Prospects for Higgs Searches at the LHC

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On behalf of the ATLAS and the CMS collaboration

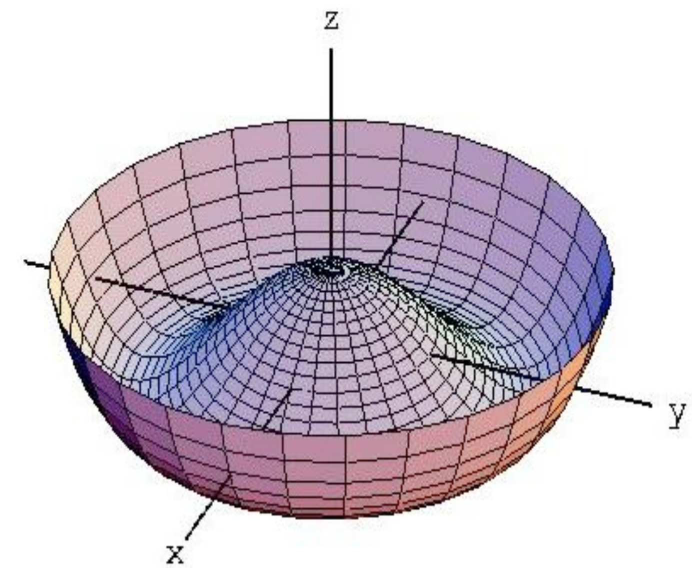
Aspen Winter Conference 2009/02/10

J.Weng

Introduction

The LHC should answer fundamental questions in the next years:

Does the Higgs Boson exist ?



yes

- Is there only one ?
- Is it a Standard Model Higgs ?
- What are its mass, width, quantum numbers ?
- Does it generate electroweak symmetry breaking *and* give mass to fermions as in the SM or is something else needed ?
- What are its couplings to itself and other particles ?
- ...

no

Be prepared for (probably) more spectacular phenomena ...

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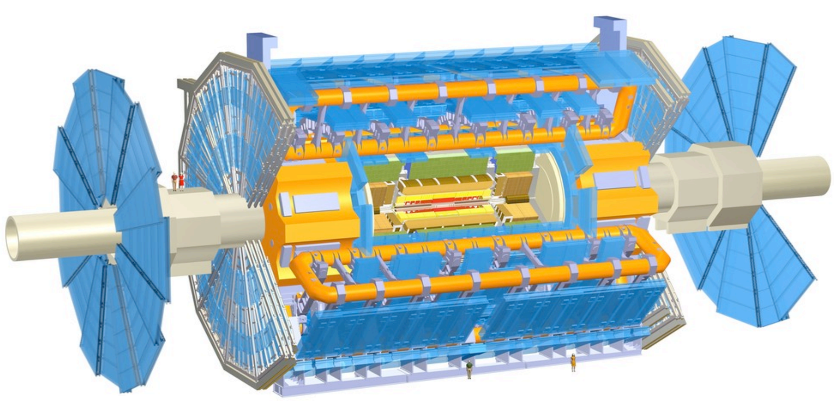
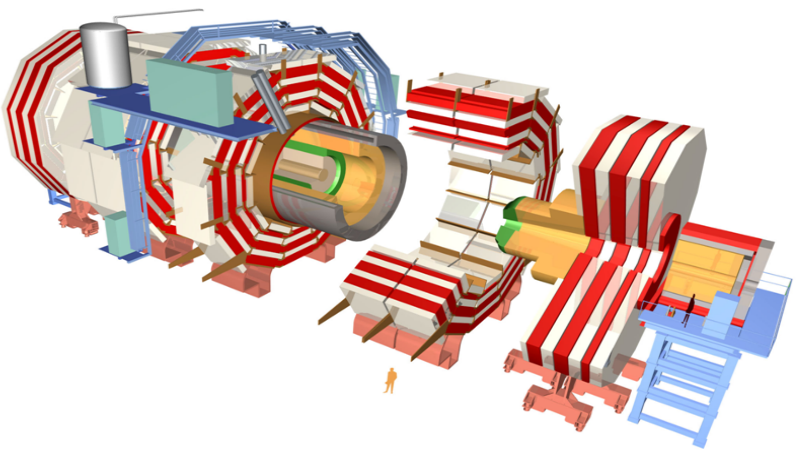
ATLAS & CMS

	ATLAS	CMS
Magnetic field	2 T solenoid + toroid (0.5 T barrel 1 T endcap)	4 T solenoid + return yoke
Tracker	Si pixels, strips + TRT $\sigma/p_T \approx 5\text{x}10^{-4} p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5\text{x}10^{-4} p_T + 0.005$
EM calorimeter	Pb+LAr $\sigma/E \approx 10\%/\sqrt{E} + 0.007$	PbWO4 crystals $\sigma/E \approx 2\text{-}5\%/\sqrt{E} + 0.005$
Hadronic calorimeter	Fe+scint. / Cu+LAr (10λ) $\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV	Cu+scintillator (5.8λ + catcher) $\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV
Muon	$\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV (ID+MS)	$\sigma/p_T \approx 1\%$ @ 50GeV to 5% @ 1TeV (ID+MS)
Trigger	L1 + RoI-based HLT (L2+EF)	L1+HLT (L2 + L3)





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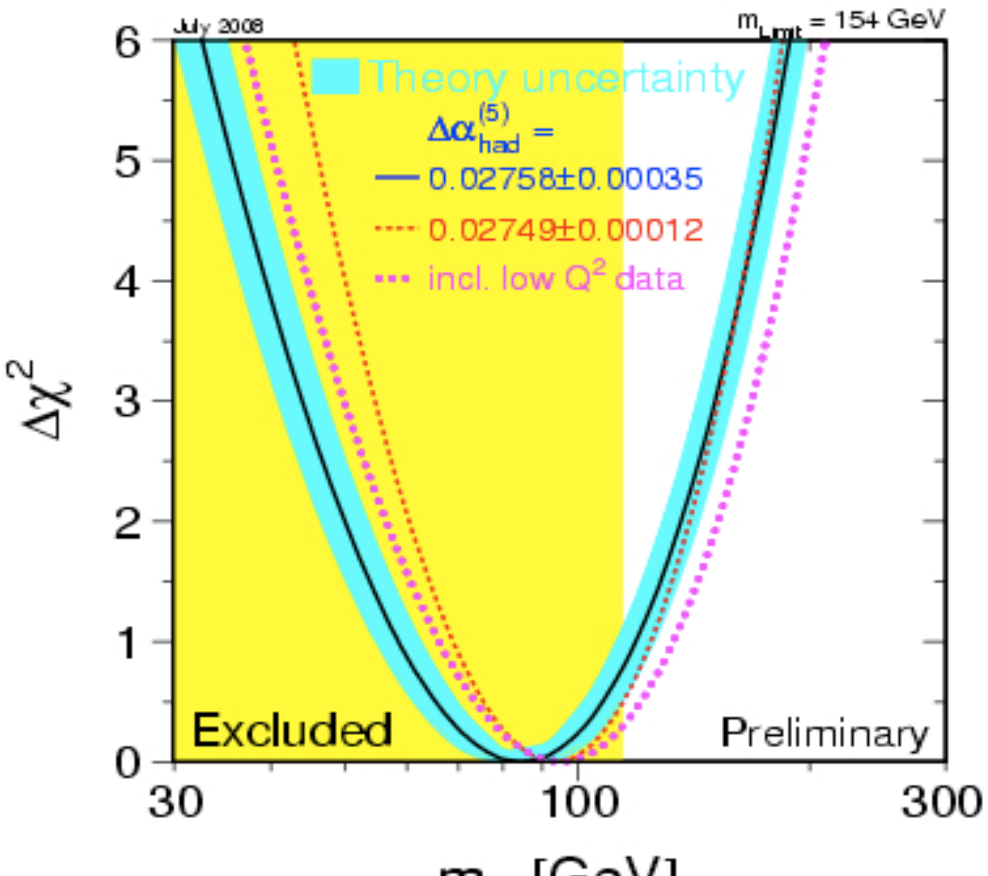
Higgs current Limits

http://lepewwg.web.cern.ch/LEPEWWG/



Simplest model of EW symmetry breaking predicts the existence of a Higgs scalar –
Higgs boson mass is only free parameter in theory

Limits:

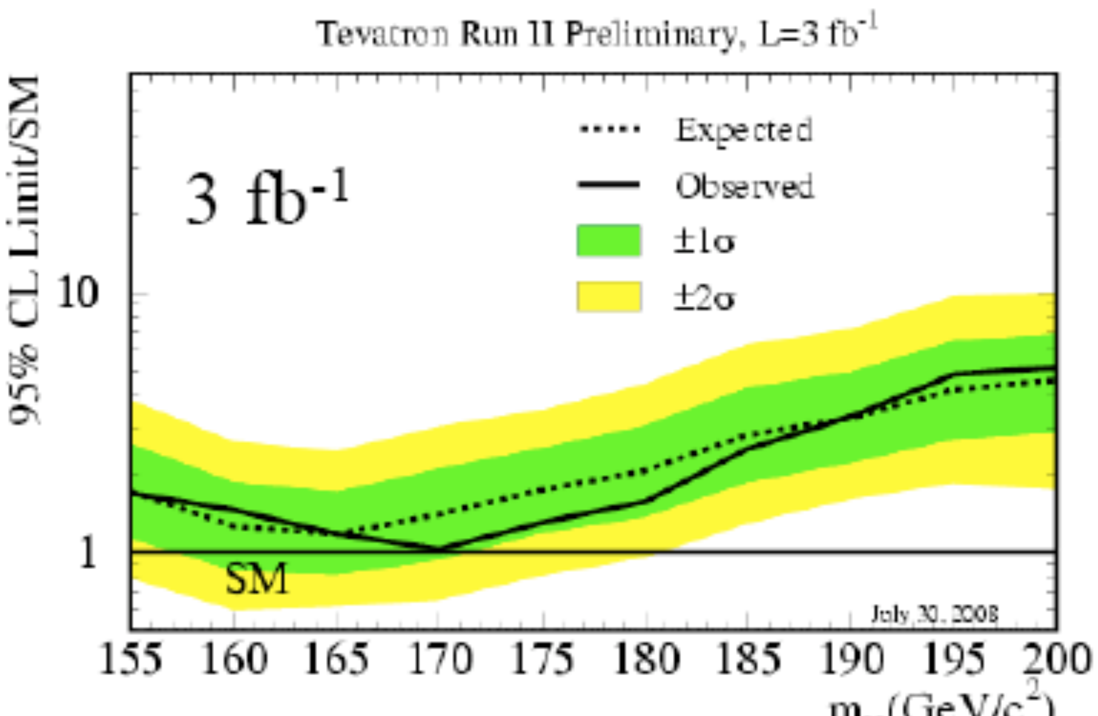
Masses of Higgs, top and W connected through loop diagrams

=> precision electroweak fits sensitive to Higgs mass

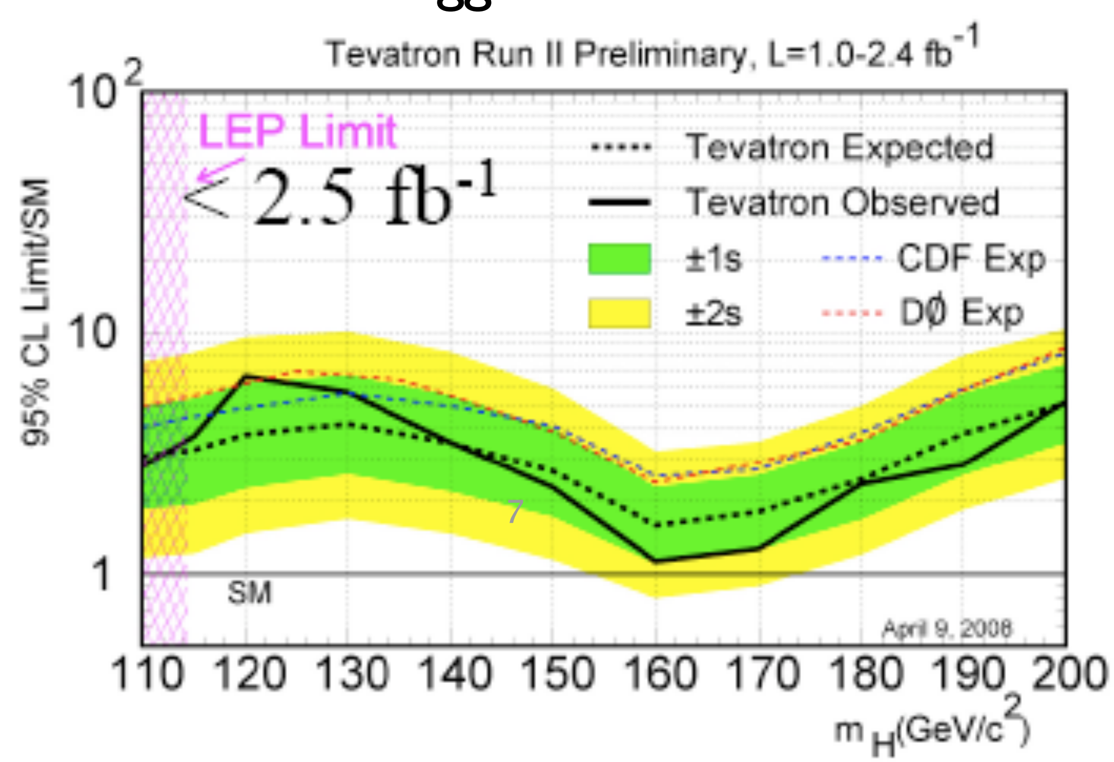
$m_H = 84^{+34}_{-26}$ GeV (including LEP: m_H < 185 GeV)

=>LEP Direct: m_H>114.4 GeV @ 95% CL

Tevatron :
m_H = 170 GeV excluded @ 95% C.L.



Still a long way to go before reaching sensitivity to lower SM Higgs boson masses...



Higgs Production at the LHC

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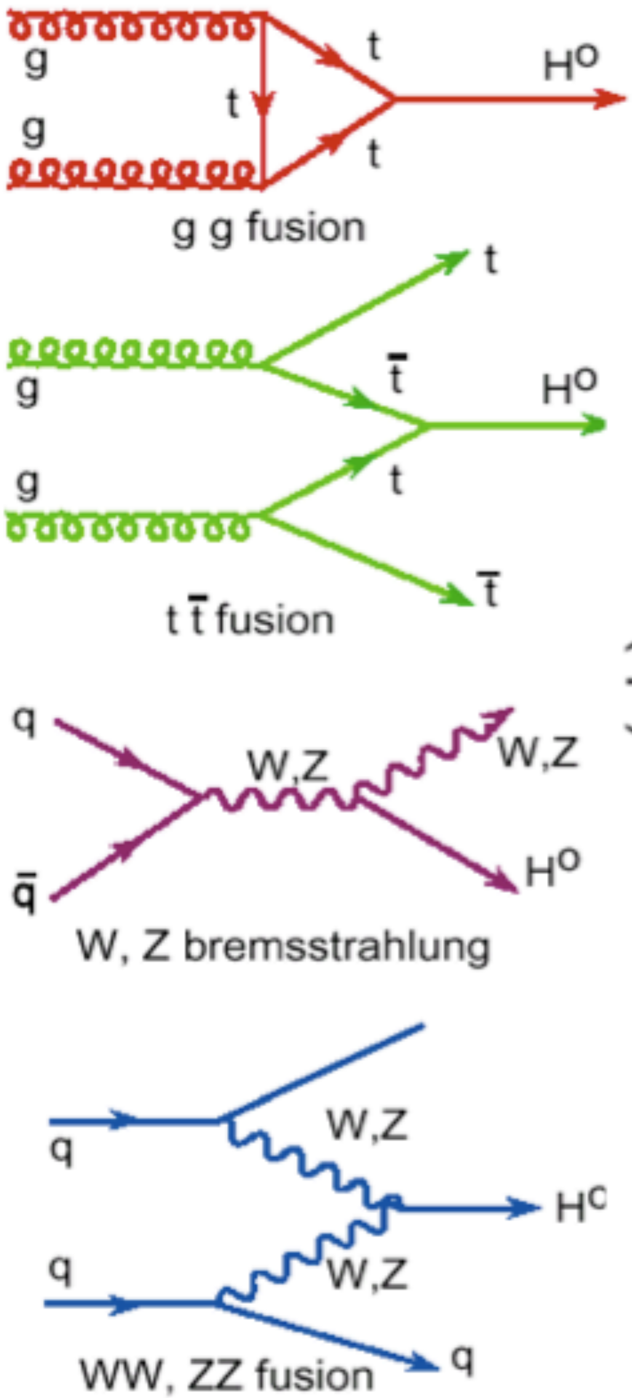
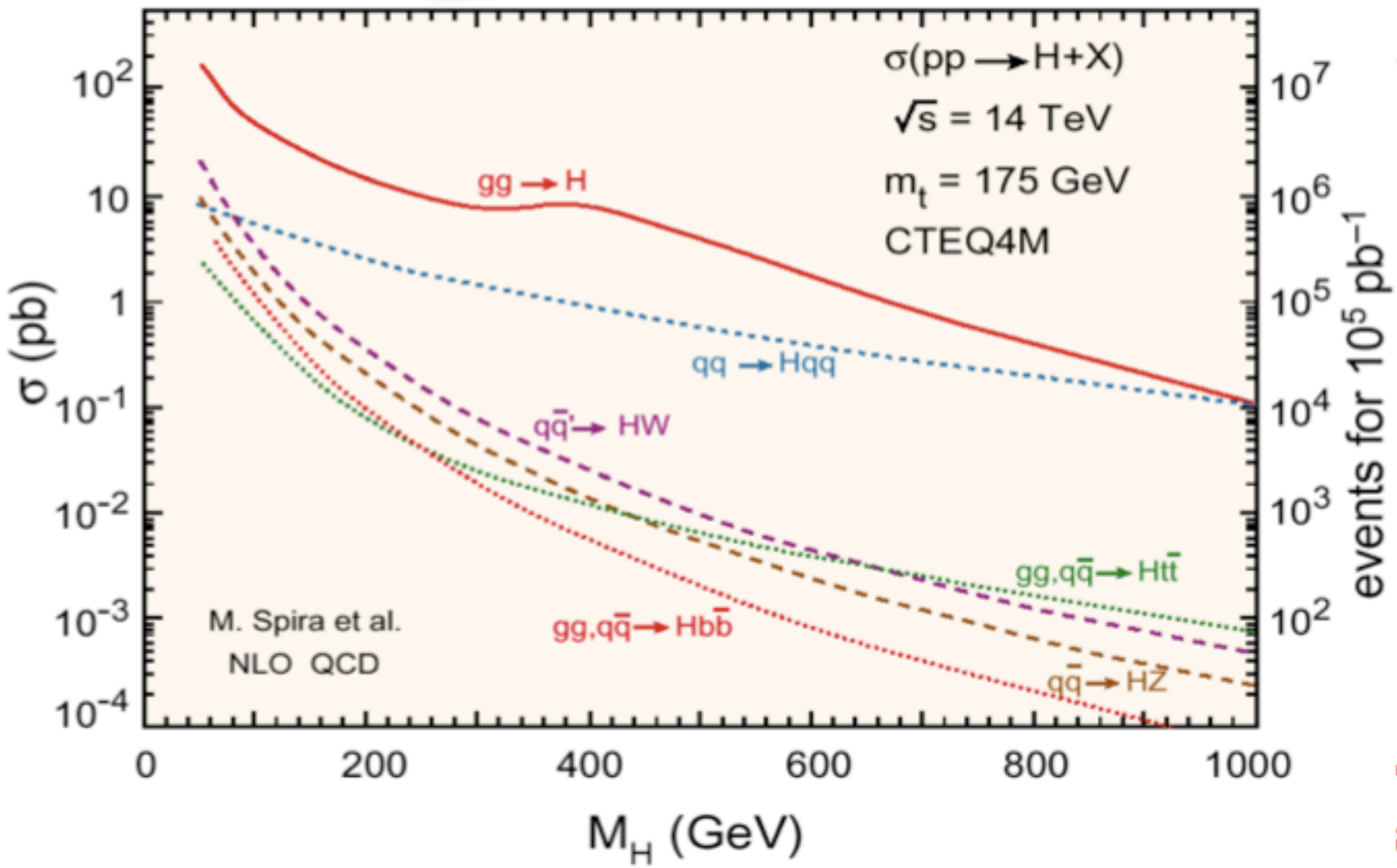


Uncertainties ~5-20%



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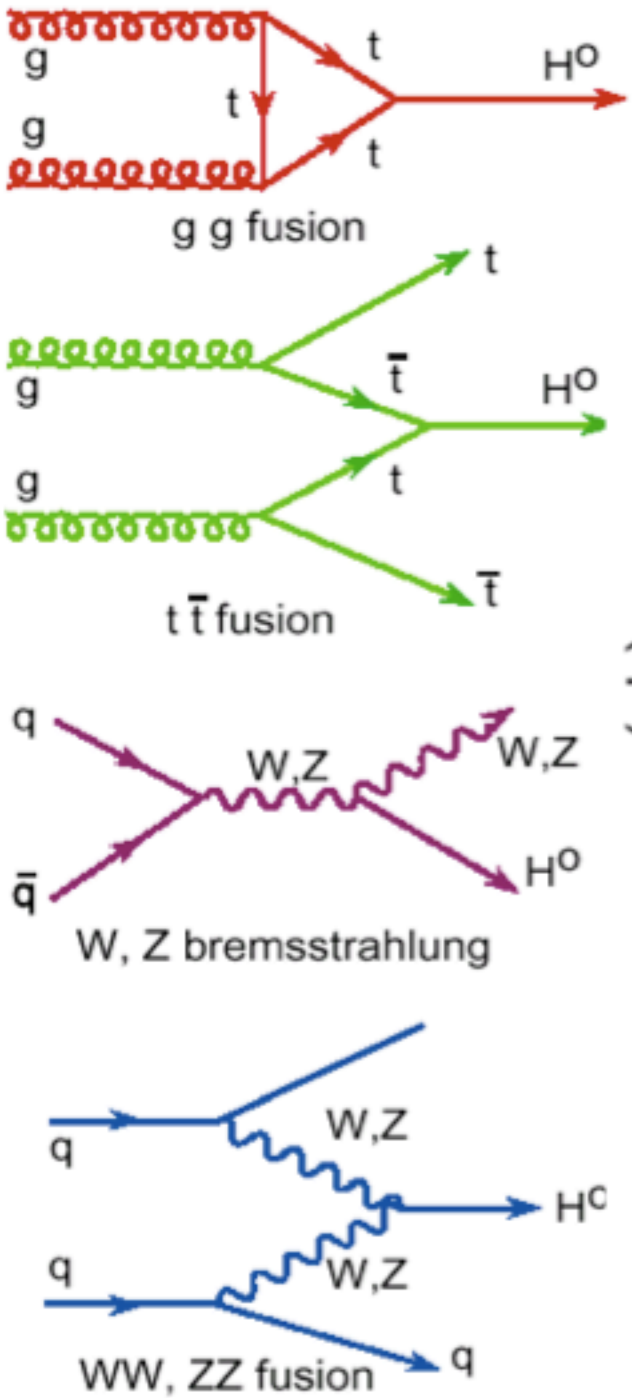
Higgs Production at the LHC



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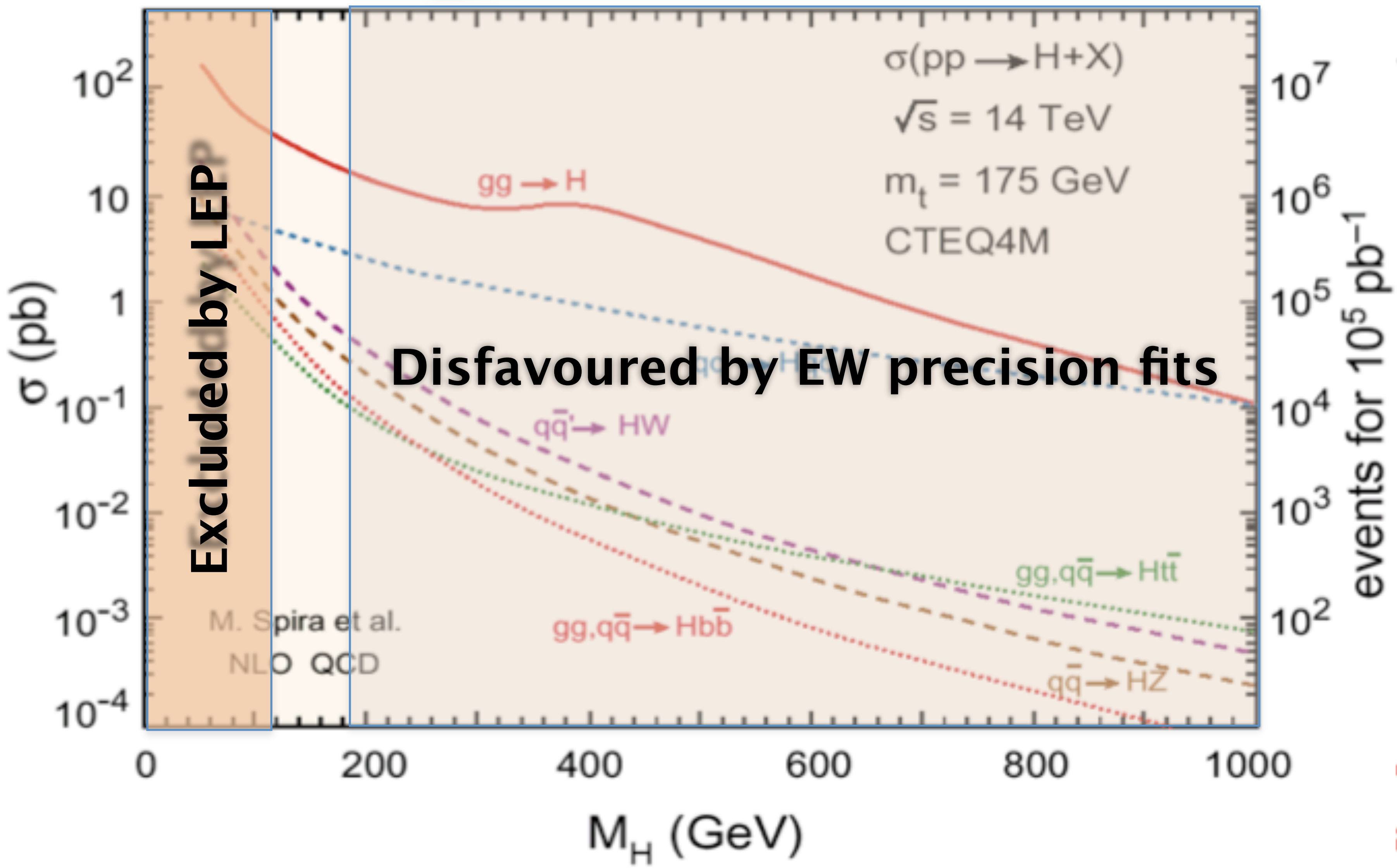

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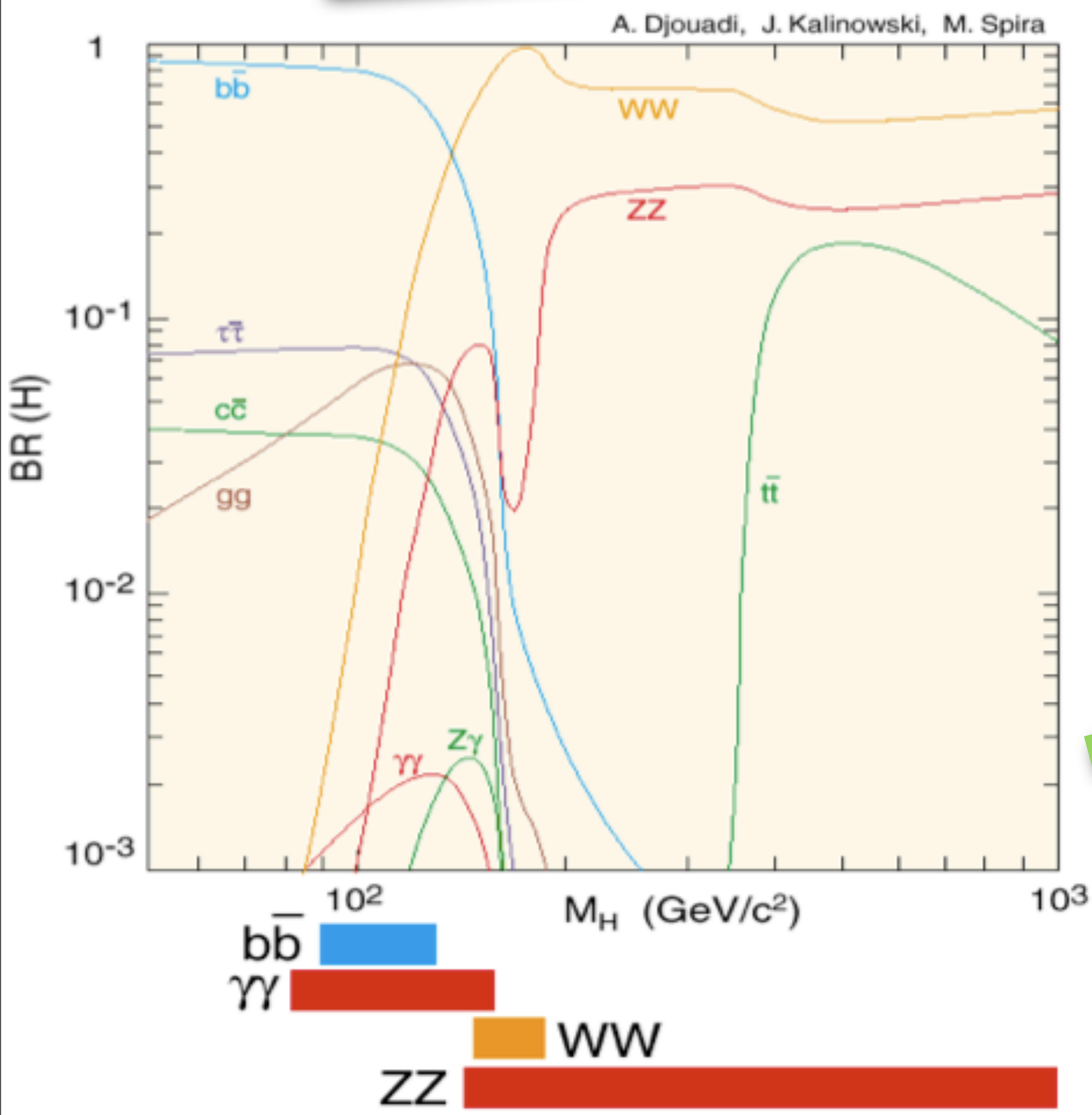
Higgs Channels

Uncertainties ~ a few %



BSM: γγ, ττ, and bb channels can be changed, even within MSSM ...

In this talk :
Only SM Higgs Searches **@ 14 TeV**

New :

Important changes w.r.t. previous studies:

- **ttH → tt bb** disappeared in both ATLAS and CMS studies from the discovery plot

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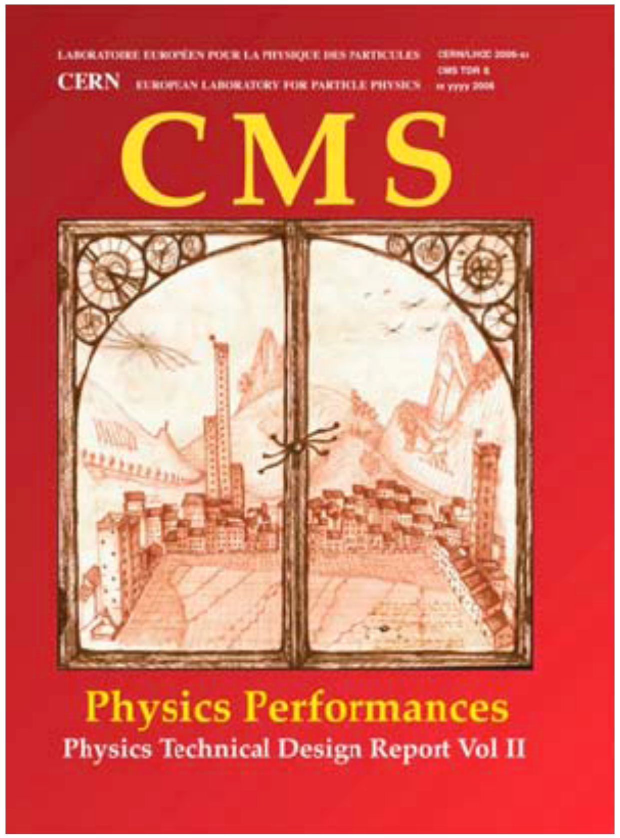
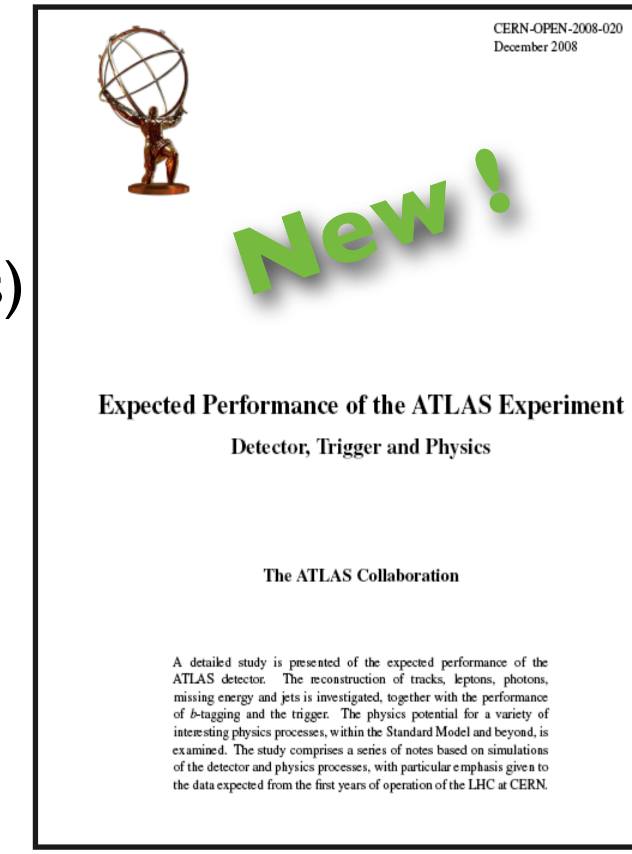
Status of Studies



CMS: CERN / LHCC 2006-021
\+ Some Updates

- Better detector description and simulation : geometry, material budget, Geant4 ⇒ more realistic
- New (N)NLO Monte Carlos (also for backgrounds) (MCFM, MC@NLO)
- New approaches to match parton showers and matrix elements (ALPGEN + MLM matching, SHERPA etc.)
- More detailed, better understood reconstruction methods (partially based on test beam results,…)
- Improved trigger simulation, event reconstruction and analysis tools
- Strategies to estimate backgrounds from data
- Improved statistical treatment (also including treatment of systematic uncertainties)



CERN-OPEN-2008-020
December 2008

New !

Expected Performance of the ATLAS Experiment

Detector, Trigger and Physics

The ATLAS Collaboration

A detailed study is presented of the expected performance of the ATLAS detector. The reconstruction of tracks, leptons, photons, missing energy and jets is investigated, together with the performance of b-tagging and the trigger. The physics potential for a variety of interesting physics processes, within the Standard Model and beyond, is examined. The study comprises a series of notes based on simulations of the detector and physics processes, with particular emphasis given to the data expected from the first years of operation of the LHC at CERN.

ATLAS: CERN-OPEN 2008-020

One of the most important improvements : **sensitivities given at NLO**

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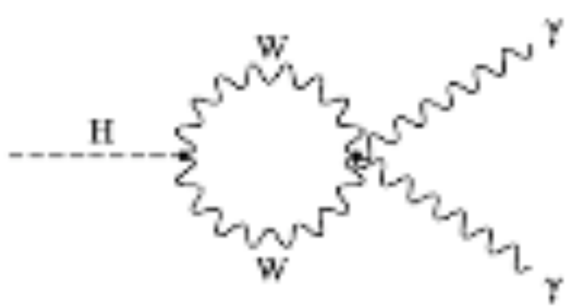
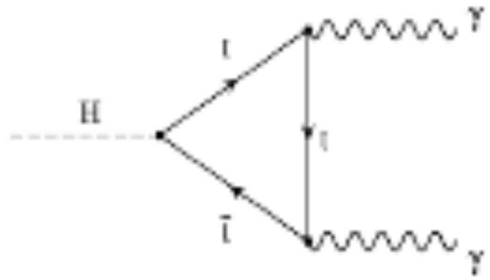
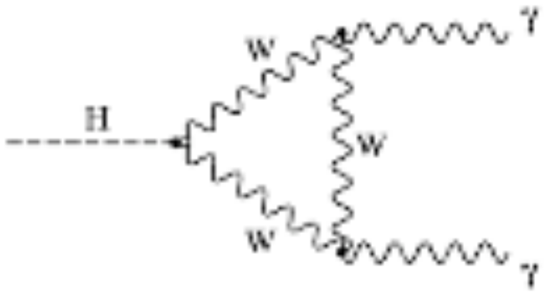
Higgs -> γ γ

- Small branching ratio (BR≈0.002 @m_H=120GeV)





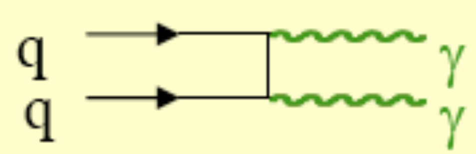


- Important for low-mass region (120-140 GeV)

Backgrounds:

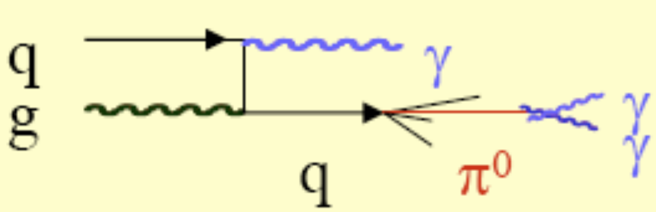
Irreducible: γγ, γγ+jets

γγ irreducible background



Reducible: γ+jets, jets,
Drell-Yan

γ-jet and jet-jet (reducible)



Main experimental tools for background suppression:

- Photon identification(also converted γ)
- Need good γ-jet separation (10^{-3}-10^{-4} to get $\sigma_{\gamma j}+\sigma_{jj} << \sigma_{\gamma\gamma}$)
- Need good mass resolution (~1.5 GeV)
- Vertex reconstruction
- Both experiments use cut-based analyses and multivariate (NN, likelihood) methods

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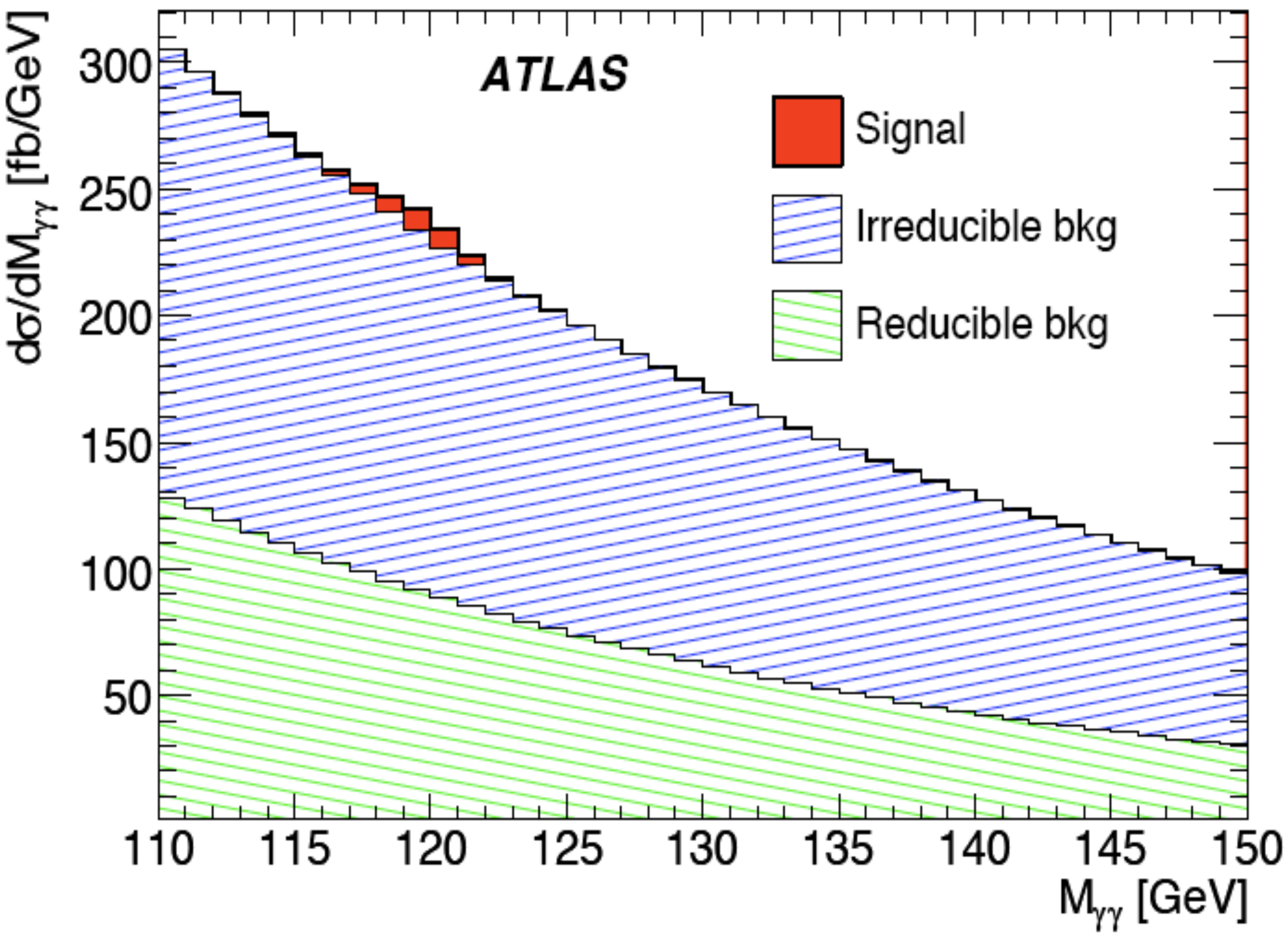
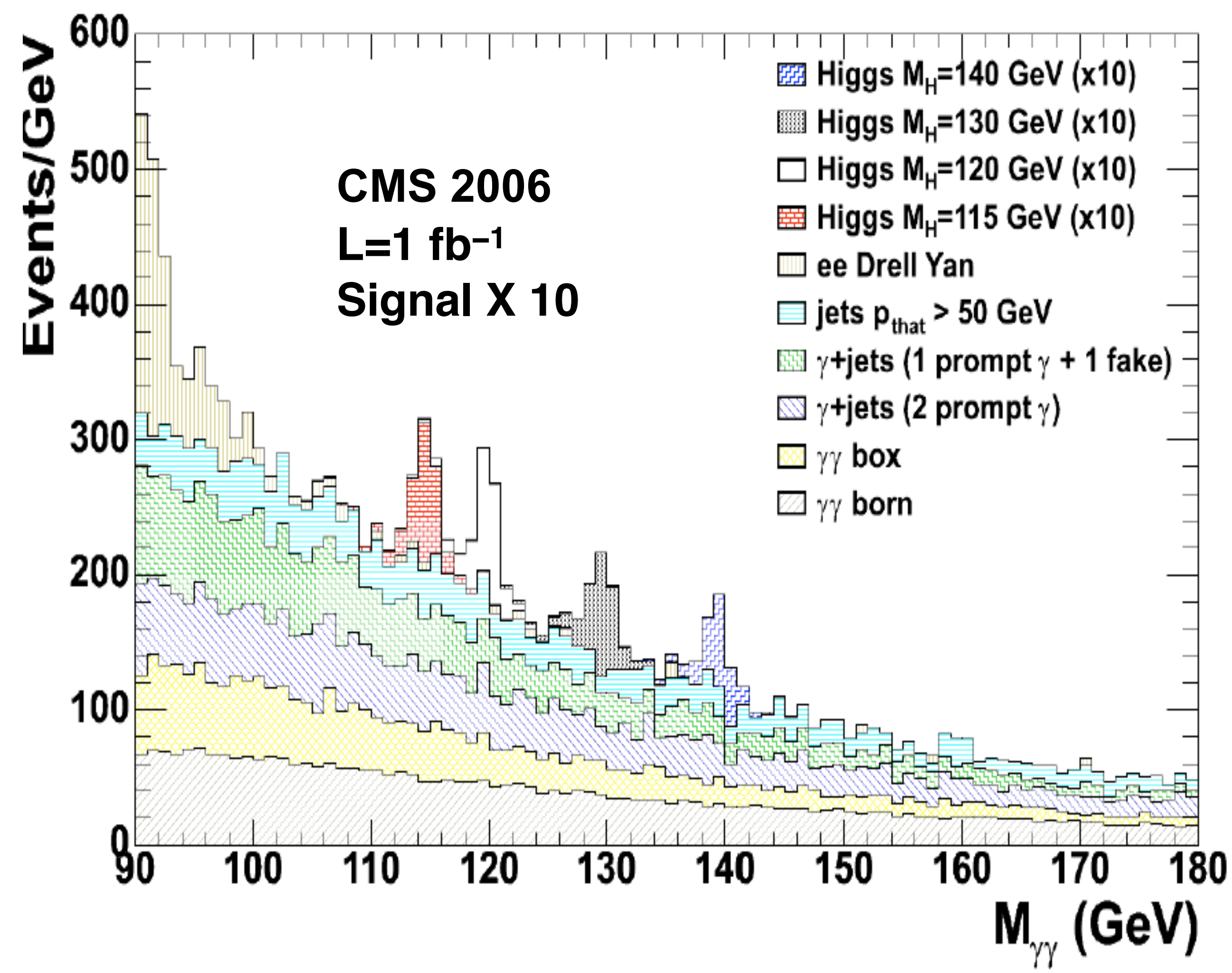
Higgs -> γ γ

2008 cross-sections in fb





ATLAS

- Signal divided into categories according to η_γ, #jets, #converted photons
- Search for di-photons with **jets**

CMS

cut-based

- Signal categories according to η_γ and
- lateral shower shape variable
- kinematics, isolation, $M_{\gamma\gamma}$-peak

optimized

- event-by-event kinematical Likelihood Ratio with background pdf taken from sidebands,

Results:Higgs -> γ γ

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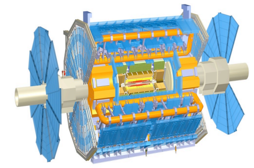
ATLAS

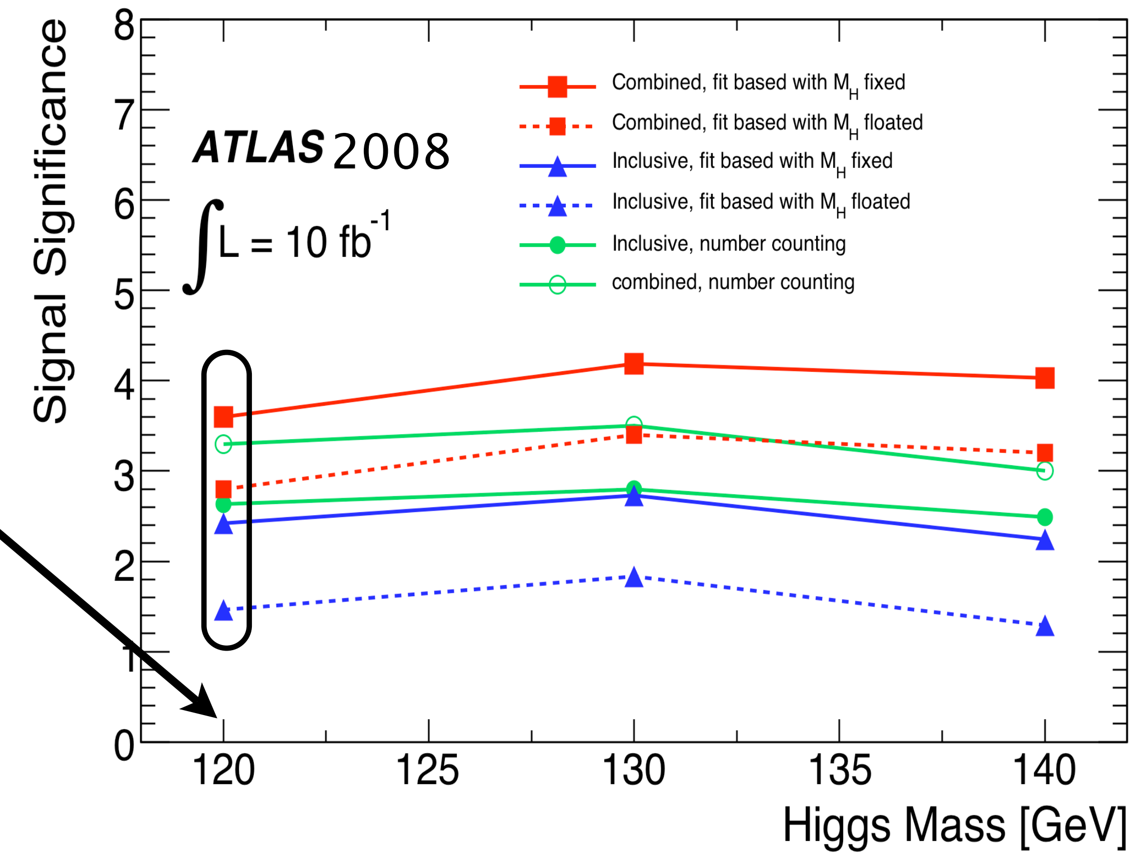


Event Counting: σ= 2.6 for 10fb^{-1}

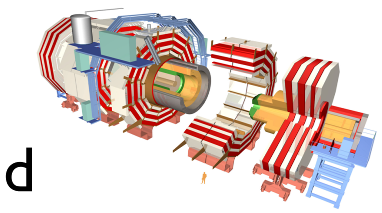
Floating (fixed) mass fit, associated productuion with jets: σ=2.8 (3.6) for 10fb^{-1}

Changes:

- more reducible background with one fake photon(x2)
- Combining the 0, 1 and 2 jets analyses

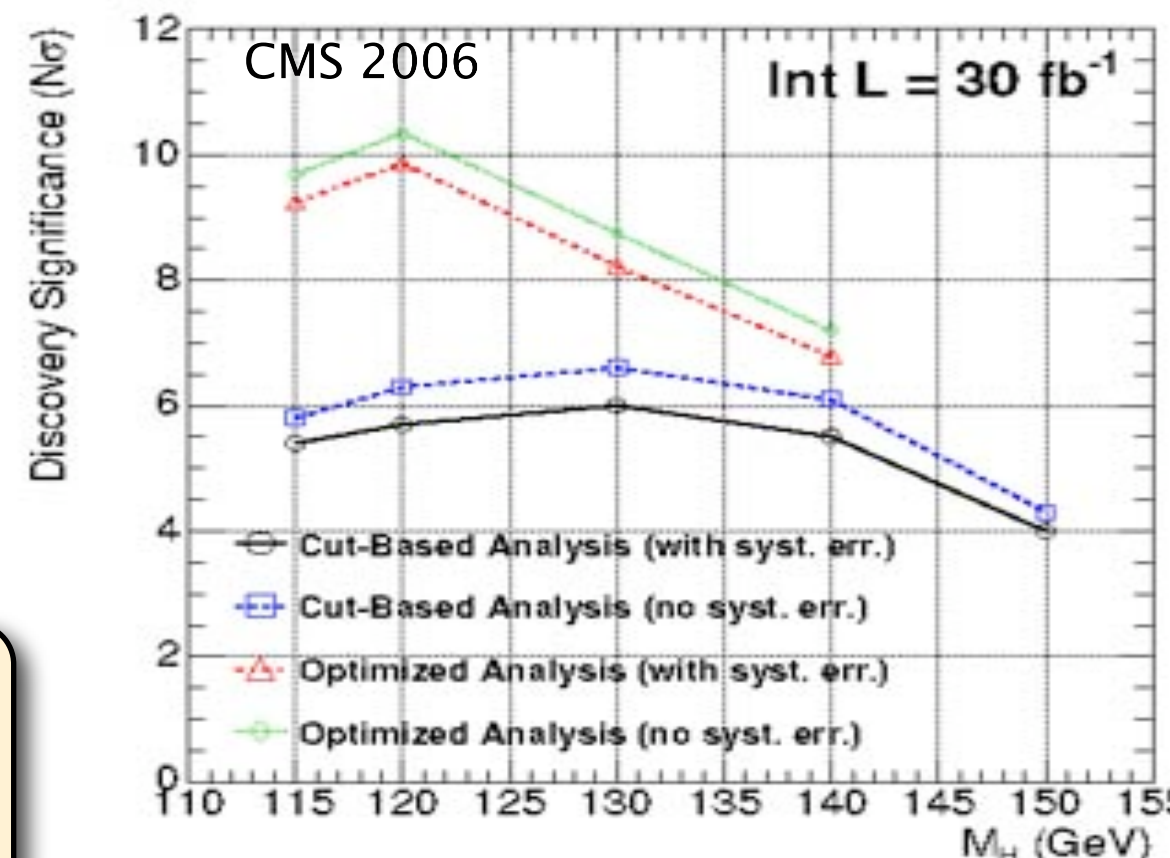


CMS (TDR)



5σ discovery between LEP lower limit and 140 GeV with less than **30 fb−1** of integrated luminosity.

5σ discovery with event by event estimation of the s/b ratio possible at m_H=120GeV with **7-8 fb^{-1}**



=> CMS slightly higher sensitivity

=> Improvements possible by using more exclusive γγ + jet topologies

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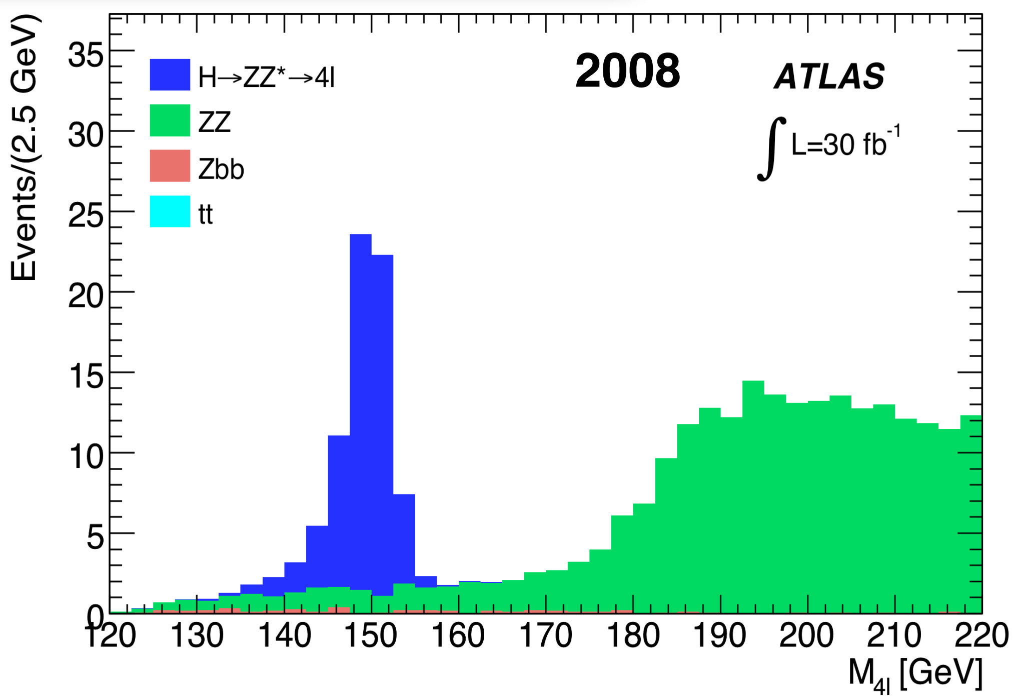
Higgs -> ZZ -> 4l

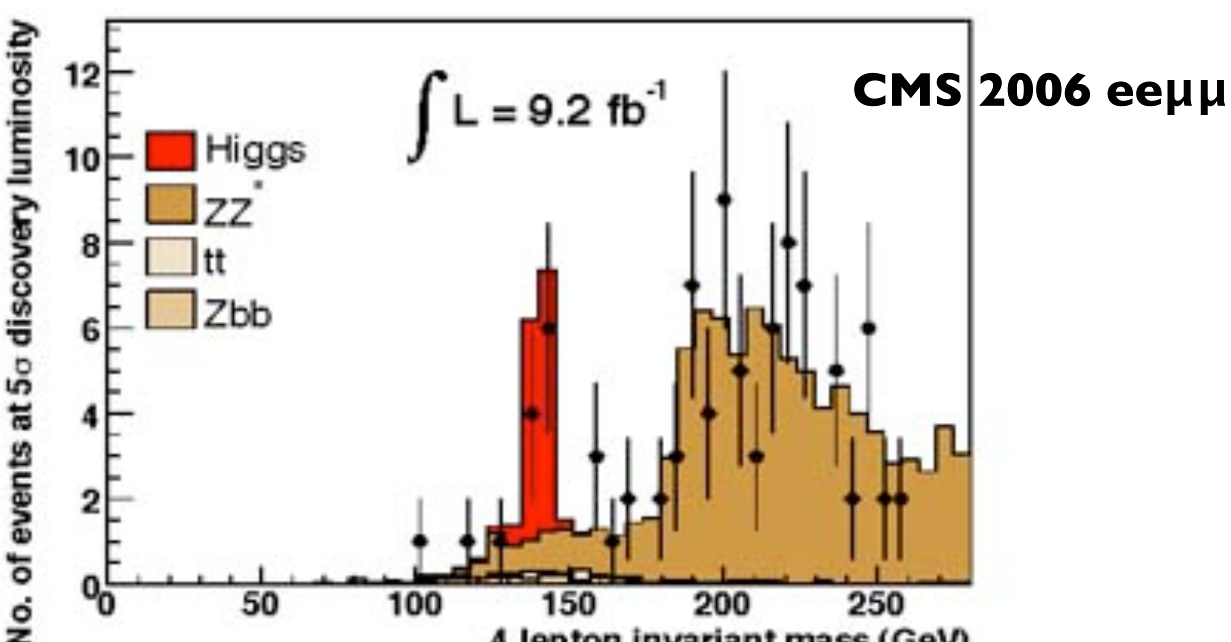
The "golden channel" : H->ZZ*->4e/4μ/2e2μ for a wide mass range, except $m_H \approx 2\ m_W$

Backgrounds:

- **Irreducible:** ZZ* dominant
- **Reducible:** Zbb, tt, ZW, Z + X

- Examples:





Main experimental tools for background suppression:

- lepton isolation in the tracker and in the calorimeter
- Isolated muon and electron pairs with opposite charge
- Reject Zbb, tt, etc using quality cuts: isolation, lepton track, impact parameter, vertex constraints
- At least one Z->ll on shell
- Reconstruct 4-lepton invariant mass
- Data-driven methods to estimate backgrounds, efficiencies, resolutions etc
- Z-peak (Z and ZZ production are very similar)

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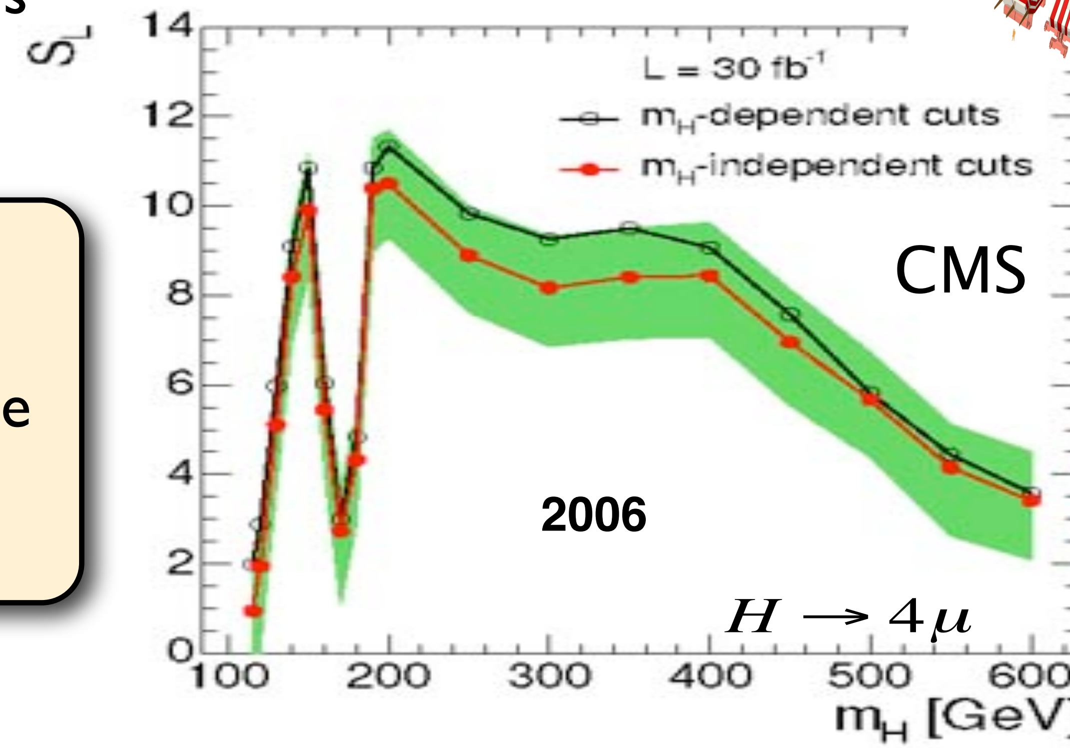
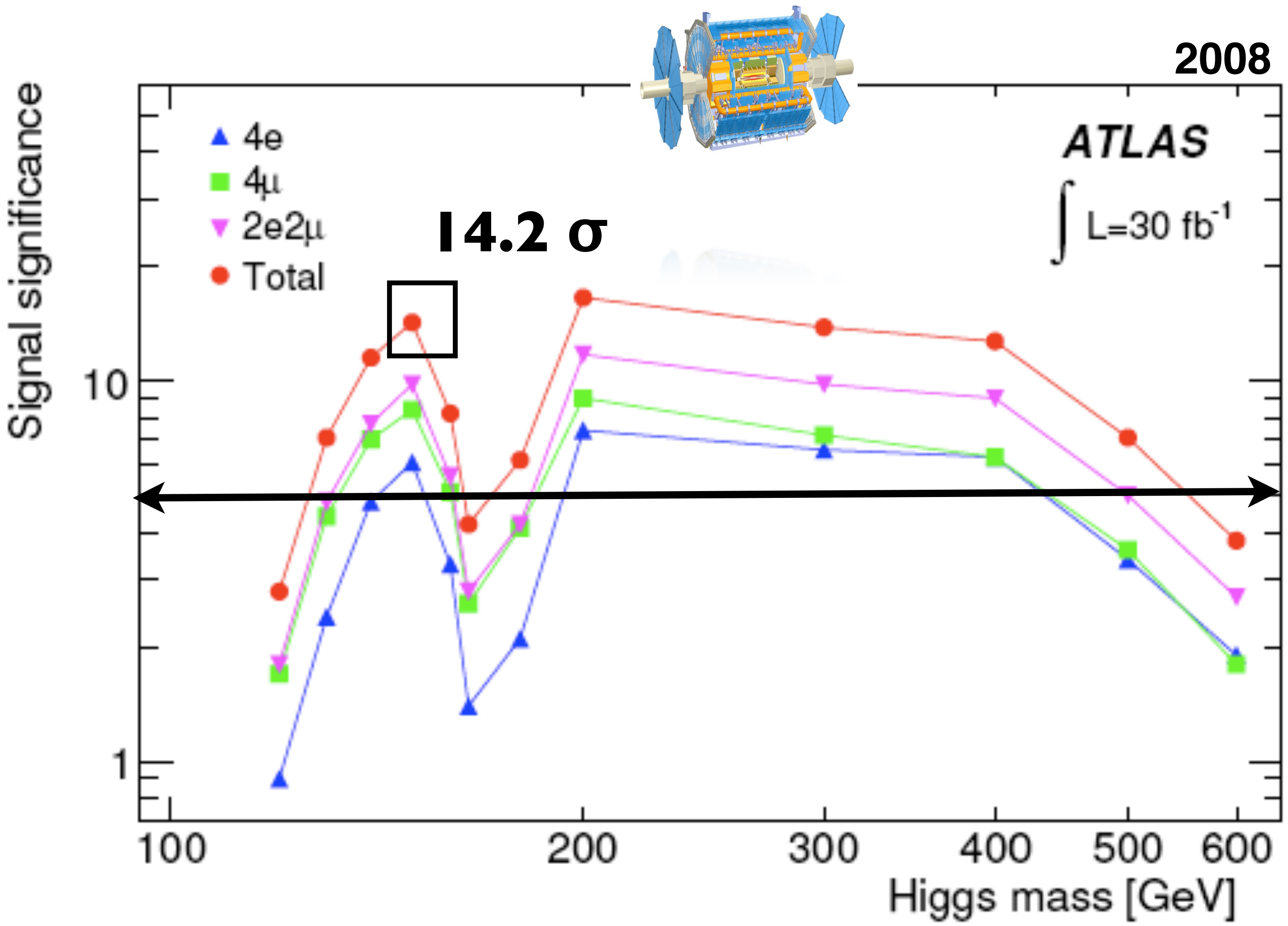
Higgs -> ZZ -> 4l

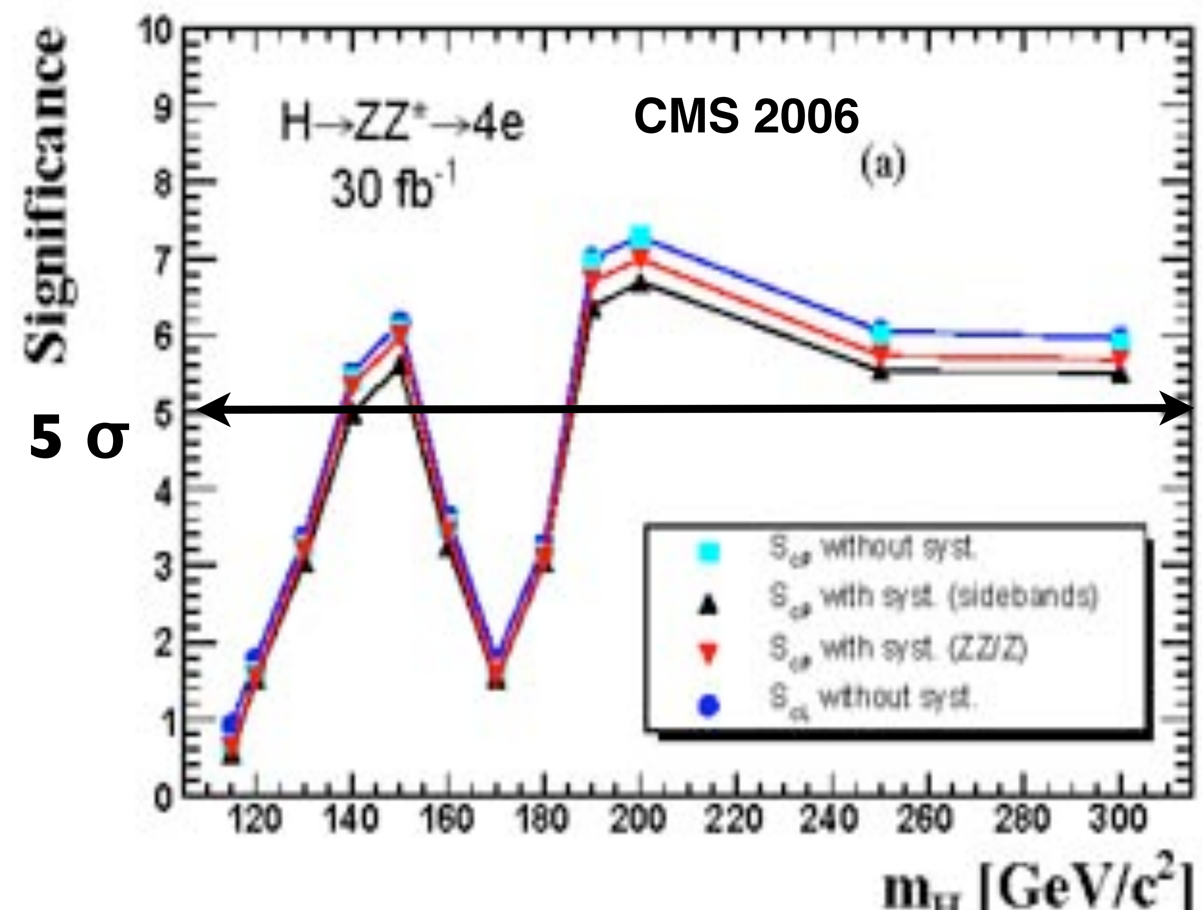
- Four CMS analyses (TDR), one combined ATLAS analysis
- Varied level of systematic uncertainties treatment

=>Comparable significance

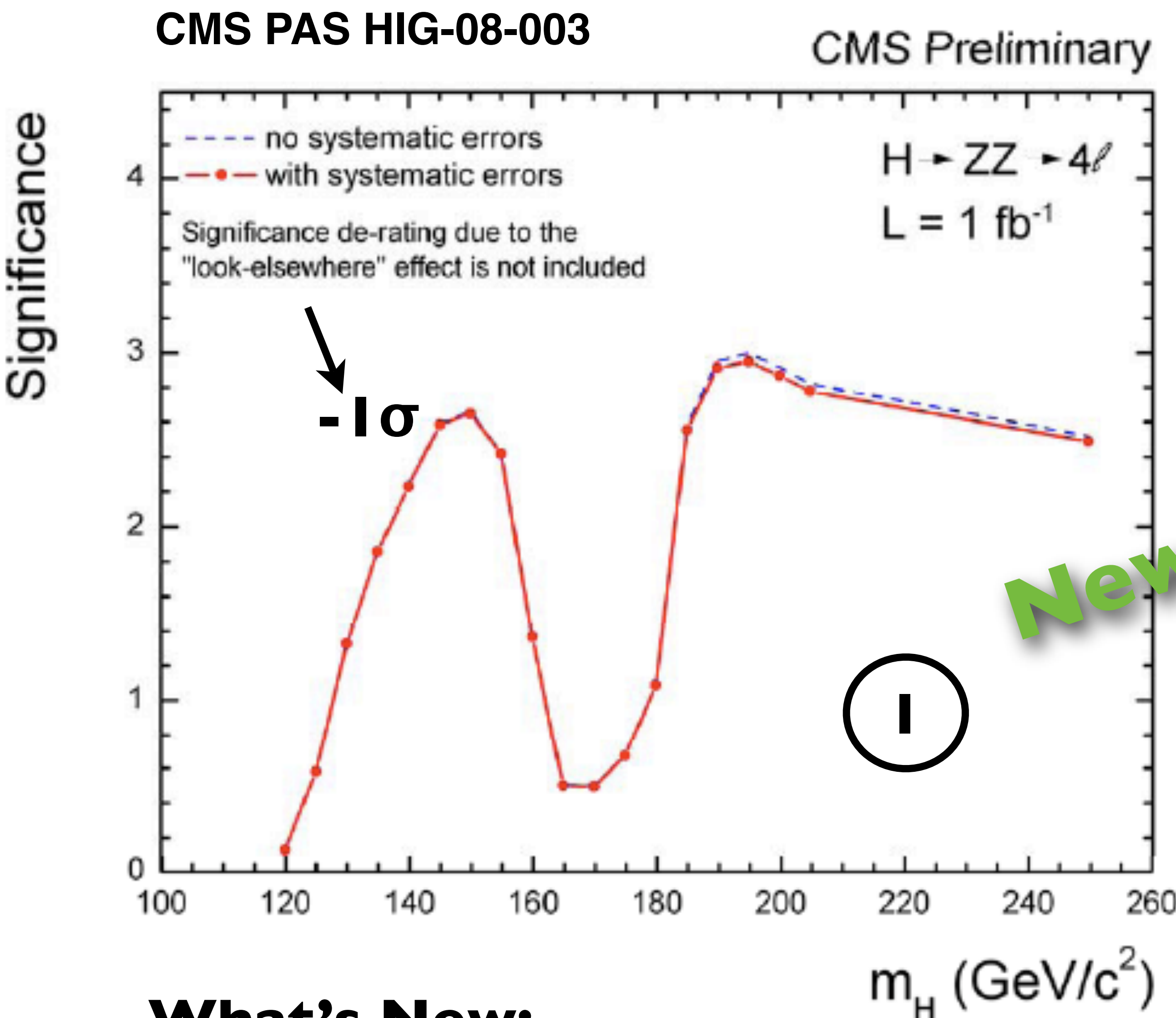
The H -> ZZ -> 4 channel is highly sensitive in the high mass region **(400 GeV > mH > 200 GeV)** and in the **150 GeV** region, where the Higgs boson should be discovered with **5 fb−1.**

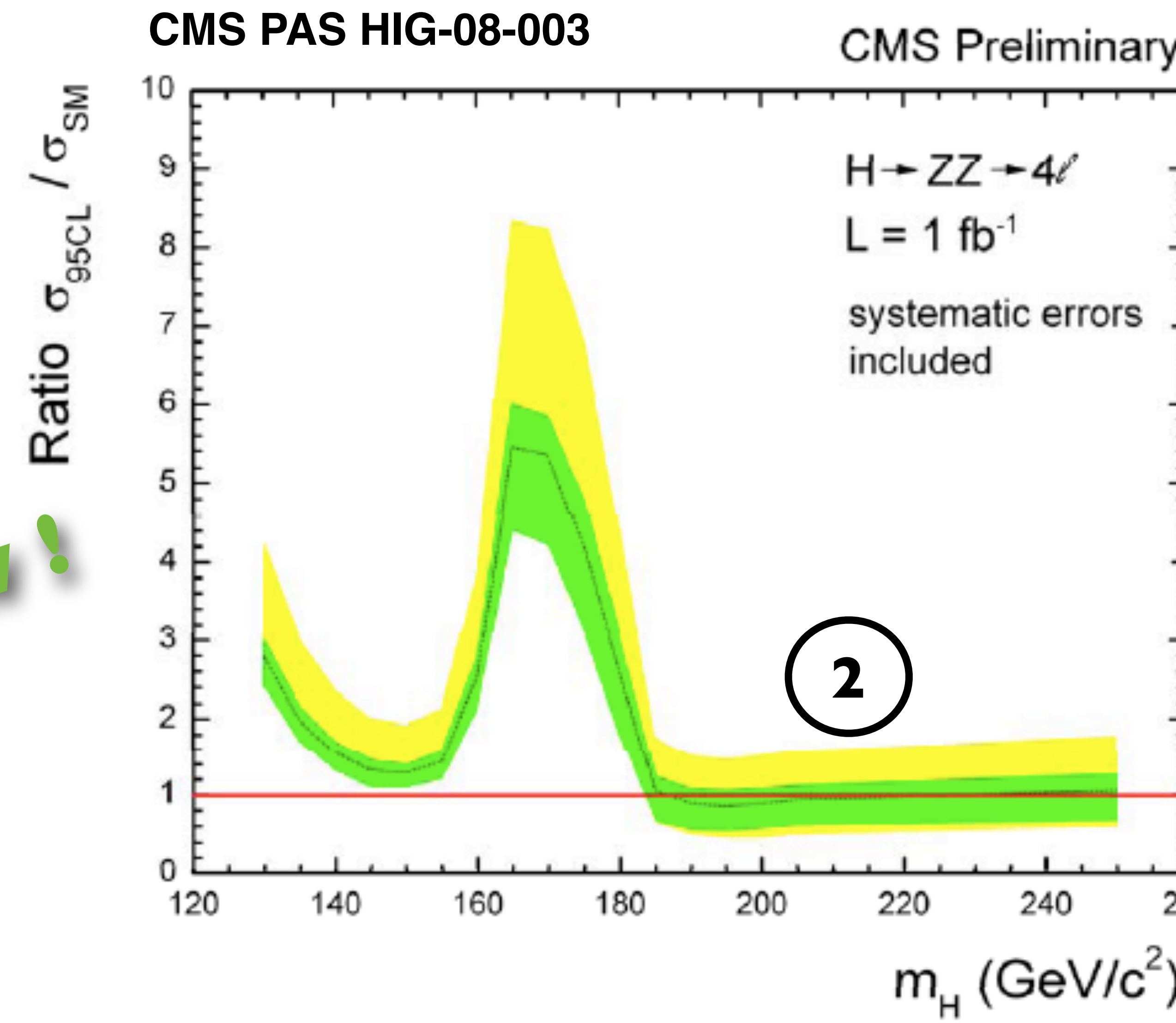


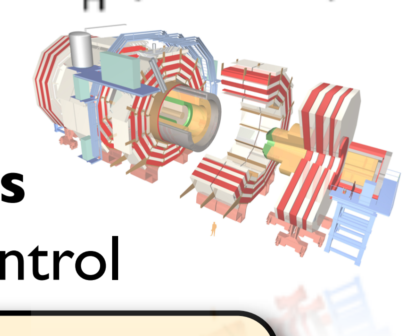




H-> ZZ Update







What's New:

- Simple sequential cut-based approach with **common baseline selection**
- All three channels 4e/4μ/2e2μ combined for **Significance & Exclusion limits**
- Cuts optimised for 1 fb^{-1}, Data driven methods for background optimization control

1. => Significance of about **2 σ** can be reached for $m_H \sim 200$ GeV at $\int Ldt = 1\ fb^{-1}$
2. => SM – like Higgs boson can be excluded for $m_H > 185$ GeV with $\int Ldt = 1\ fb^{-1}$
3. => Comparable with TDR if scale and combine channels and ATLAS (~2.6@150GeV)

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H-> ZZ Update

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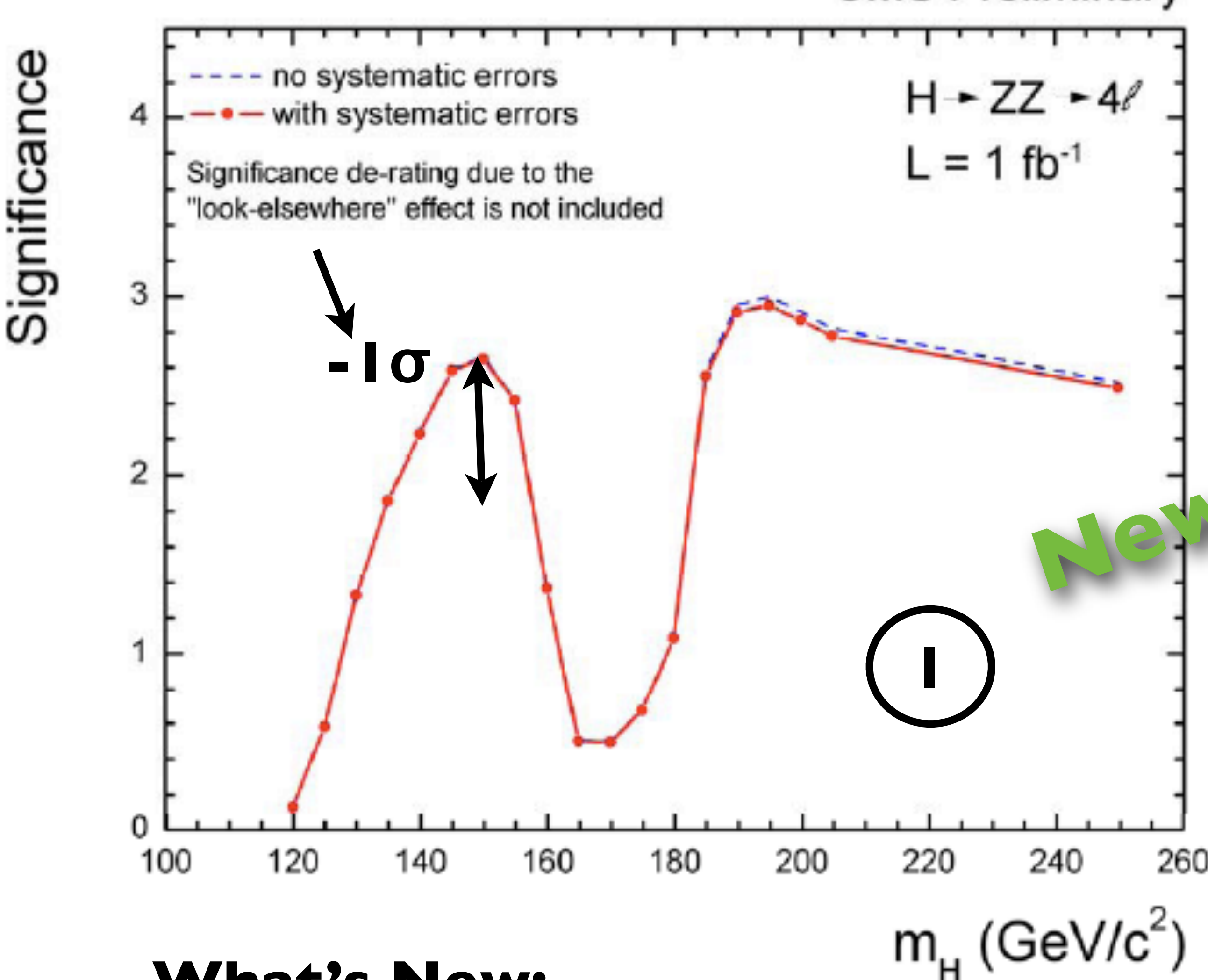
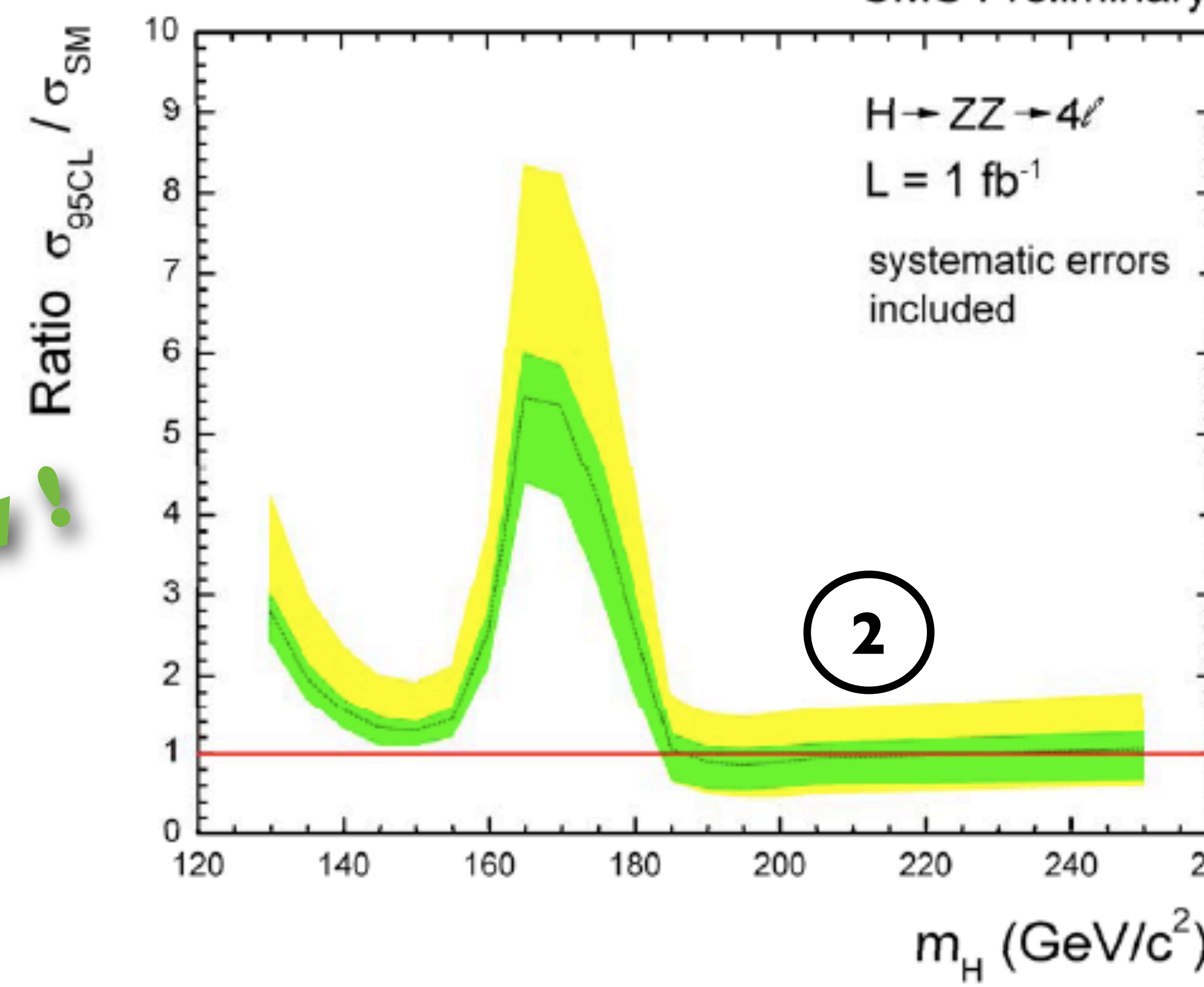
CMS PAS HIG-08-003



CMS PAS HIG-08-003



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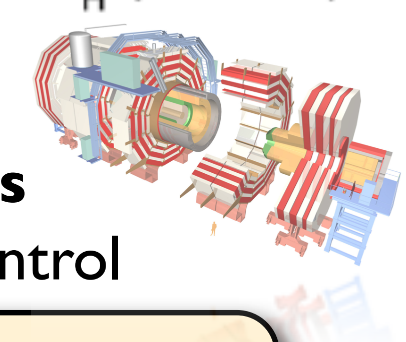

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2 => SM – like Higgs boson can be excluded for m_H > 185 GeV with ∫Ldt = 1 fb^{-1}

3 => Comparable with TDR if scale and combine channels and ATLAS (~2.6@150GeV)

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$H \to WW \to \ell\nu\ell\nu$

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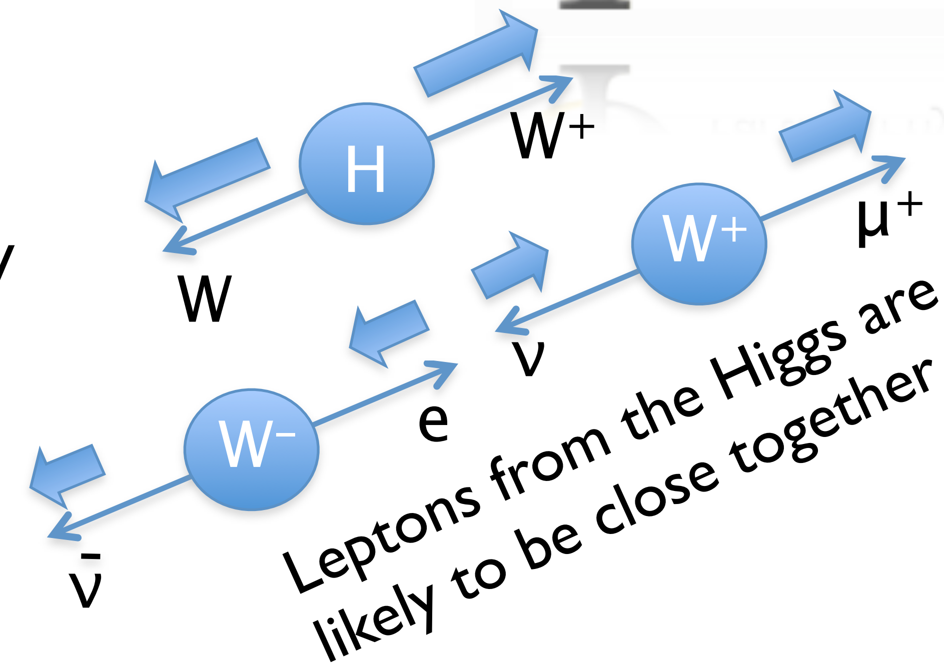
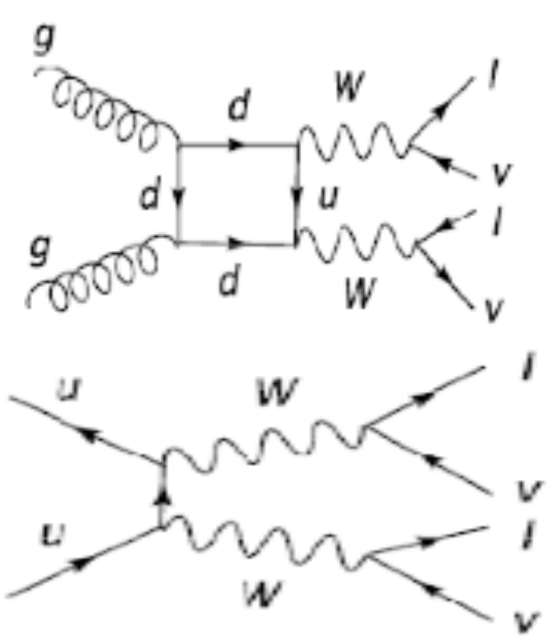
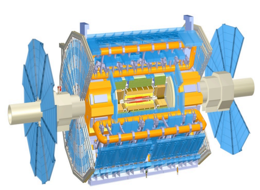
- Main search channel for mass in range: $2m_W < m_H < 2m_Z$
- Highest branching ratio >140 GeV: 95% @ m_H = 160 GeV
- **Analyses:**
  - H + 0 jets -> lνlν (dominated by gluon fusion)
  - H + 2 jets -> lνlν; H + 2 jets -> lνqq (dominated by VBF)



Backgrounds:
a very precise determination of the backgrounds necessary
WW, tt, Wt(b), WZ, ZZ





<u>Main experimental tools for background suppression (ATLAS):</u>

- No mass peak => Use transverse mass, e/μ kinematics, isolation, MET
- Need precise knowledge of the backgrounds:
  - **Strategy:** fit transverse mass and Higgs candidate p_T in 2 bins of di-lepton azimuthal angle $\Delta\varphi_{ll}$ to extract S/B ratio in signal region

Two main discriminants:

- Angular correlation between leptons
- Veto on additional jets

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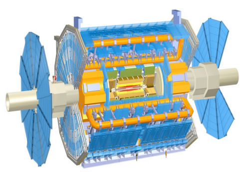
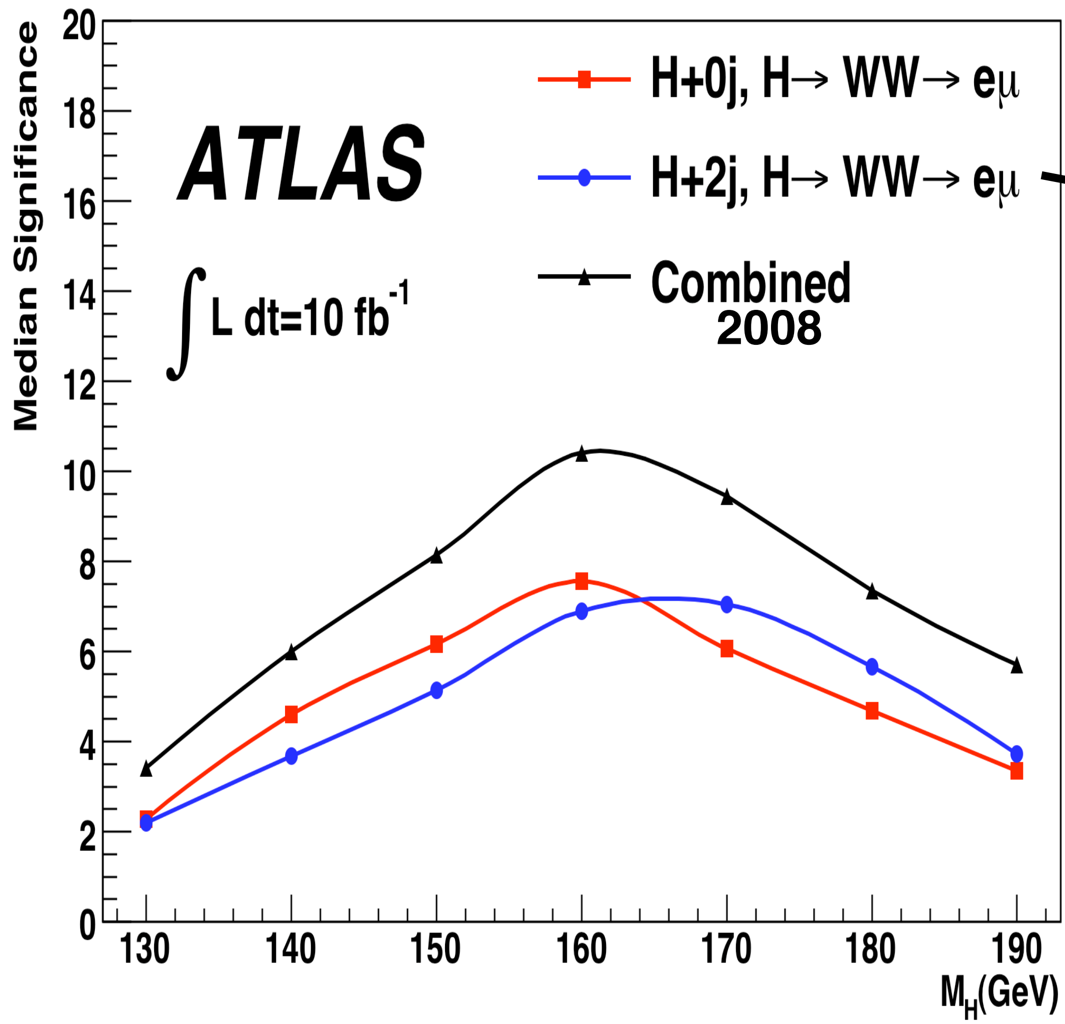
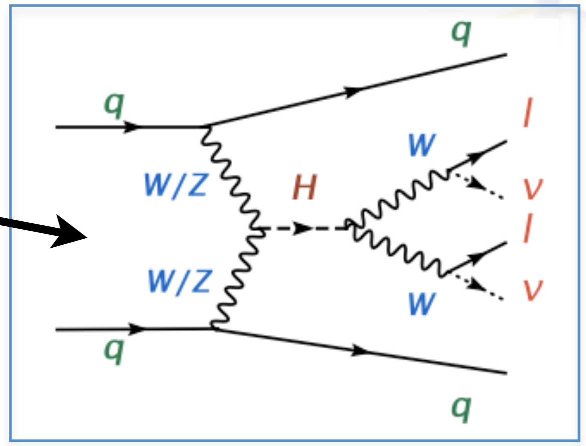
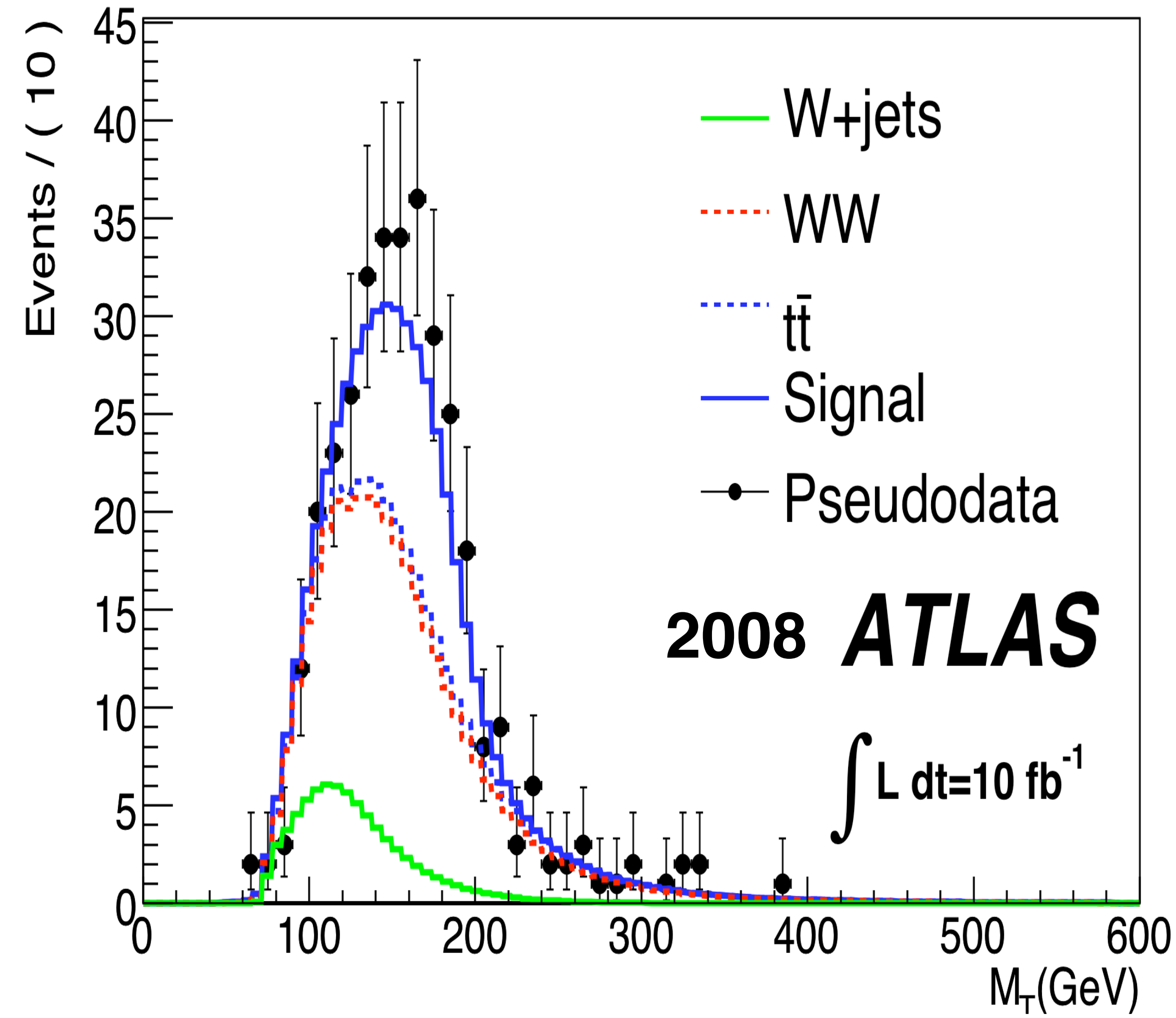
$H \to WW \to \ell\nu\ell\nu$









=> Combining the 0, 2 jets analyses, the significance is > 5 @ 10 fb-1 for m_H $\in$ **[135,190]** GeV

=> Only eμ final states in ATLAS

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H-> WW Update

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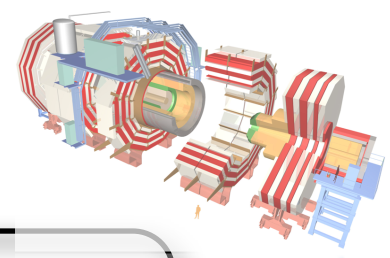
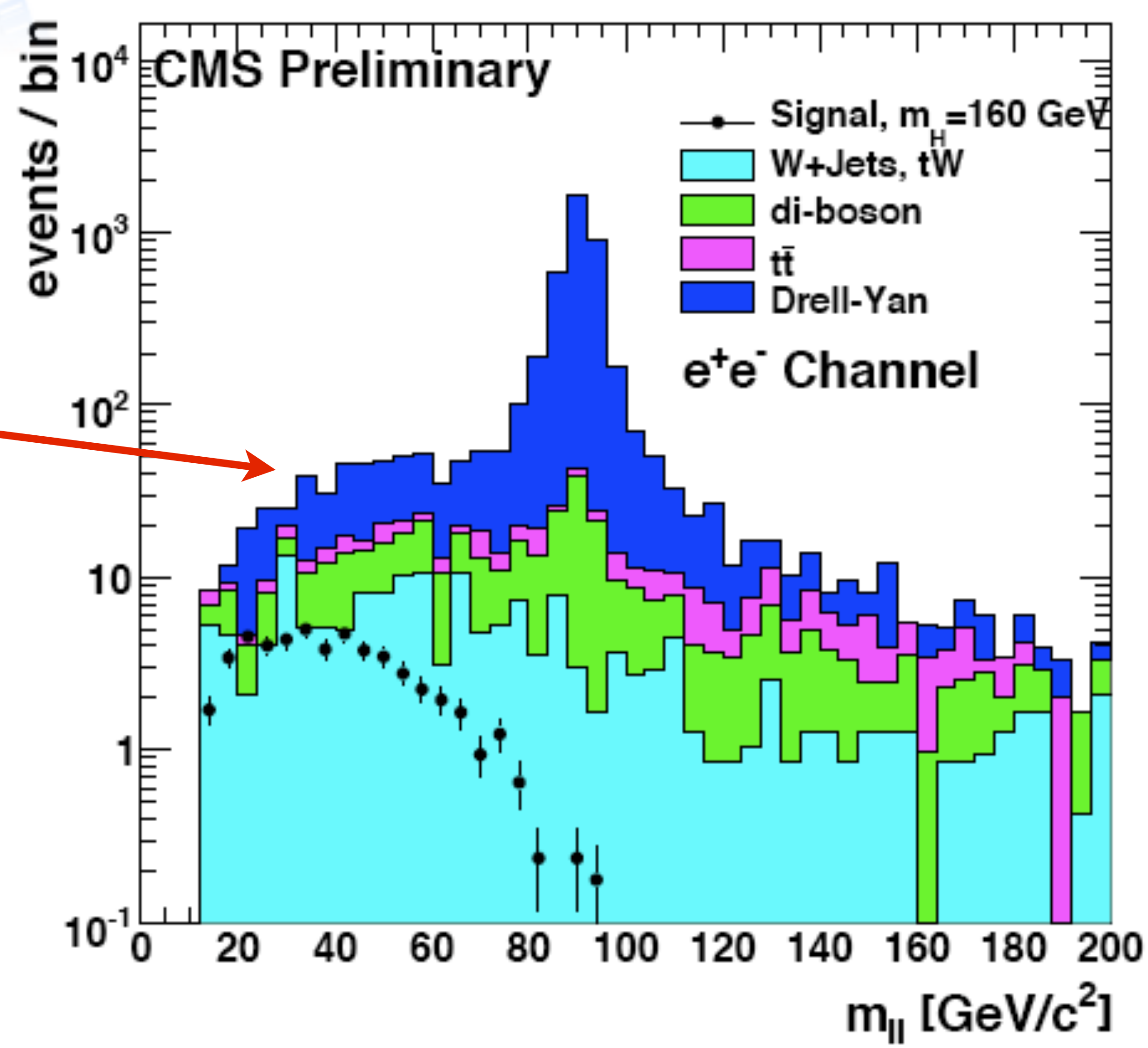


New !

CMS PAS HIG-08-006

Analysis Flow:

+ HLT
+ 2 opposite-sign isolated and identified leptons
+ $p_T^{\ell 1/\ell 2} > 20/15$ GeV/c
+ $E_T^{miss} > 30$ GeV, $m_{\ell\ell} > 12$ GeV/c^2
+ No central jets
+ Final requirements:
  cut based
  multivariate techniques
+ Control regions:
  fake leptons, background normalization
+ Systematics
+ Confidence levels



=> Different final state configurations e±e, e±μ and μ±μ (compared to ATLAS)
=> Lepton ID improved , mass dependent cuts, more data driven approaches (compared to TDR)
=> Cuts have been optimized separately for 1fb-1 maximizing the expected statistical significance.

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H->WW Update

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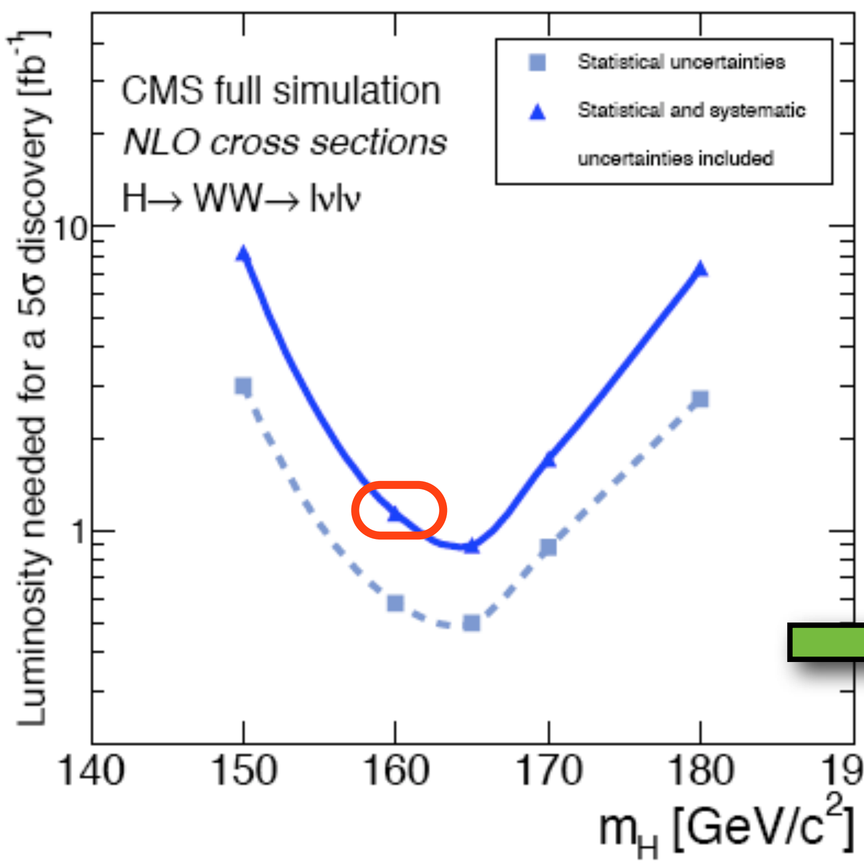
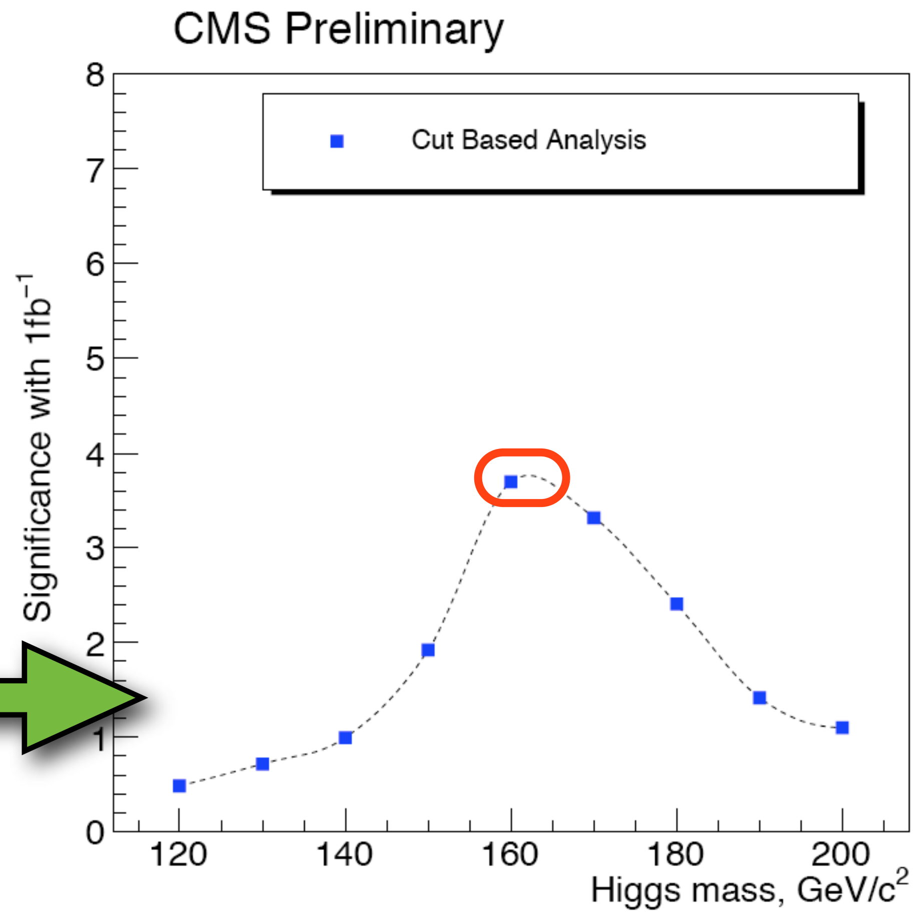
New !

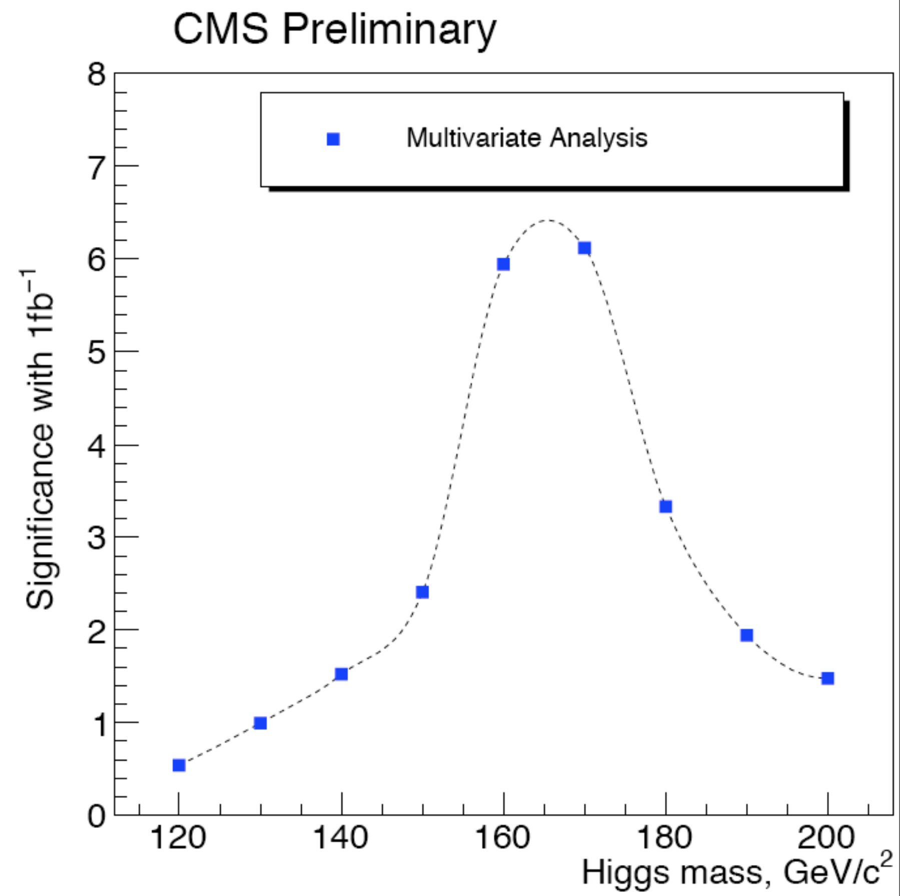
2006 TDR



CMS PAS HIG-08-006



CMS PAS HIG-08-006



- A bit worse in ~160 GeV region compared to TDR cut based analysis
- Analysis extended to other masses (mass dependant optimization), multivariate approach
- ATLAS results have to be scaled with $\sqrt{2}$ and to 1 fb-1

=> Using such a **multivariate** technique, a SM Higgs could be found at **5 σ** around m_H = **160 GeV** for an integrated luminosity of 1 fb^{-1}.

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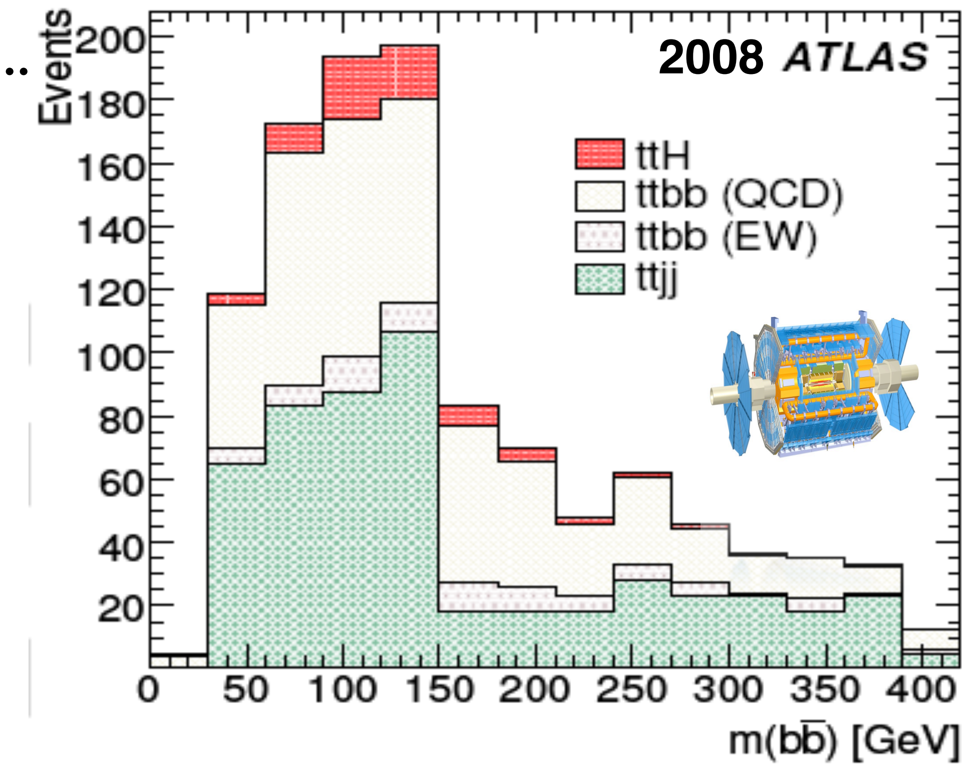
SM Higgs: ttH, H->bb

Basically the only possibility to observe H→ bb at LHC ...

- Updated CMS study (2006):

ALPGEN matrix element calculations for backgrounds



Backgrounds:

→ large combinatorial background

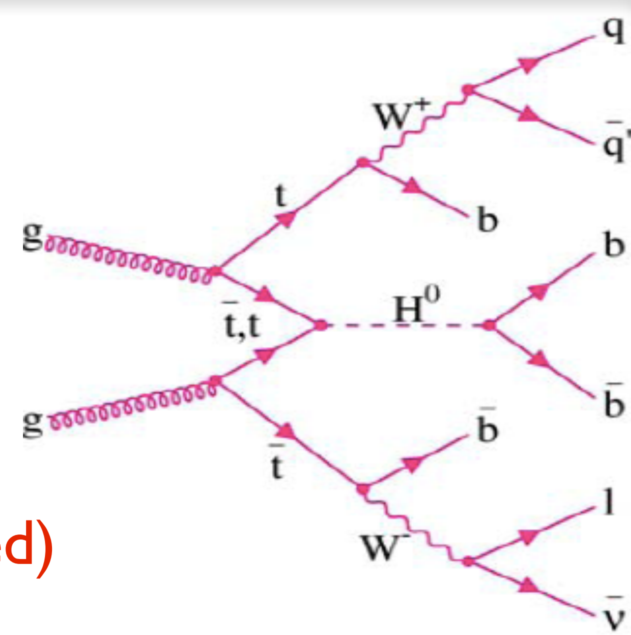
≥ 6 jets (4 b),

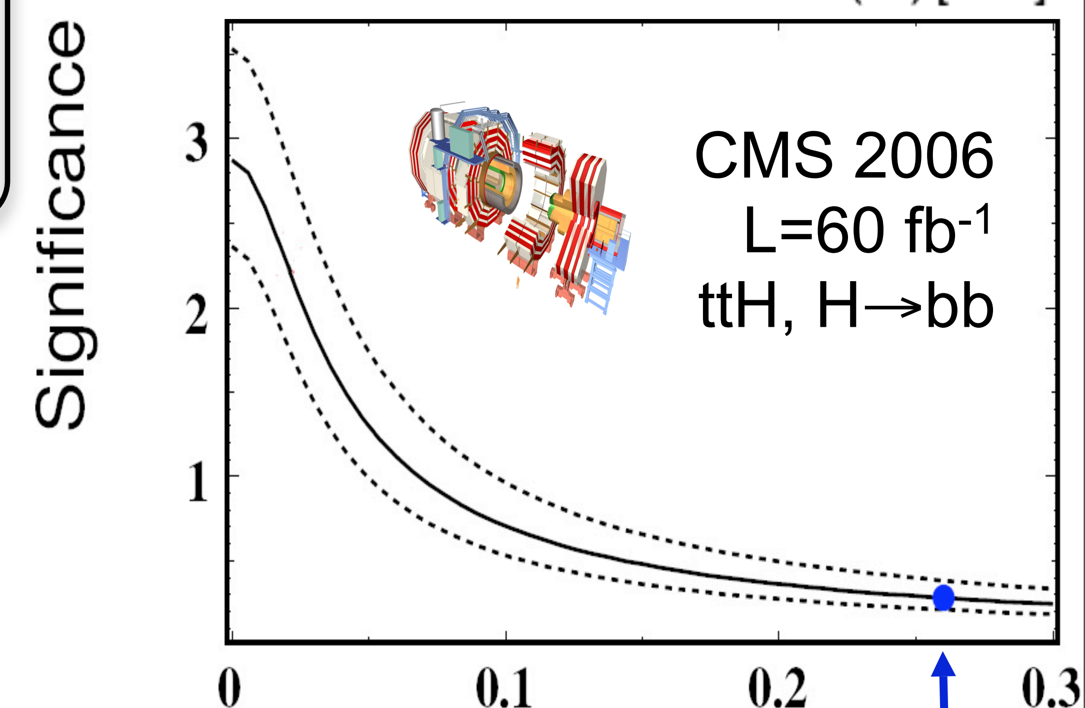
→ background prediction uncertain,

no easy control samples to select

tt + 2 jets, ttbb , Wjjjjjj, WWbbjj, etc.

(excellent b-tag performance required)





current estimate of background uncertainties

jet energy scale (3-10%)

jet energy resolution (10%)

b/c-tag efficiency (4%)

uds/g-tag efficiency (10%)

luminosity (3%)

dB

Before: might be observable already at L=30 fb^{-1} ...

ATLAS-2008 analysis:

S/B ~ 0.1; @ 30 fb-1, m_H = 120 GeV: σ ~ 2.0

=> No sensitivity anymore with systematics included

CMS-2006 analysis:

~same conclusion

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Higgs Searches at $\sqrt{s} < 14\,\text{TeV}$

• LHC will start working with center of mass energy lower than 14 TeV – likely around 10 TeV

=> **Main Effect: cross section changes**

Different energy of LHC has two effects:

- Cross section for signals (and background) goes down
- Signal (Higgs production) goes down faster – Higgs is mainly produced from gg and backgrounds from qq

Process	$\frac{\sigma_{\sqrt{s}=10\,TeV}}{\sigma_{\sqrt{s}=14\,TeV}}$	$\frac{\sigma_{\sqrt{s}=6\,TeV}}{\sigma_{\sqrt{s}=14\,TeV}}$
$t\bar{t}$	0.450	0.113
Wt	0.450	0.113
WW	0.650	0.320
WZ	0.650	0.320
ZZ	0.650	0.320
$Z \to \ell\ell$	0.681	0.371
$W \to \ell\nu$	0.681	0.371
$gg \to H$	0.540	0.190

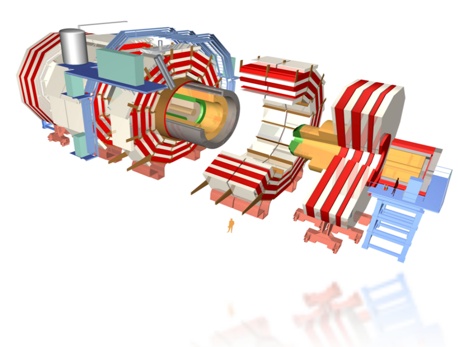
=> **Efficiency and Acceptance:**

Higgs (or ZZ system) becomes relatively "heavier", i.e. decay products become relatively more central for smaller LHC energies

the corresponding second order correction is larger than 1 (scaling factor)

Example : HWW + HZZ combined

∫L for 5σ	14 TeV	10 TeV
m_H =200 GeV	0.6 fb-1	1.3 fb-1



PYTHIA for HZZ (LO) and MCFM for HWW cross section calculations, standard CMS MC Samples used for estimate

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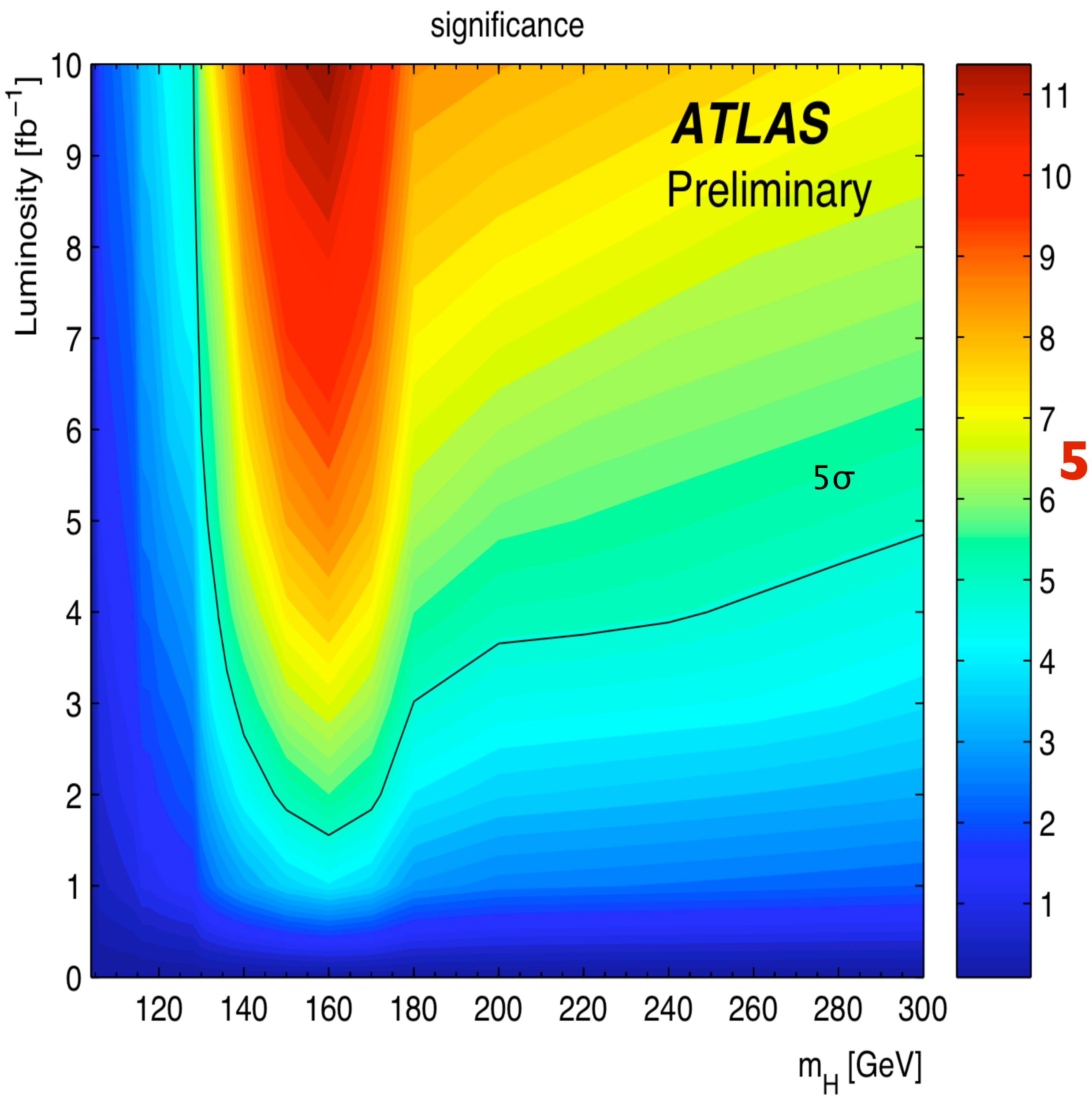
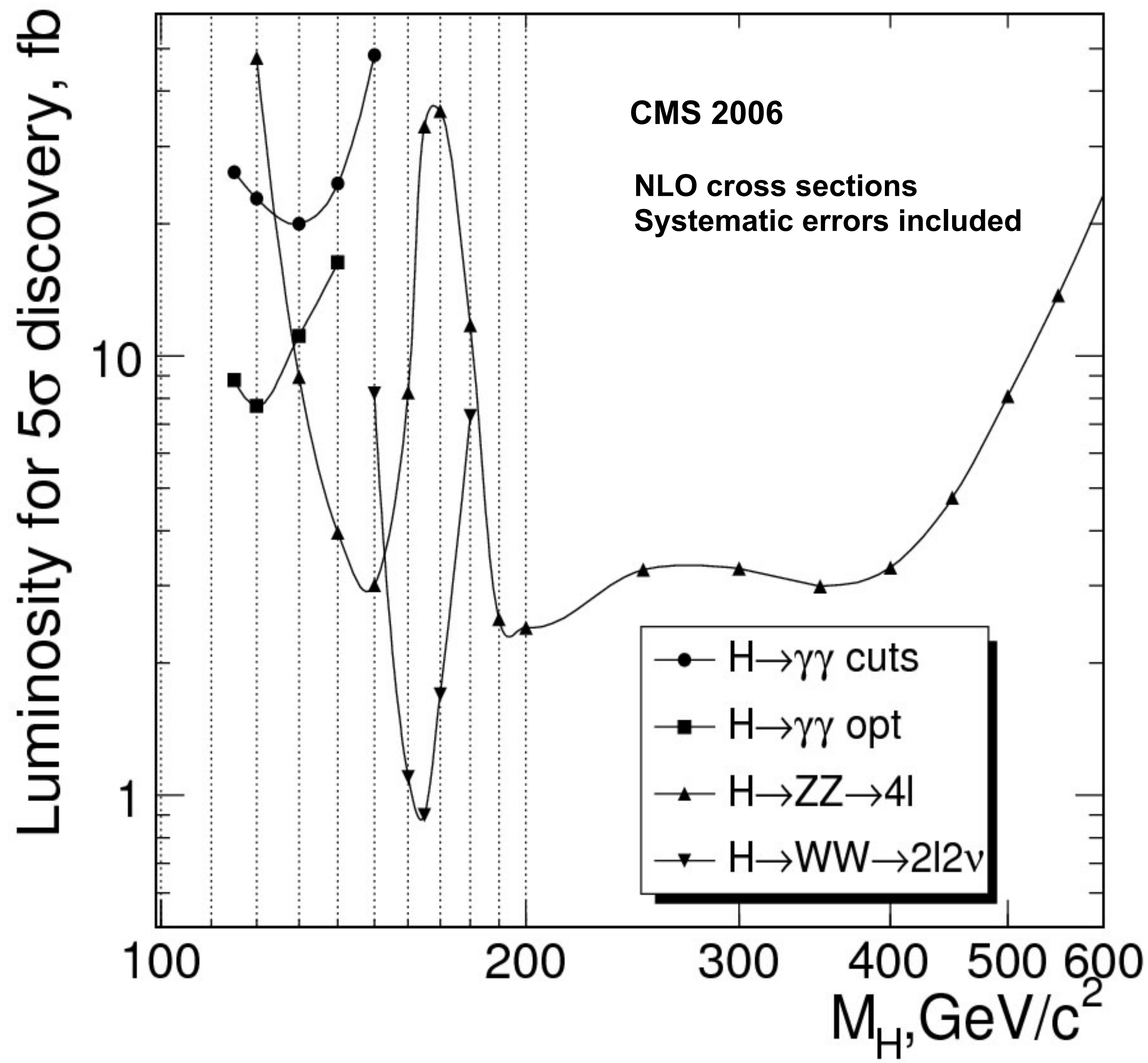
Conclusion



5 fb^{-1}



=> With 10 fb^{-1} (*normally* considered as one LHC year at low luminosity),
5σ discovery for $m_H \in$ [~120, ~500] GeV
=> With 1-2 fb^{-1} we can first say something the H-> WW channel

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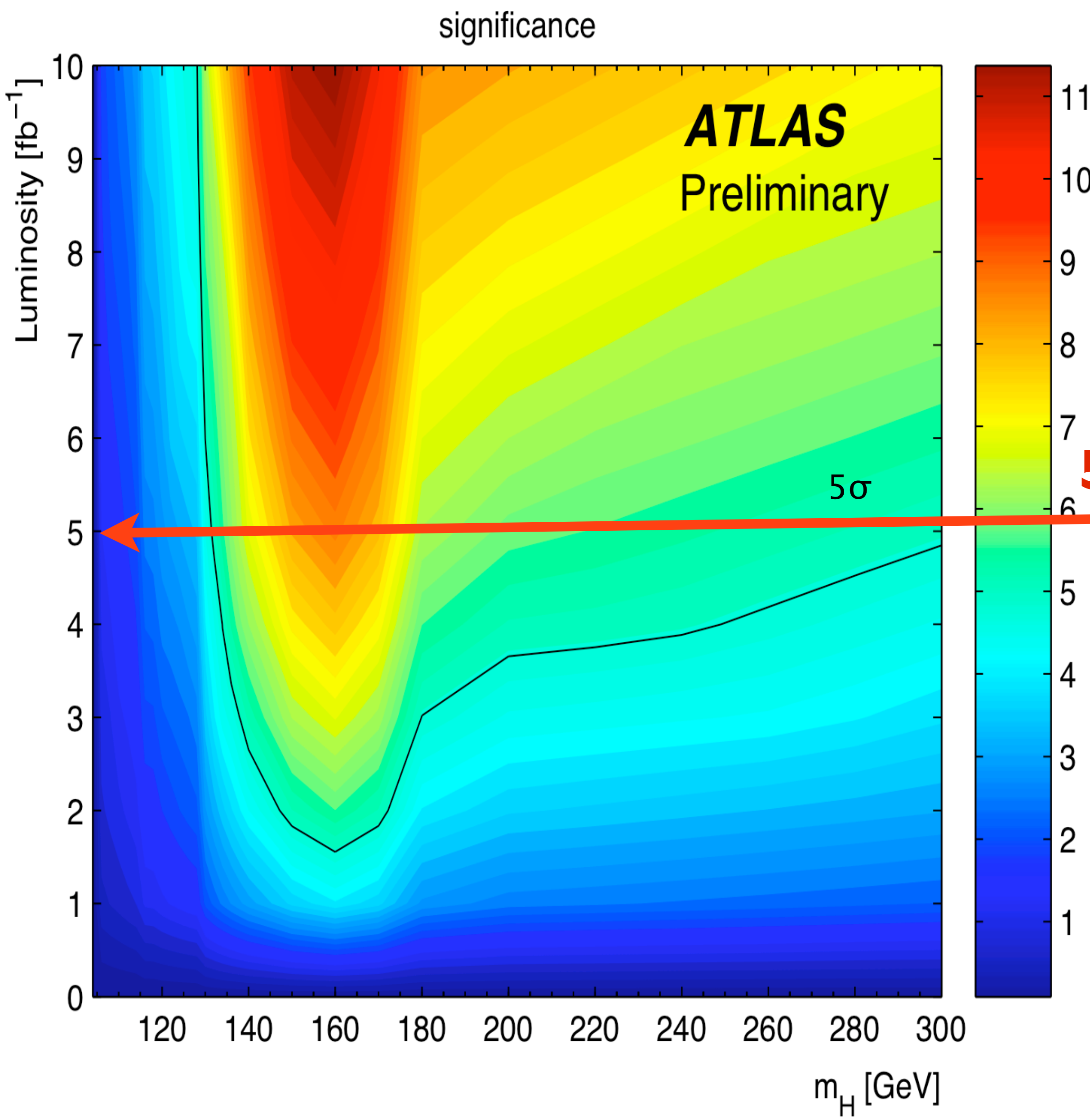
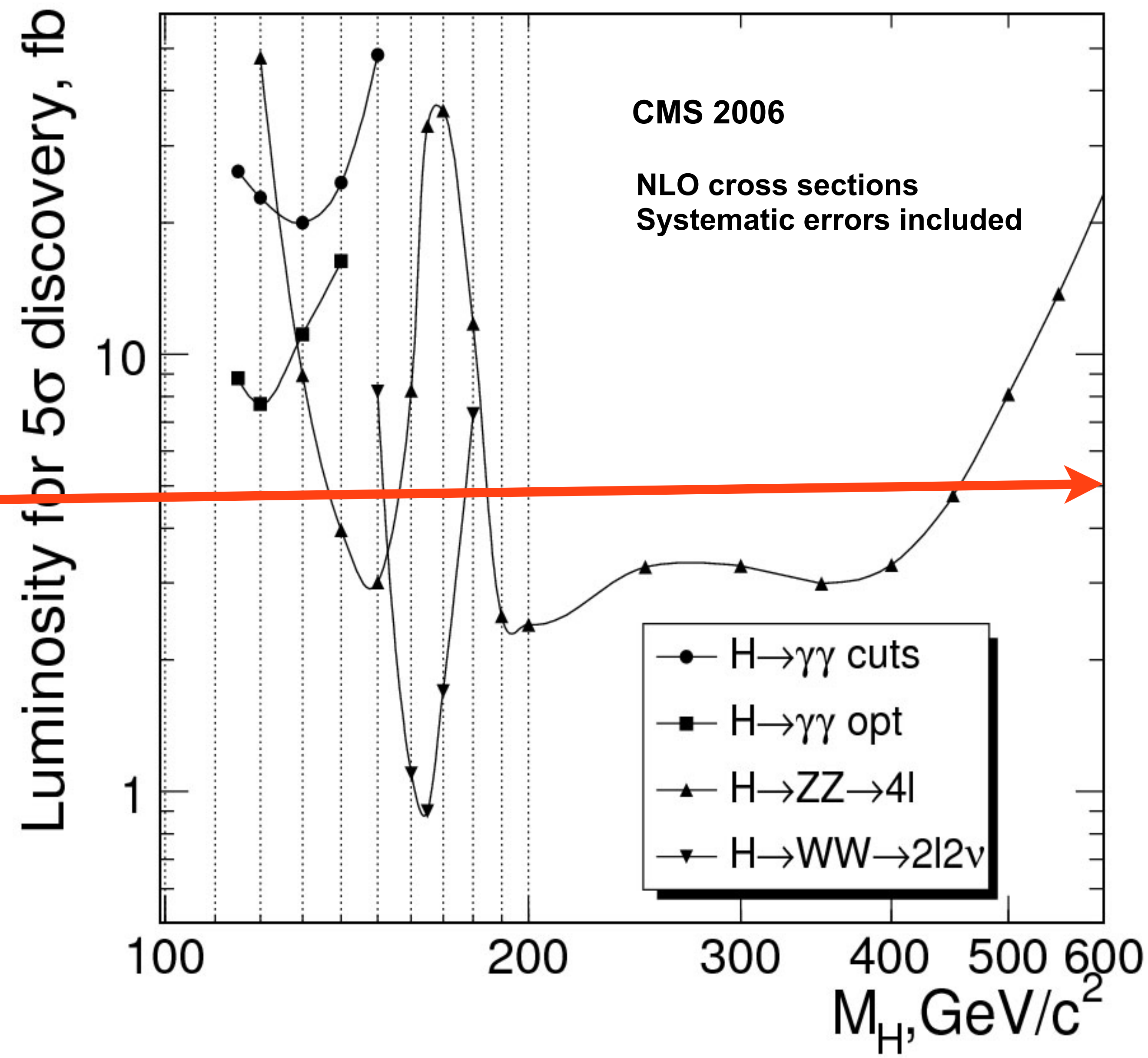
Conclusion





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Higgs@LHC ...

... at least one seen in ATLAS and CMS !

Backup

VBF Higgs ->ττ

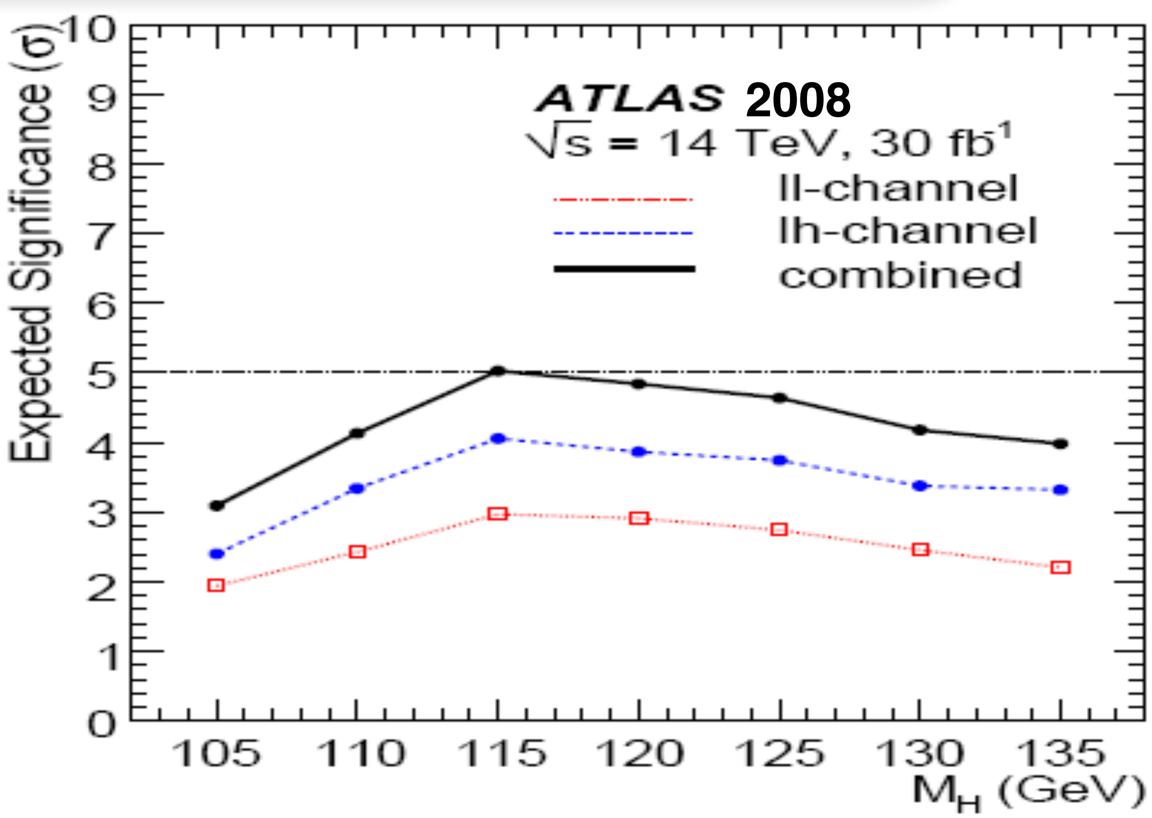
- Very important channel for **low** Higgs mass
- **Three channels:** lepton-lepton, lepton-hadron, hadron-hadron

Backgrounds:

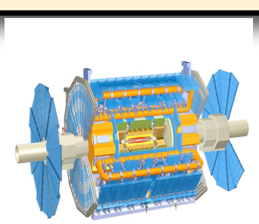
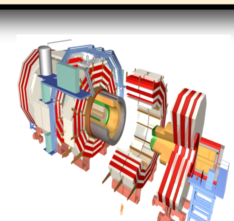
- Zjj, tt,Z/γ*->ττ

Main experimental tools for background suppression:

- efficient tau identification
- control of Z → ττ background from data !
- b-tagging (against tt)
- Central Jet Veto used to reject QCD background
- good ET miss resolution



=> Combination of lep-lep and lep-had should allow ~ 5σ measurement with 30 fb^{-1} in the range $115<m_H<120$ GeV/c^2

=>  and  agree