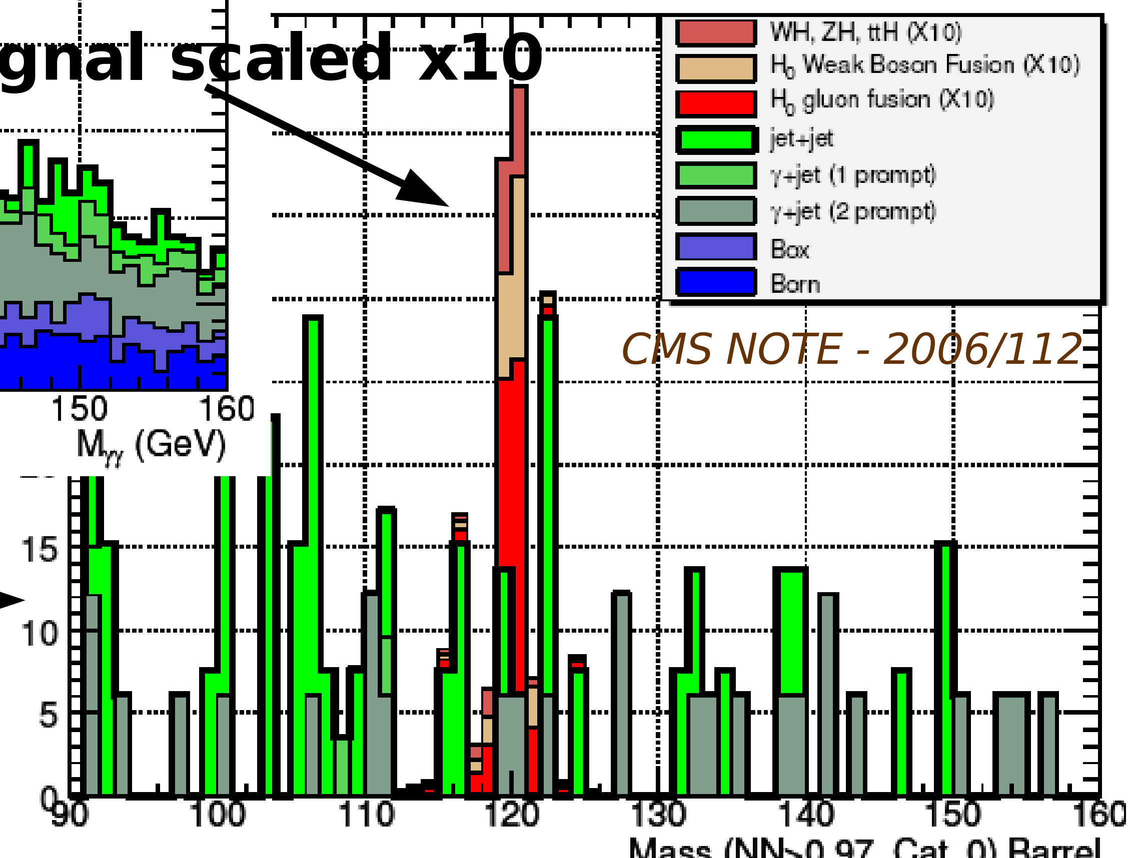


m_H = 120 GeV
int. lum. 7.7 fb^{-1}

signal scaled x10

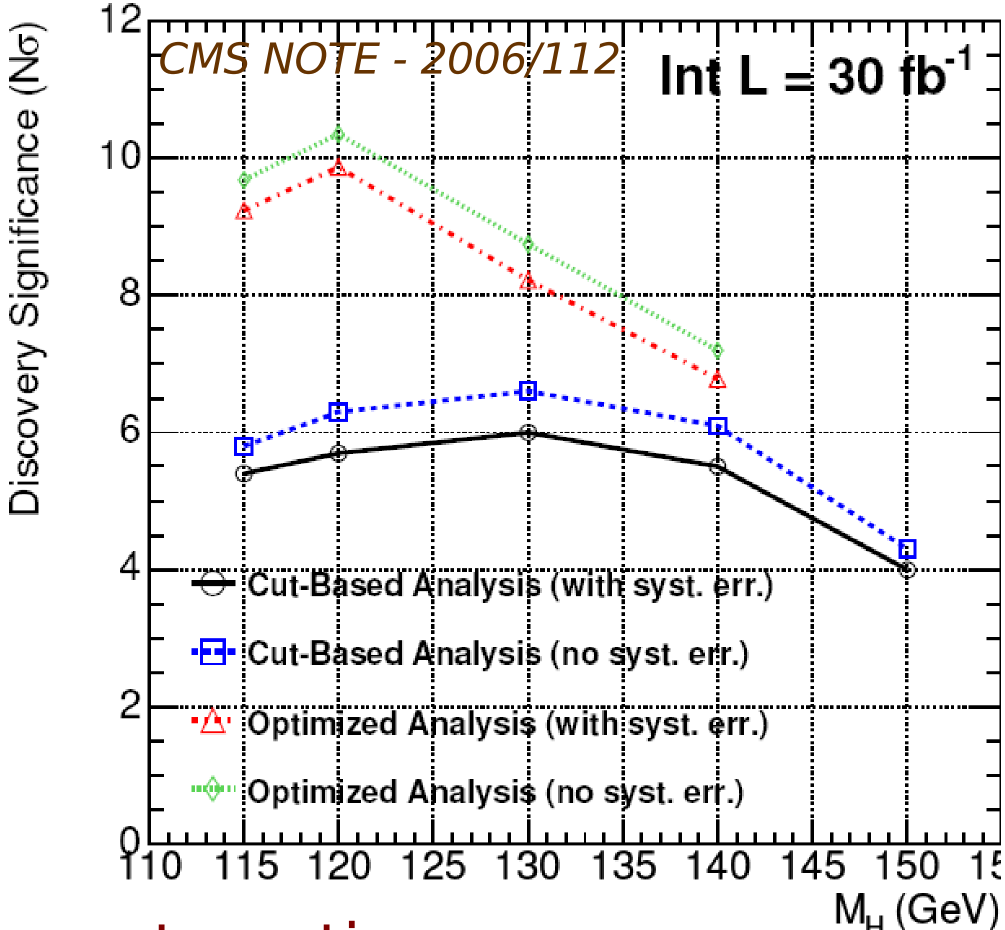
soft cut on NN

tight cut on NN →

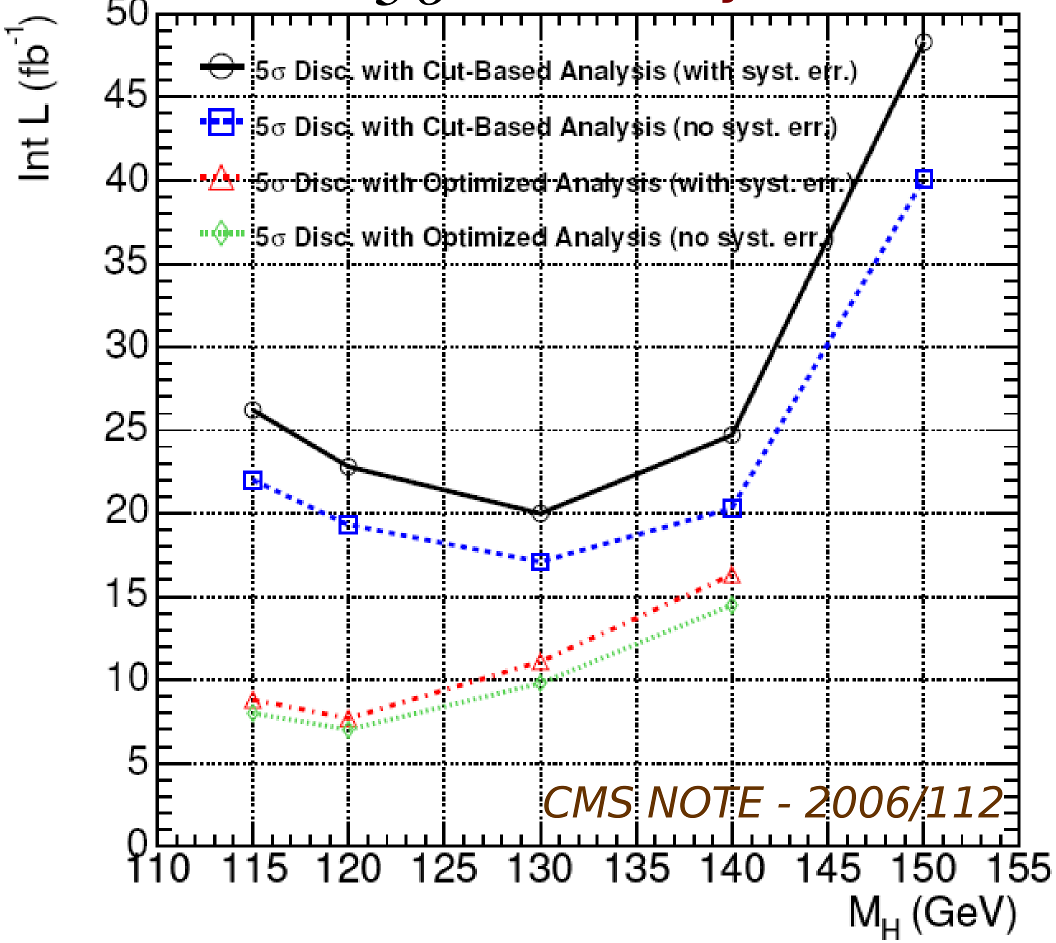


$H\to\gamma\gamma$ CMS Results

discovery sensitivity



required luminosity for 5σ discovery

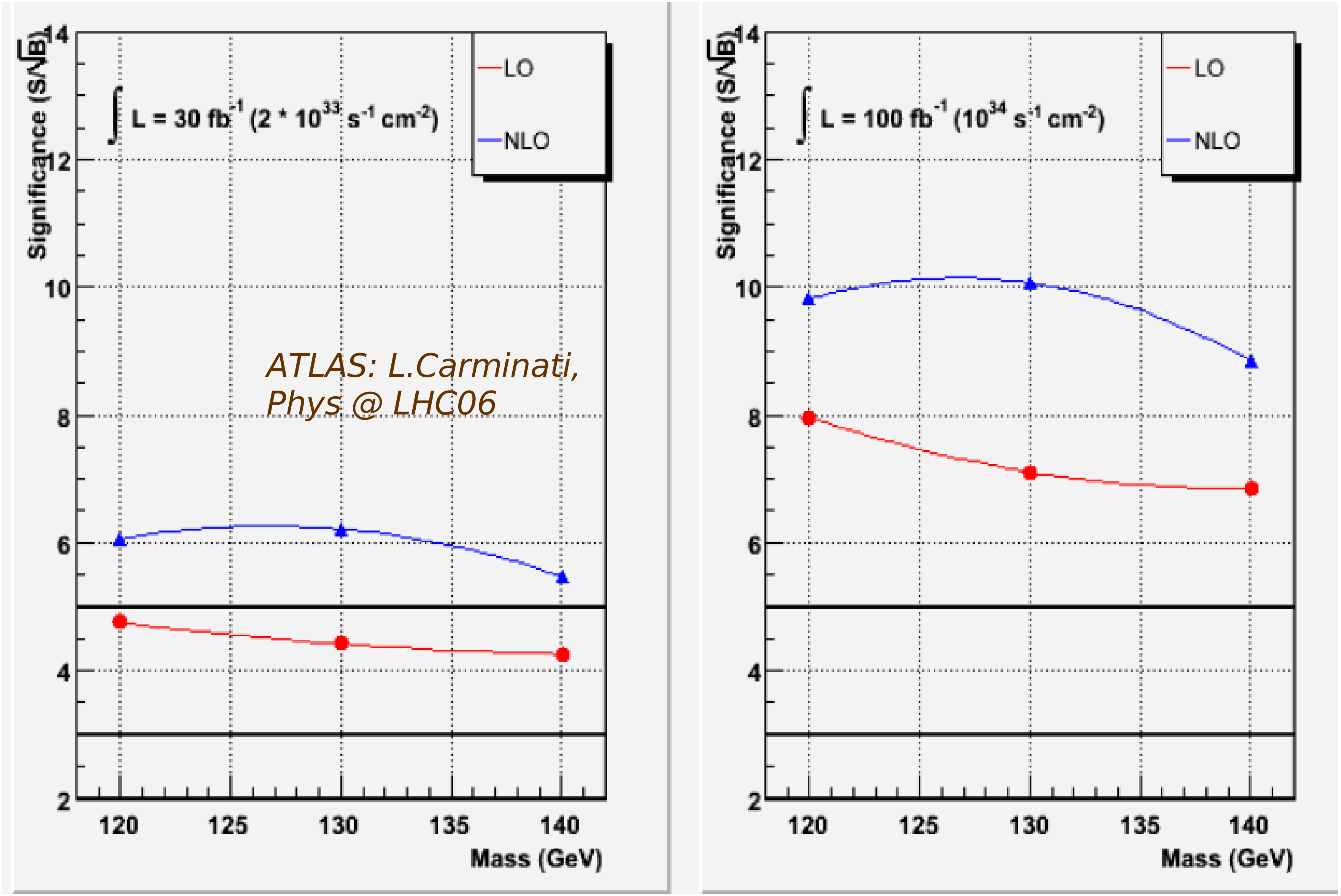


systematic errors:

background: small, measured from data => error on fit, statistics, different fitting functions **~1%**

signal: estimated **20%** (theory 15%, luminosity 5%, trigger 1%, tracker material 1%, ... => mostly affects exclusion limits

ATLAS Results



for cut based analysis CMS and ATLAS give similar results

30 - 40% improvement using likelihood gets close to CMS NN results

$$H \rightarrow WW \rightarrow l\, l\, \nu\, \nu$$

Introduction

this channel is expected to be the main discovery channel for Higgs bosons with intermediate masses $2m_W < m_H < 2m_Z$

- the H->WW branching ratio is almost 1 in this mass range
- no narrow mass peak can be reconstructed, because of the nu
  => background normalization more difficult (not from sidebands)

LO and NLO signal cross sections:

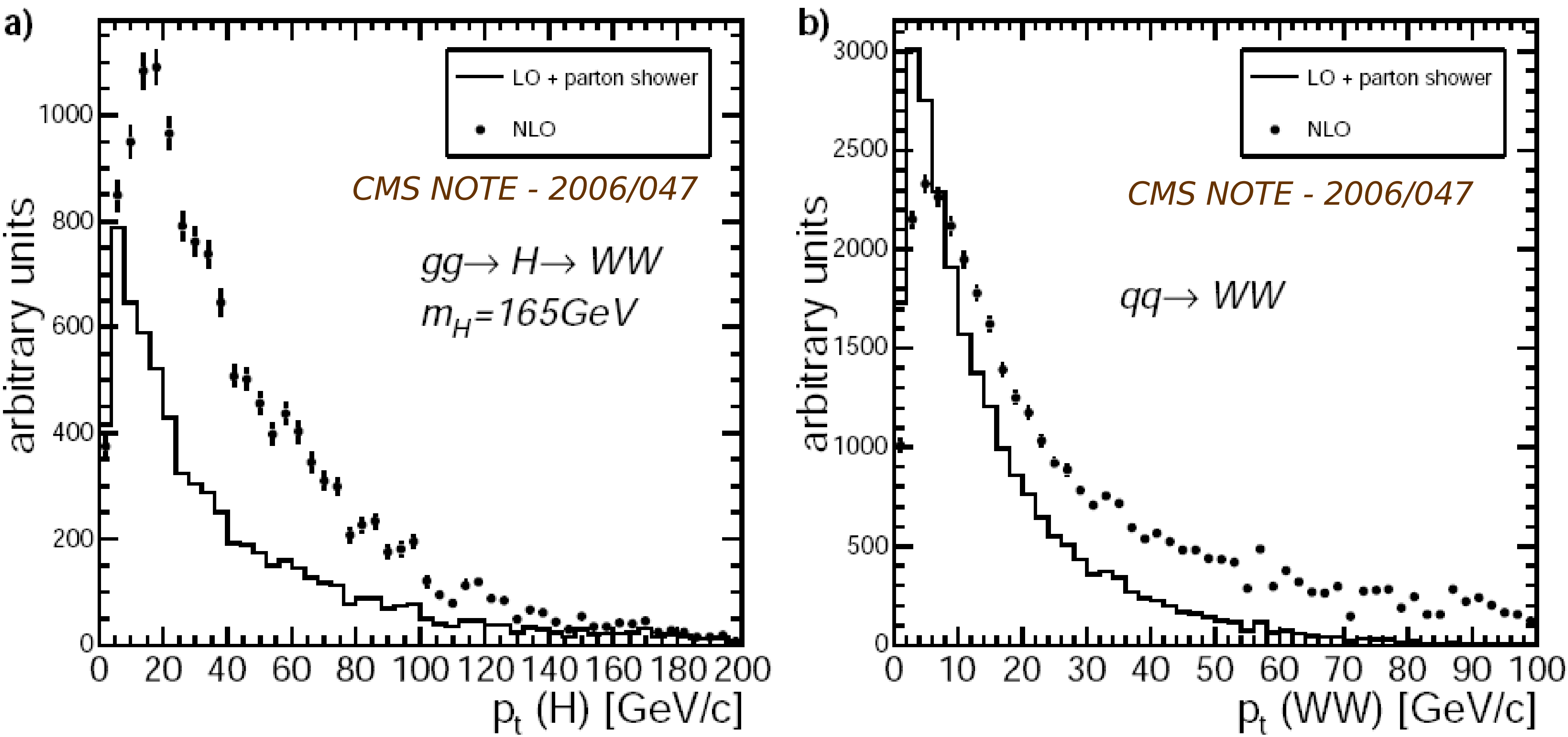
	$\sigma^{LO} \times BR(e,\mu,\tau)$ [pb] (PYTHIA)		$\sigma^{NLO} \times BR(e,\mu,\tau)$ [pb]		
	Gluon fusion	VBF	Gluon fusion	VBF	Total
120 GeV	0.26	0.07	0.50	0.06	0.56
130 GeV	0.50	0.13	0.94	0.12	1.06
140 GeV	0.71	0.20	1.39	0.19	1.58
150 GeV	0.89	0.25	1.73	0.25	1.98
160 GeV	1.00	0.31	2.03	0.31	2.34
165 GeV	1.00	0.31	2.04	0.32	2.36
170 GeV	0.97	0.30	1.95	0.31	2.26
180 GeV	0.84	0.27	1.71	0.28	1.99
190 GeV	0.66	0.21	1.29	0.22	1.51
200 GeV	0.56	0.19	1.11	0.19	1.30

CMS NOTE - 2006/047

K-Factors

p_t dependent K factors introduced for signal and backgrounds:

PYTHIA reweighted to MC@NLO *JHEP 0405 (2004) 009*



Backgrounds

background processes:

- continuum vector boson production (WW, ZZ, WZ)
- top production ($t\bar{t}$ and Wt)

backgrounds can be suppressed by constraints:

- kinematical: angle between leptons, missing Et
- jet veto

LO and NLO background cross sections:

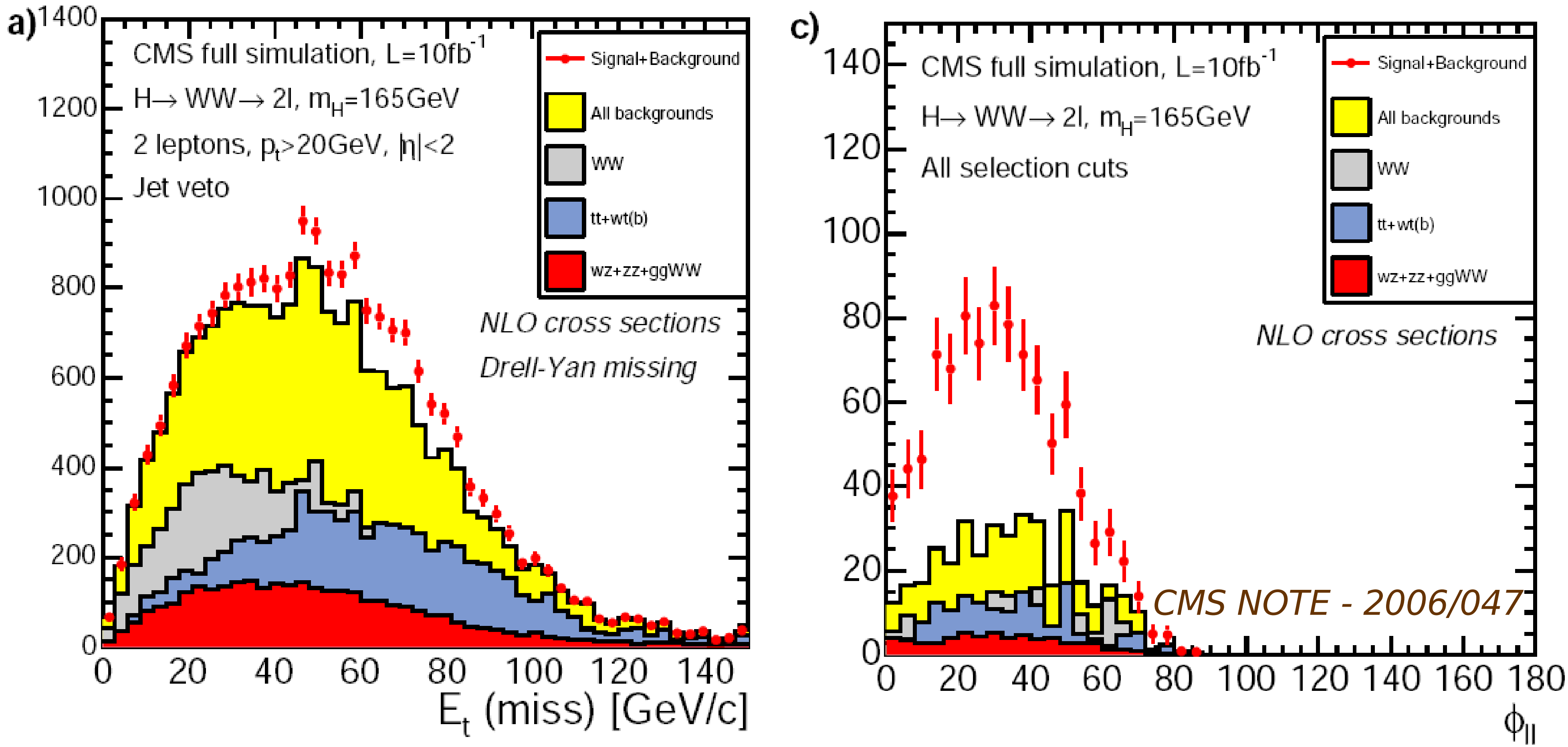
Process	$\sigma^{LO} \times BR(e, \mu, \tau)$ [pb]	$\sigma^{NLO} \times BR(e, \mu, \tau)$ [pb]
$qq \to WW \to \ell\nu\ell\nu$	7.4	11.7
$gg \to WW \to \ell\nu\ell\nu$	0.48	-
$qq \to t\bar{t} \to WbWb \to \ell\nu\ell\nu bb$	52.4	86.2
$qq \to tWb \to WbWb \to \ell\nu\ell\nu bb$	4.9	3.4
$qq \to ZW \to \ell\ell\ell\nu$	0.88	1.63
$qq \to ZZ \to \ell\ell\ell\ell, \ell\ell\nu\nu, \nu\nu\nu\nu$	1.06	1.52

CMS NOTE - 2006/047

Analysis

analysis strategy (CMS):

- two oppositely charged leptons and isolation requirements
- require leptons to come from the same vertex
- cut on impact parameter to reduce leptons from B hadron decays
- missing transverse energy above an optimized threshold
- veto on central jets
- azimuthal angle between leptons < 45°



Systematics

this is a counting experiment:

=> systematic uncertainties on background normalization are important

methods to normalize backgrounds from data (5 fb^{-1}):

ttbar: replace jet veto by double b-tag, keeping all other cuts identical => expected uncertainty ~ 16%

WW: define normalization region in $\delta\phi_l$ and m_{ll} , keeping all other cuts identical => expected uncertainty ~17%

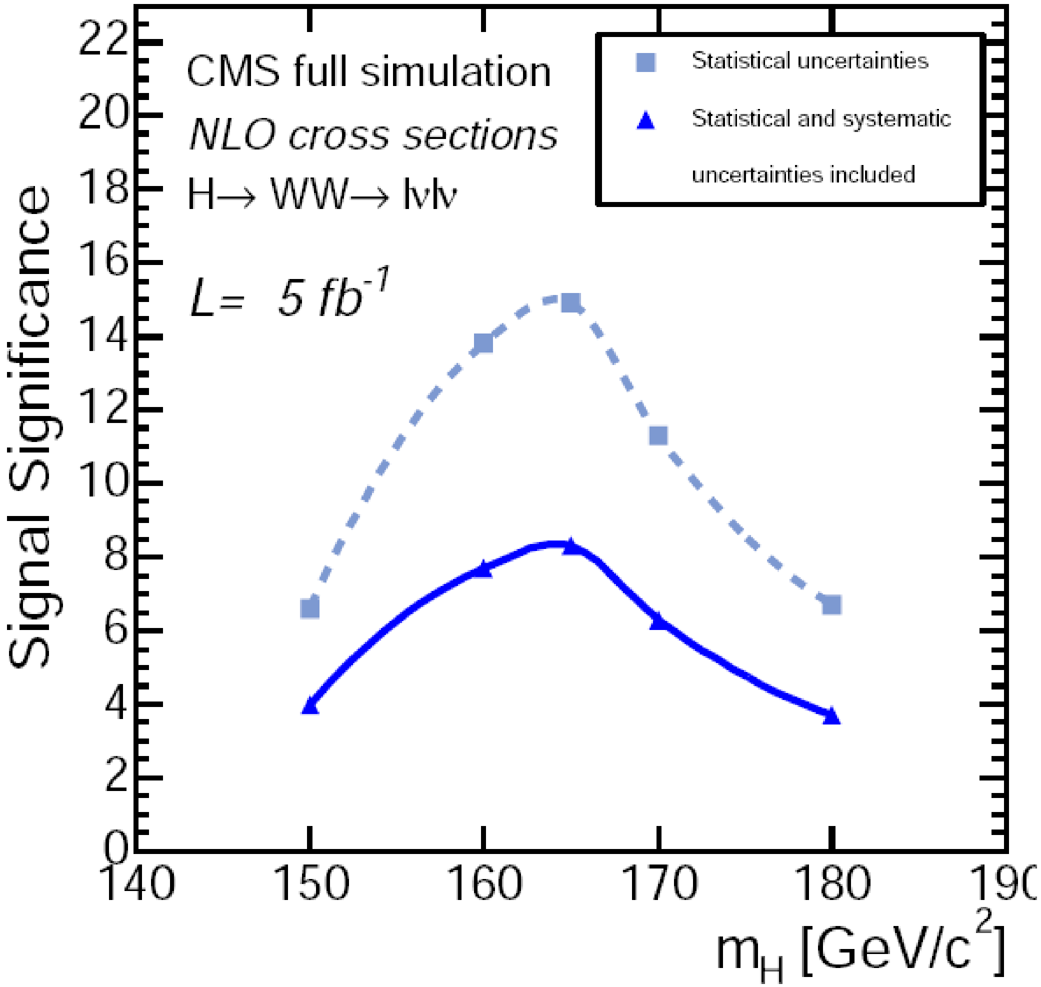
WZ: keept cuts identical, require third lepton => ~ 20%

ggWW and single top: difficult to define normalization regions => need to rely on theory predictions => ~30%

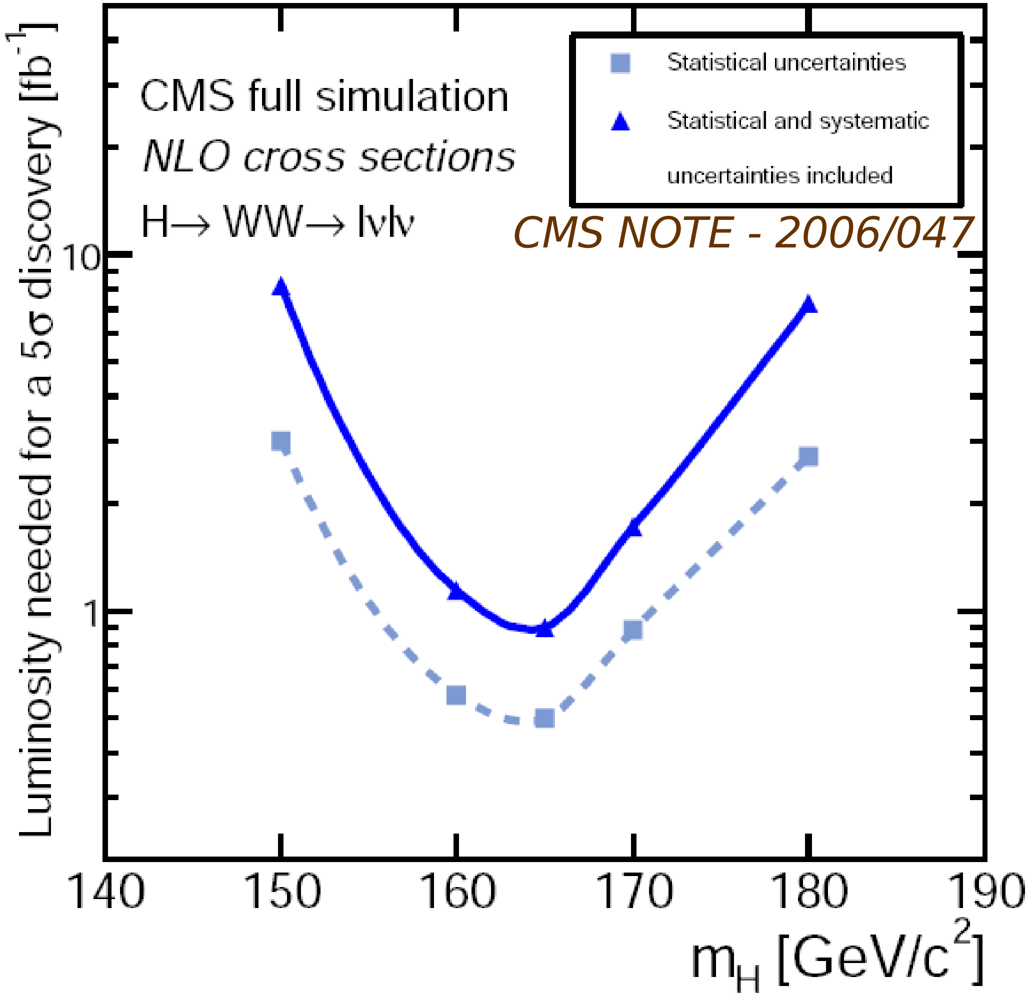
analysis being revisited in CMS in 2007:

- multivariate analysis, improve sensitivity towards lower m_H
- control systematics on missing Et and jet veto

discovery sensitivity



required luminosity for 5σ discovery



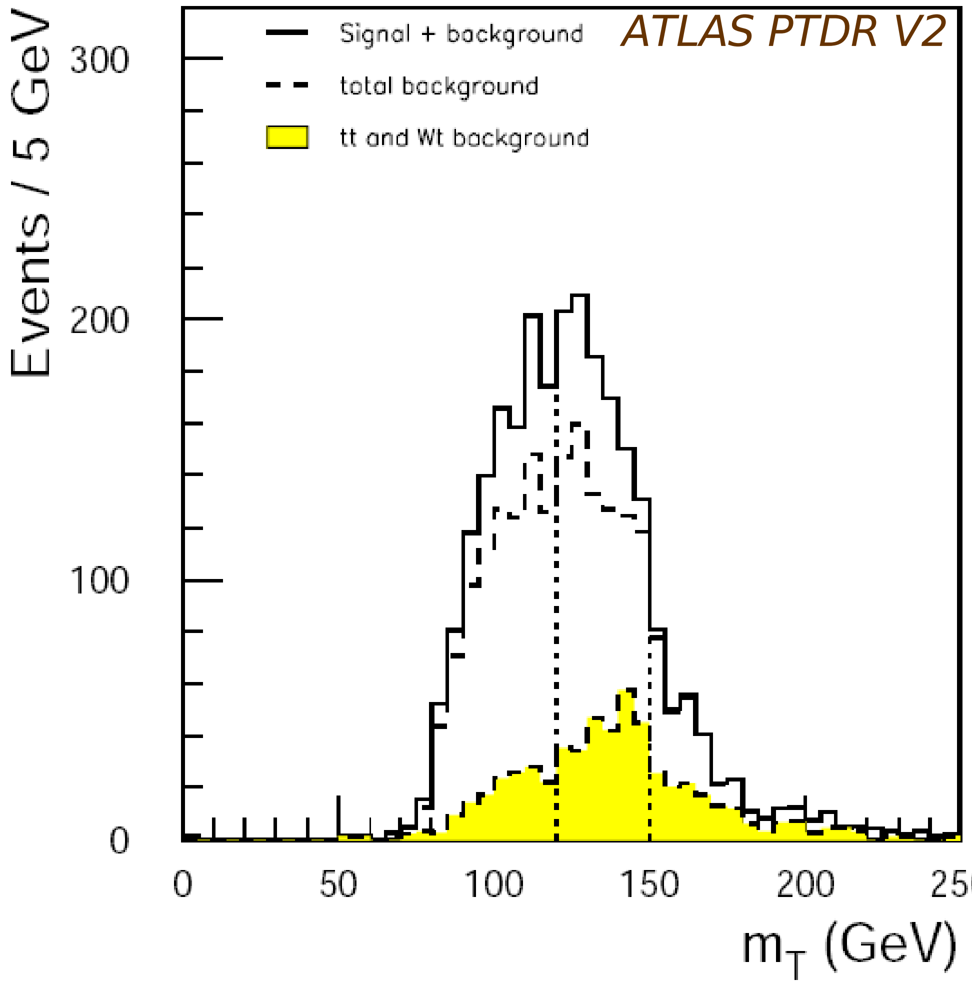
first attempt for improvements at lower m_H: *CMS NOTE-2006/114*

discovery even with $1fb^{-1}$!

analysis strategy (ATLAS):

- very similar to CMS analysis
- using transverse mass in addition:

$$m_T = \sqrt{2\,p_T^{\,ll} E_T^{\,miss}(1-\cos(\Delta\phi))}$$



results for 30 fb^{-1}

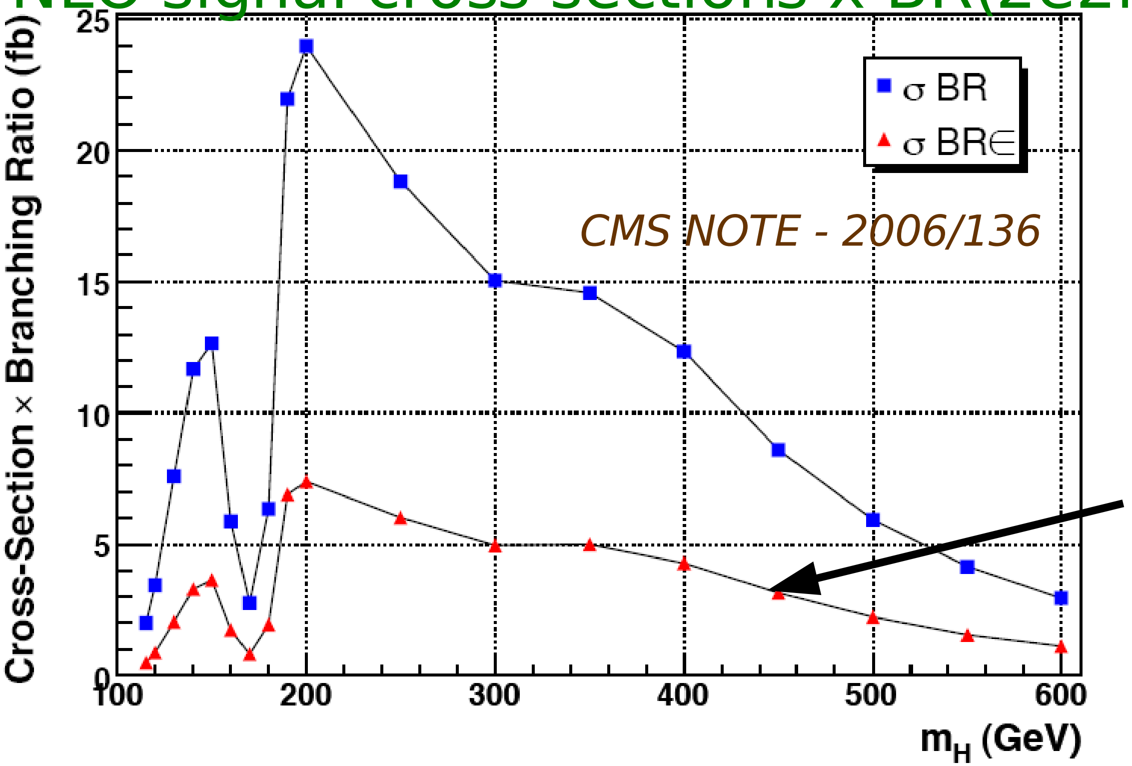
Higgs mass (GeV)	150	160	170	180	190
Significance (including 5% systematic uncertainty)	4.7	9.6	10.3	7.8	5.4

$$H \to ZZ \to 4\,l$$

Introduction

- the $H \to ZZ \to 4l$ channel has a very clean signature and moderate backgrounds
- the $e^+e^-mu^+mu^-$ final state has twice the BR of the 4e and 4mu channels
- most promising in mass range 130GeV< m_H < 500 GeV (except for $2m_W < m_H < 2m_Z$)

NLO signal cross sections x BR(2e2mu):



- gluon fusion and vector boson fusion considered

generator preselection: (CMS)

$p_t(e)$ > 5GeV , eta<2.7

$p_t(mu)$ > 3GeV, eta<2.4

Backgrounds

the analyses of the 2e2mu, 4mu and 4e final states have many things in common, e.g. backgounds and kinematic selection

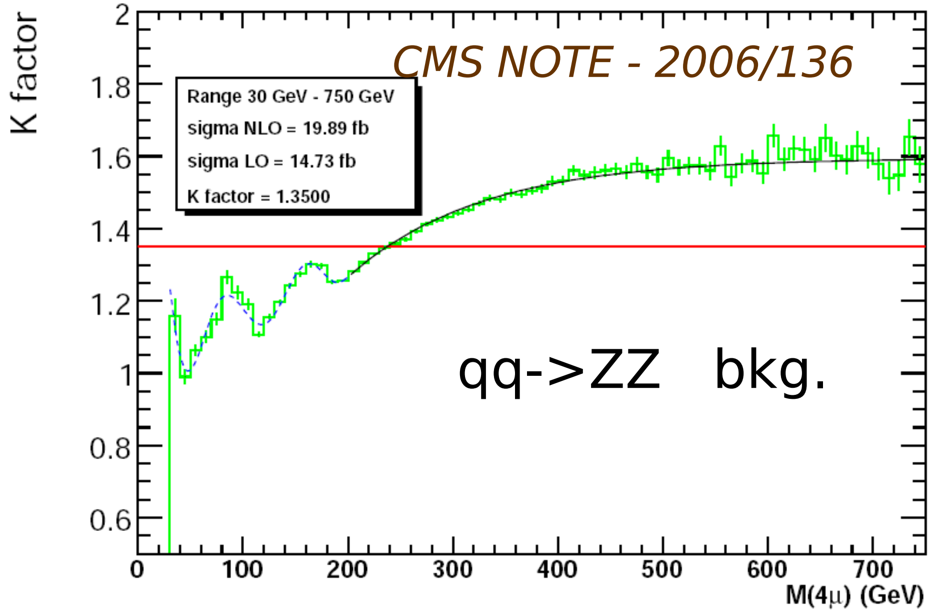
(in the following, some details about the 2e2mu analyses and main results for 4e and 4mu)

backgrounds:

ttbar: leptonic W decays, leptons in b-jets

Zbb: leptons in b-jets

ZZ: using m_{4l} dependent K factor:

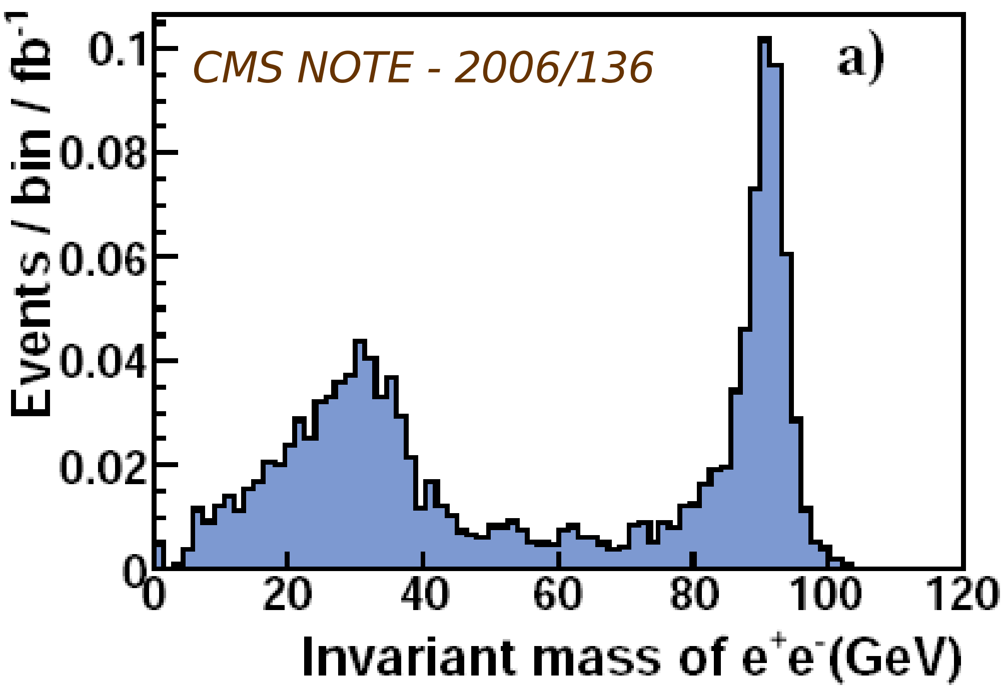


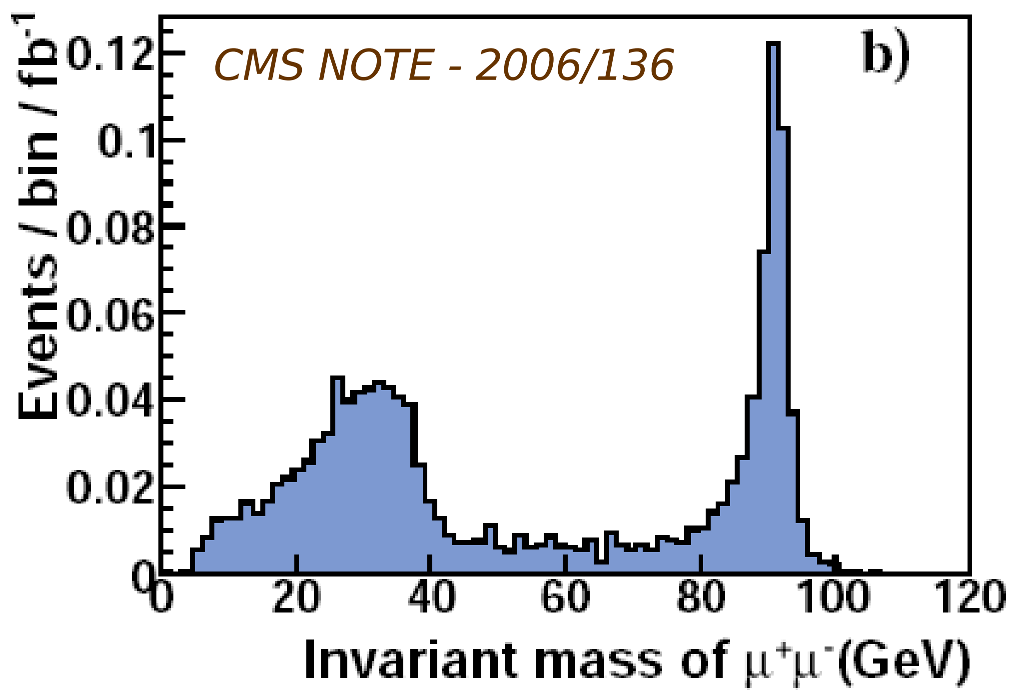
Process	$\sigma_{\rm LO}$ (pb)	K-factor	$\sigma_{\rm NLO}$ (pb)	$\sigma_{\rm NLO}$.BR.ϵ (fb)
$t\bar{t} \to W^+W^-b\bar{b} \to e^+e^-\mu^+\mu^-X$	-	-	840	743
$e^+e^-b\bar{b} \to e^+e^-\mu^+\mu^-X$	115	2.4	276	262
$\mu^+\mu^-b\bar{b} \to e^+e^-\mu^+\mu^-X$	116	2.4	279	128
$ZZ^\star/\gamma^\star \to e^+e^-\mu^+\mu^-$	18.7	$K_{NLO}(m_{4\ell}) + 0.2$	28.9	37.0

CMS NOTE - 2006/047

reconstructed Z bosons:

for m_H=130GeV, one **on-shell**, one **off-shell** boson





mass resolutions:

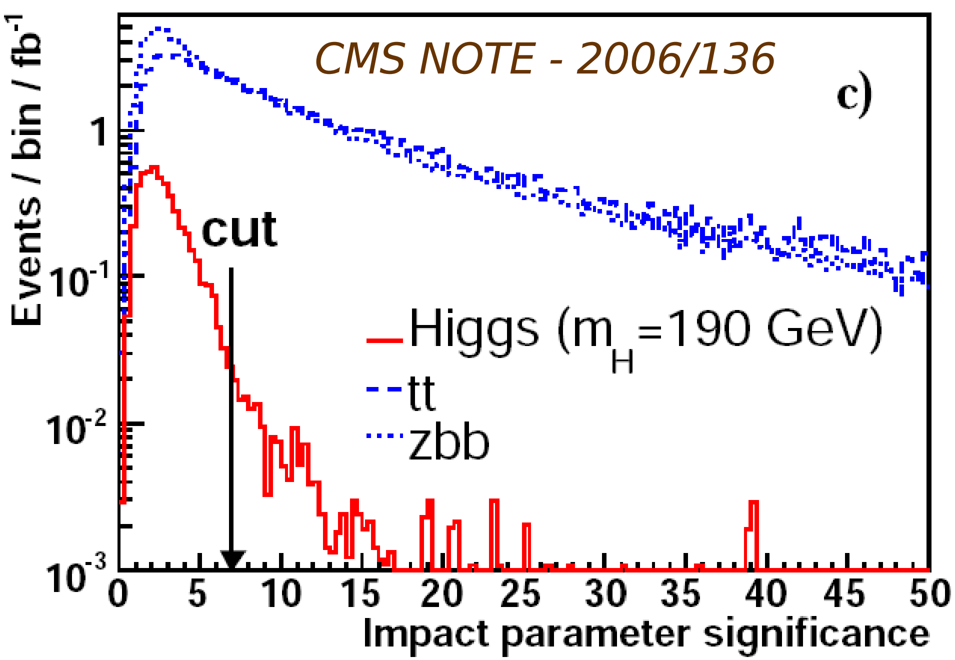
$\sigma(m/m_{true}) = 1.81\%$

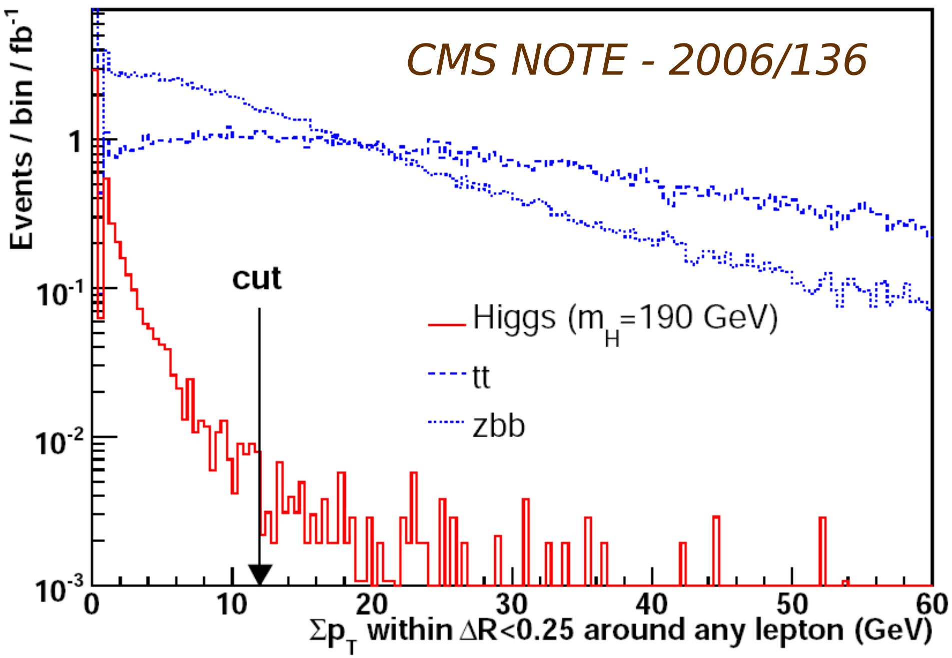
$\sigma(m/m_{true}) = 1.14\%$

analysis strategy (CMS and ATLAS):

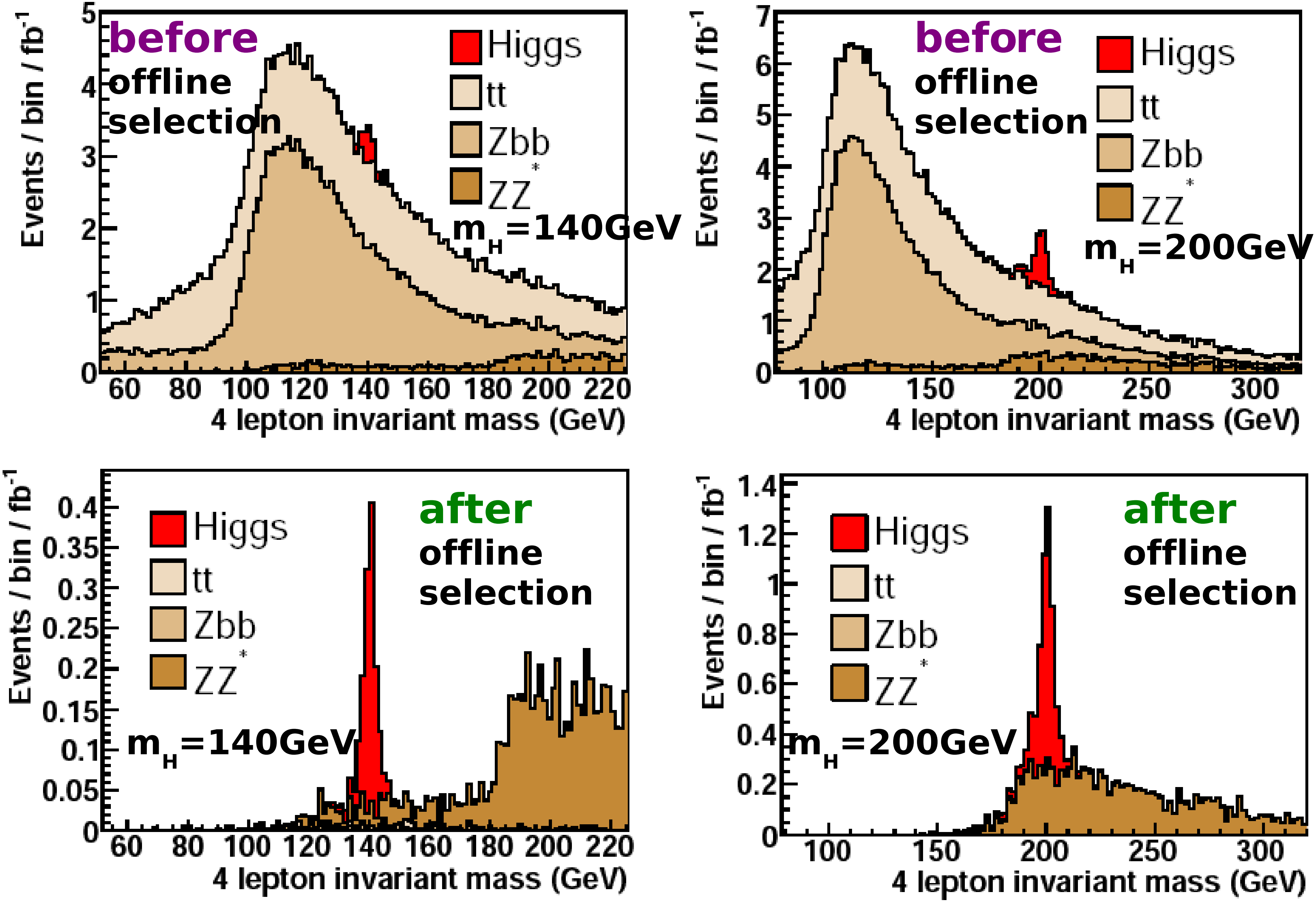
- cuts on vertex distances and IP significances (reduces b-jets)
- lepton isolation
- lepton pt and lepton pair mass cuts (Z mass windows)

- cut thresholds optimized for each Higgs boson mass hypothesis
- alternative: mass-independent cuts





$H \rightarrow ZZ \rightarrow 2e2\mu$ CMS Results



Systematics

systematic errors taken into account:

measurement of background rates from data using sidebands: 5 - 10 % for $m_H < 200$GeV, 30% for $m_H = 400$GeV

theory: shape uncertainty of ZZ/gamma: 0.5 - 4.5 %

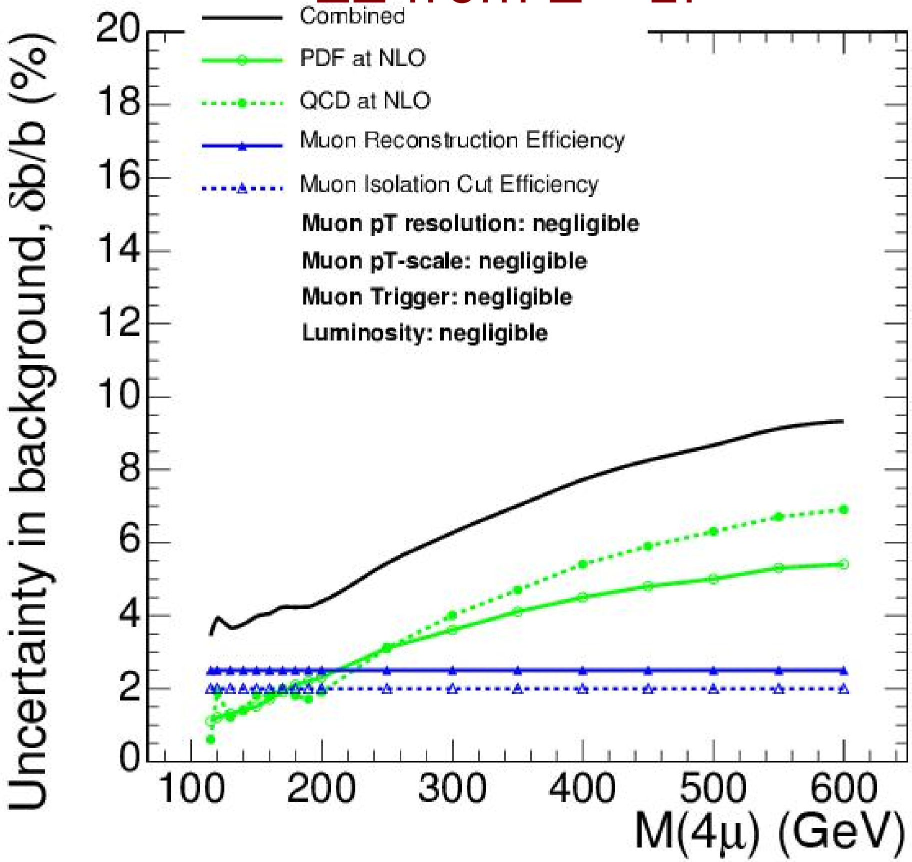
sideband method suffers from statistical problems

important alternative:

measure inclusive Z->2l production, scale down by theoretical factor of $\sigma_{ZZ}(m_{4\mu})/\sigma_Z$

- reduces PDF and QCD scale uncertainties
- reduces luminosity uncertainty

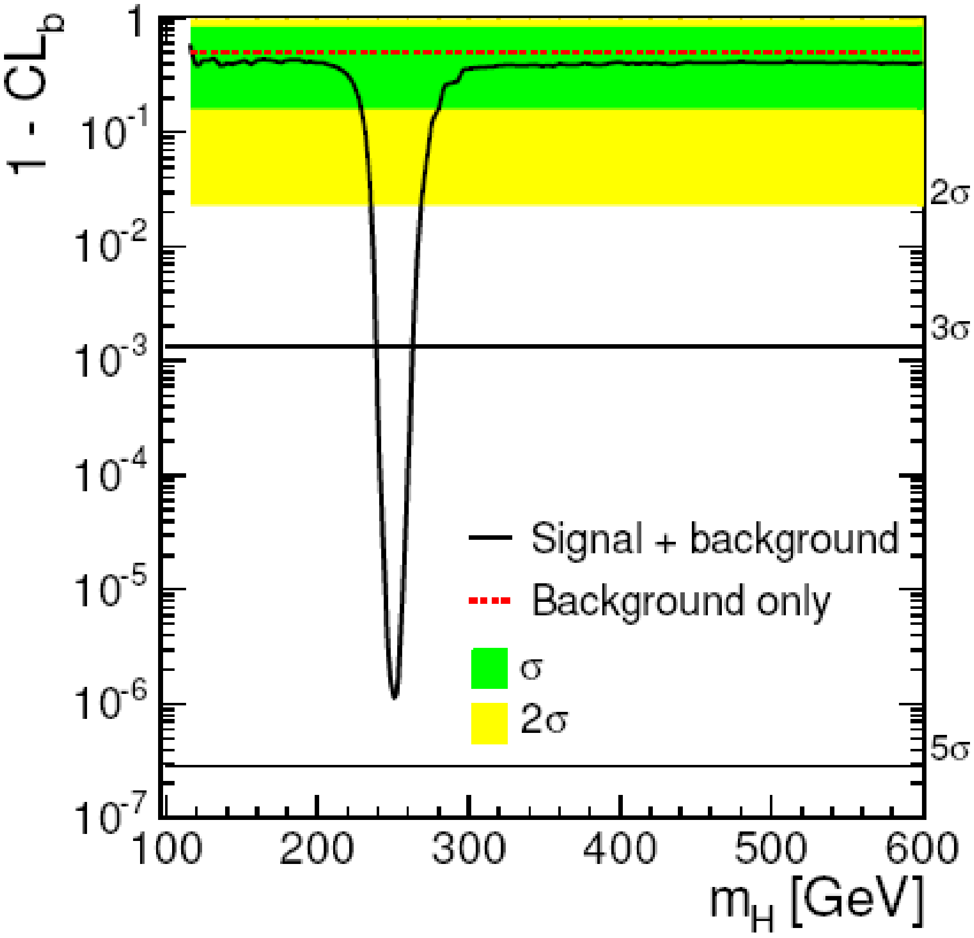
syst. error evaluating ZZ from Z->2l



Statistical Methods

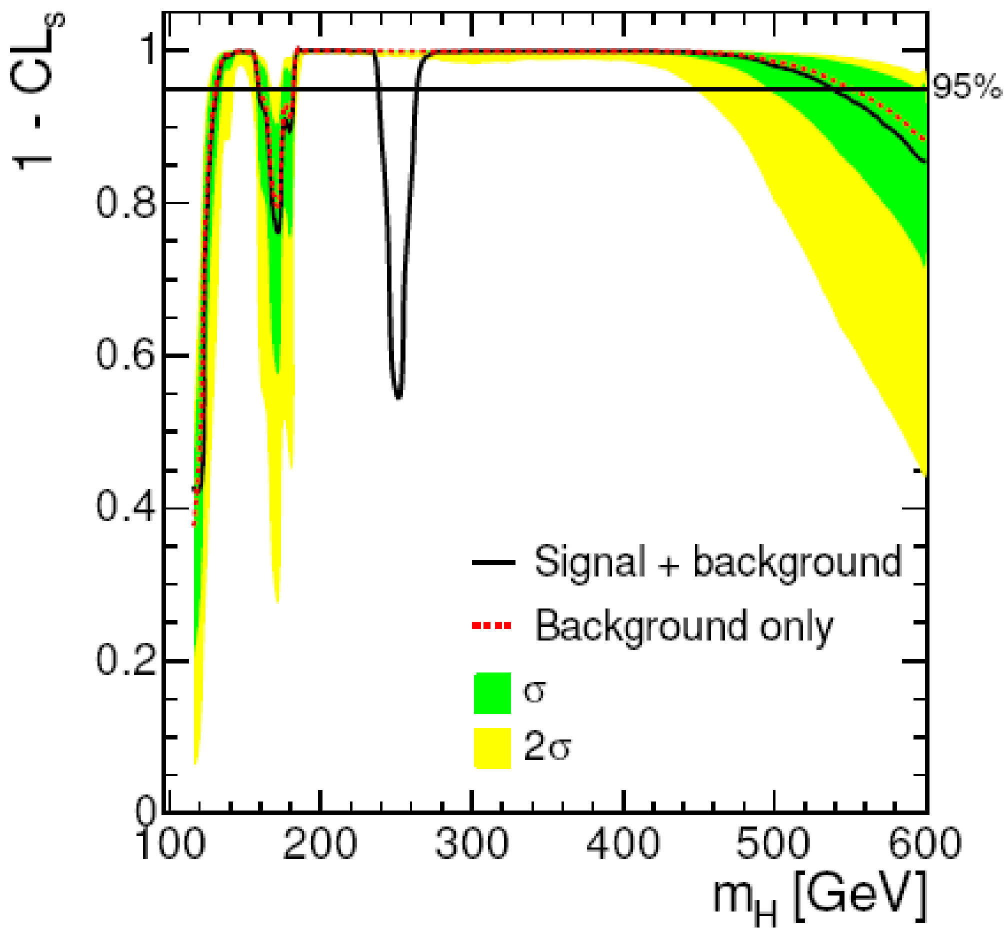
confidence limits ($10 fb^{-1}$):

for discovery:



(prob. to observe signal like behaviour in background)

for exclusion:

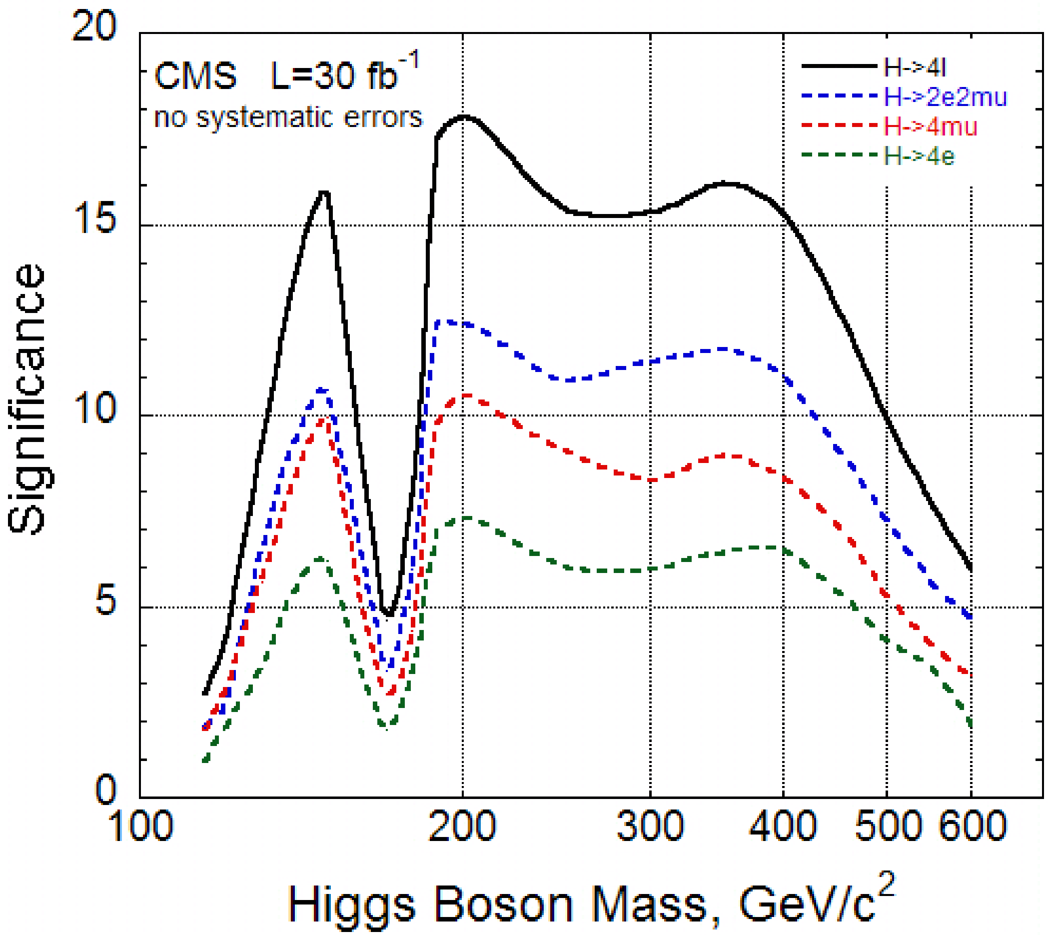


(prob. to exclude the signal hypothesis)

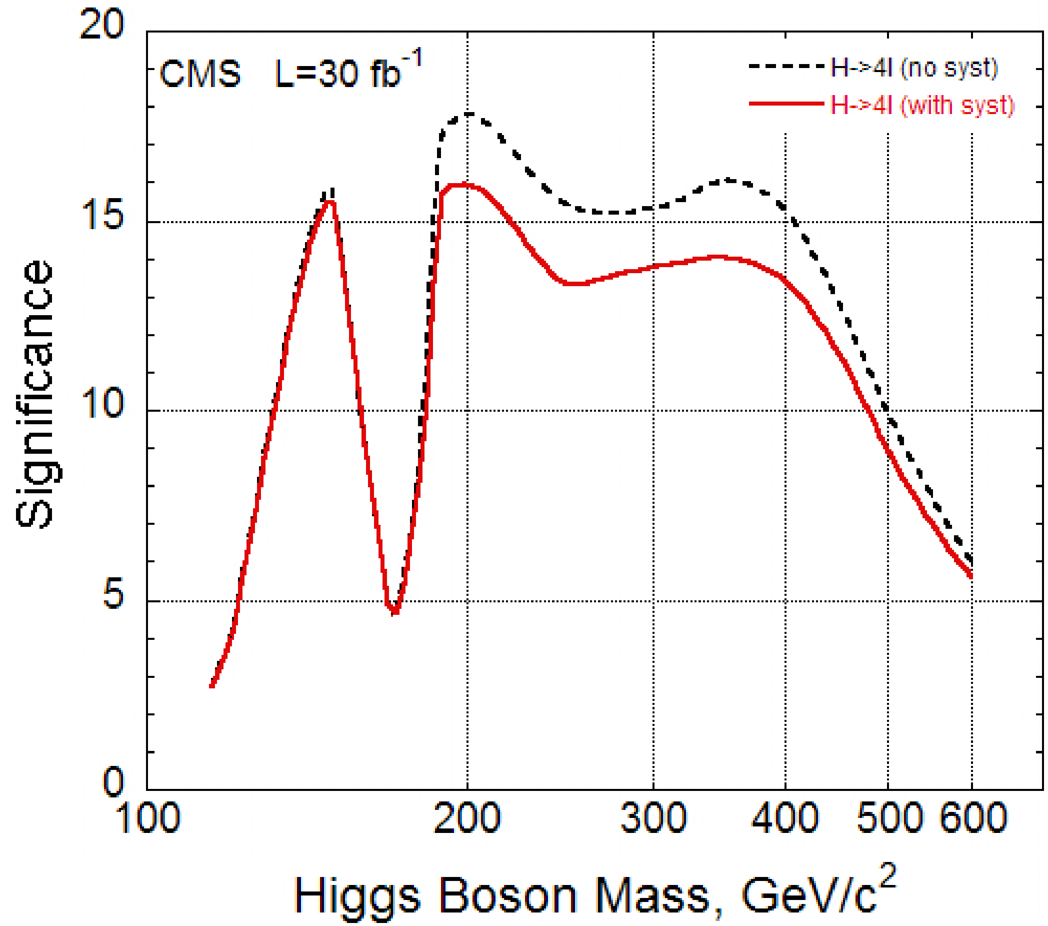
CMS Results

results for H-> 4l combined

discovery potential:



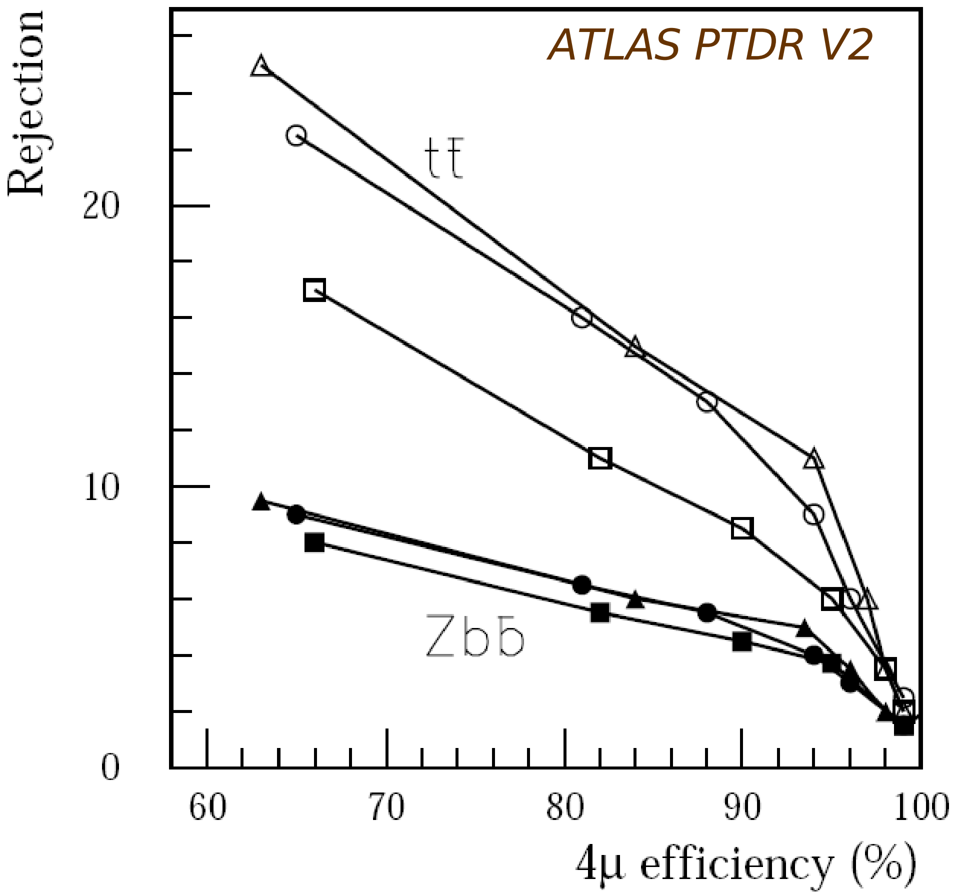
impact of systematic errors:



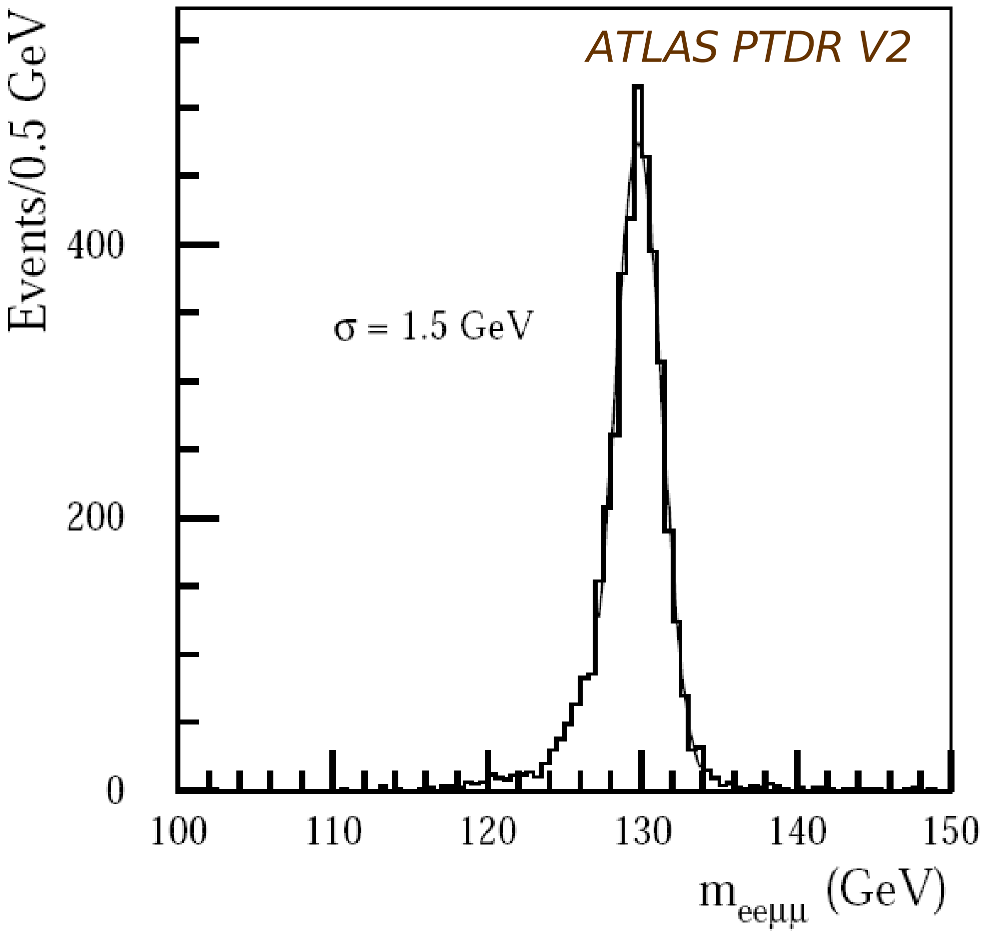
=> at 5 sigma level, systematic errors have small impact

ATLAS Results

background rejection using impact parameter and vertex cuts

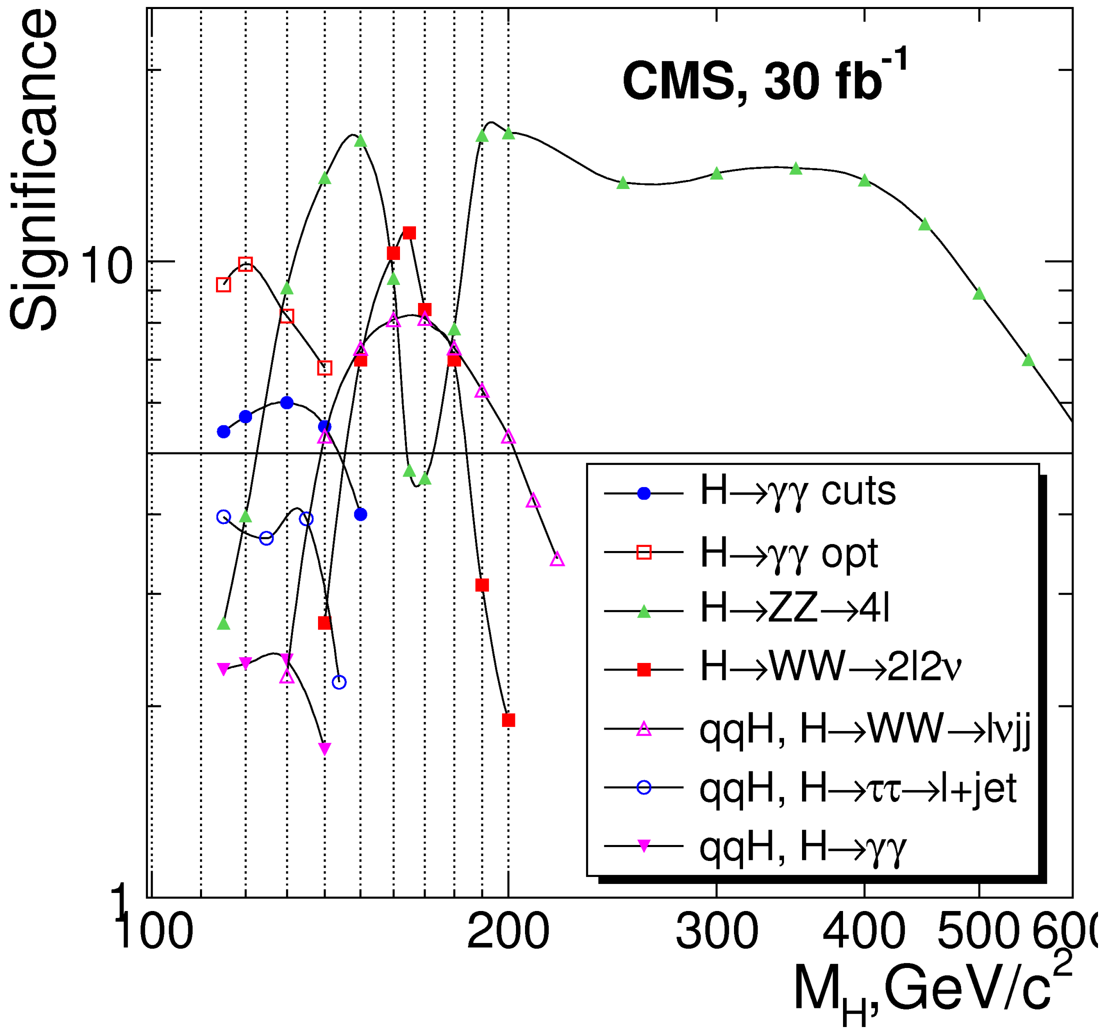


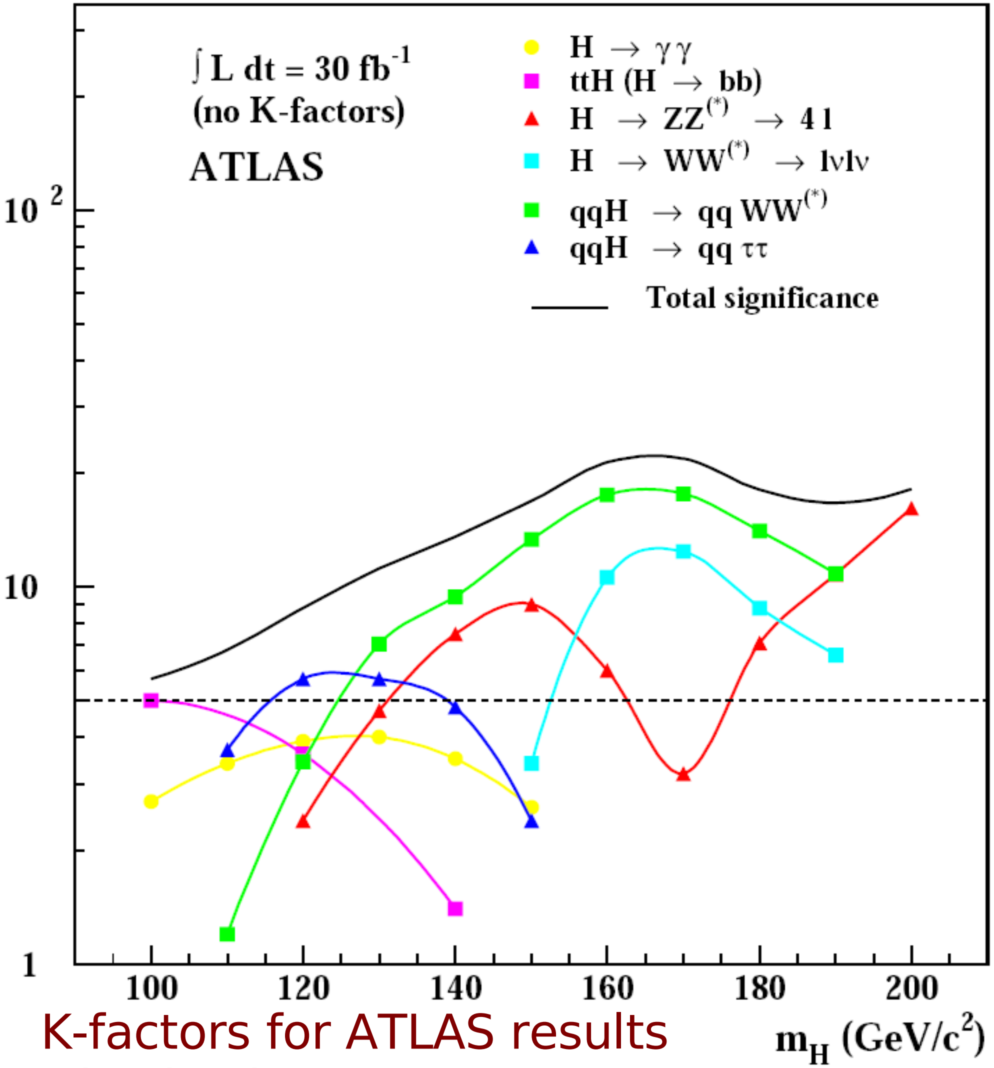
four-lepton mass resolution is 1.5GeV



Higgs mass (GeV)	120	130	150	170	180
Significance ($S/\sqrt{B}$)	3.4	7.0	15.5	4.3	11.2

Summary of the Disovery Potential





K-factors for ATLAS results will give better agreement

SM Higgs will NOT escape the LHC !!!