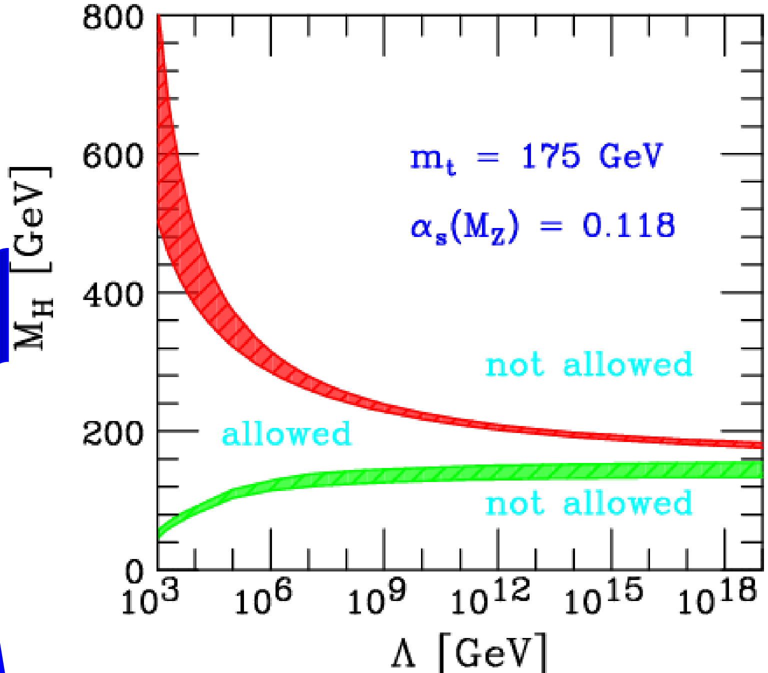
SM Higgs: prospects end 2011 and ~~beyond~~… before!!!

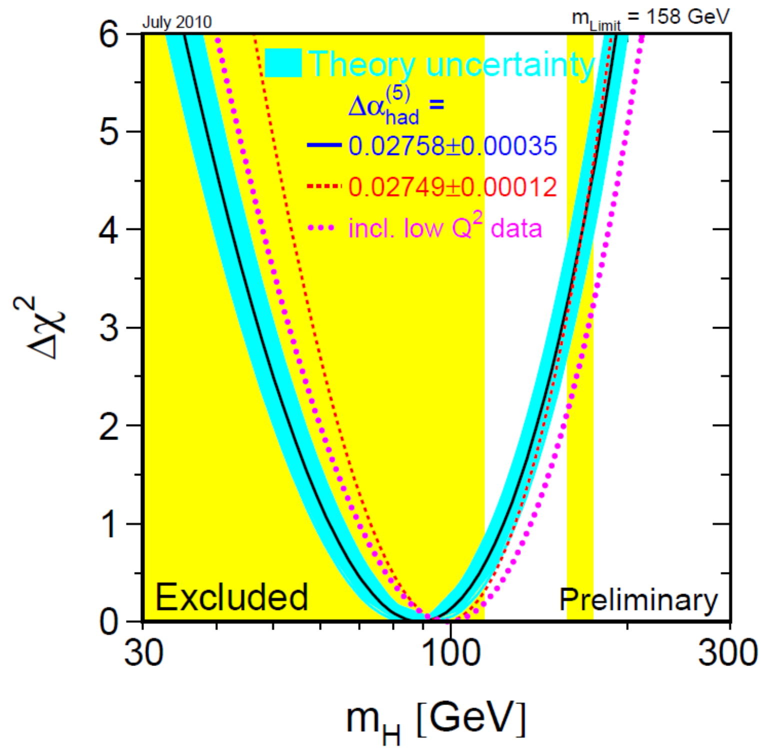
Javier Fernandez
University of Oviedo

On behalf of the ATLAS and CMS Collaborations

30th July 2010
Higgs Hunting Workshop, Orsay

SM Higgs boson: a must in LHC!!





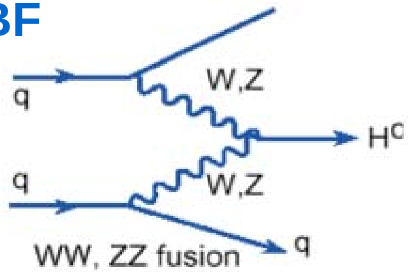
- **theoretical limits:** finite and positive Higgs couplings
- **experimental limits:**
  - direct (from **LEP+Tevatron**): m_H > 114.4 AND NOT[158<m_H<175] GeV/c^2
  - indirect (from **EW data**): m_H < 158 GeV/c^2 @ 95% CL

    m_H < 185 GeV/c^2 **incl. LEP-2 direct results**

Experimental data to date favours a light Higgs

SM Higgs production at the LHC

VBF



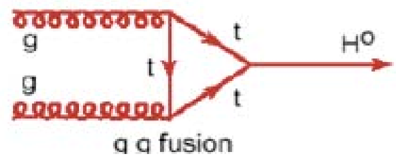
Very distinct final state

<10% unc. NLO

K~1.1

Gluon-Gluon Fusion

K ~2.0

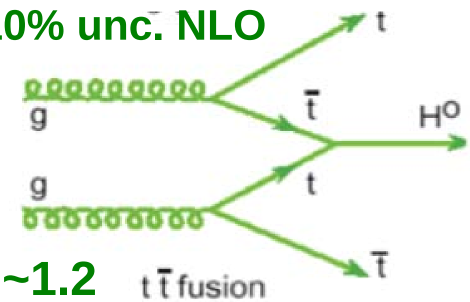


~10% unc. NNLO

NNLO/NLO ~20-30% depending on m_H

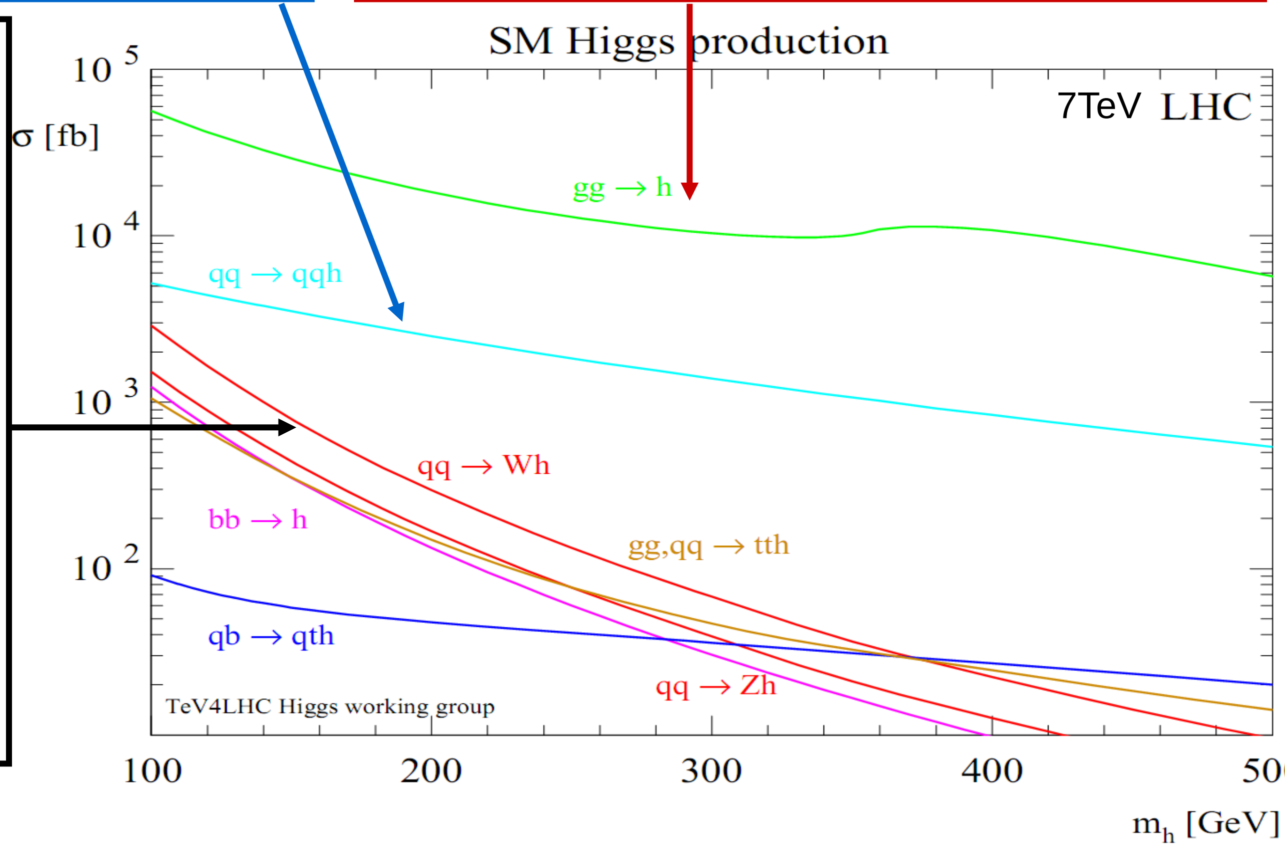
Associated production
"Easy" triggering

~10% unc. NLO



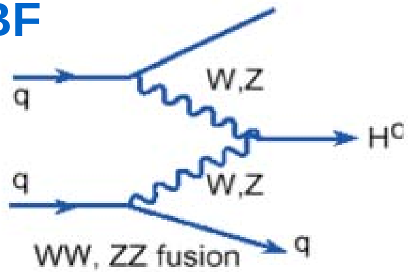
K ~1.2

<5% unc. NNLO K~1.4



SM Higgs production at the LHC

VBF



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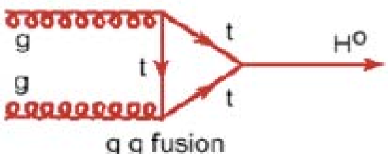

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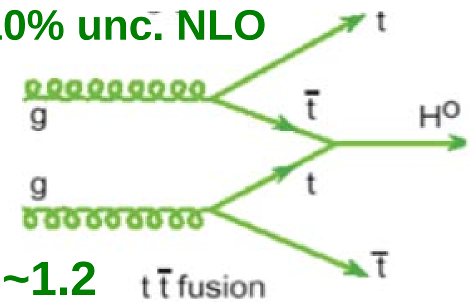

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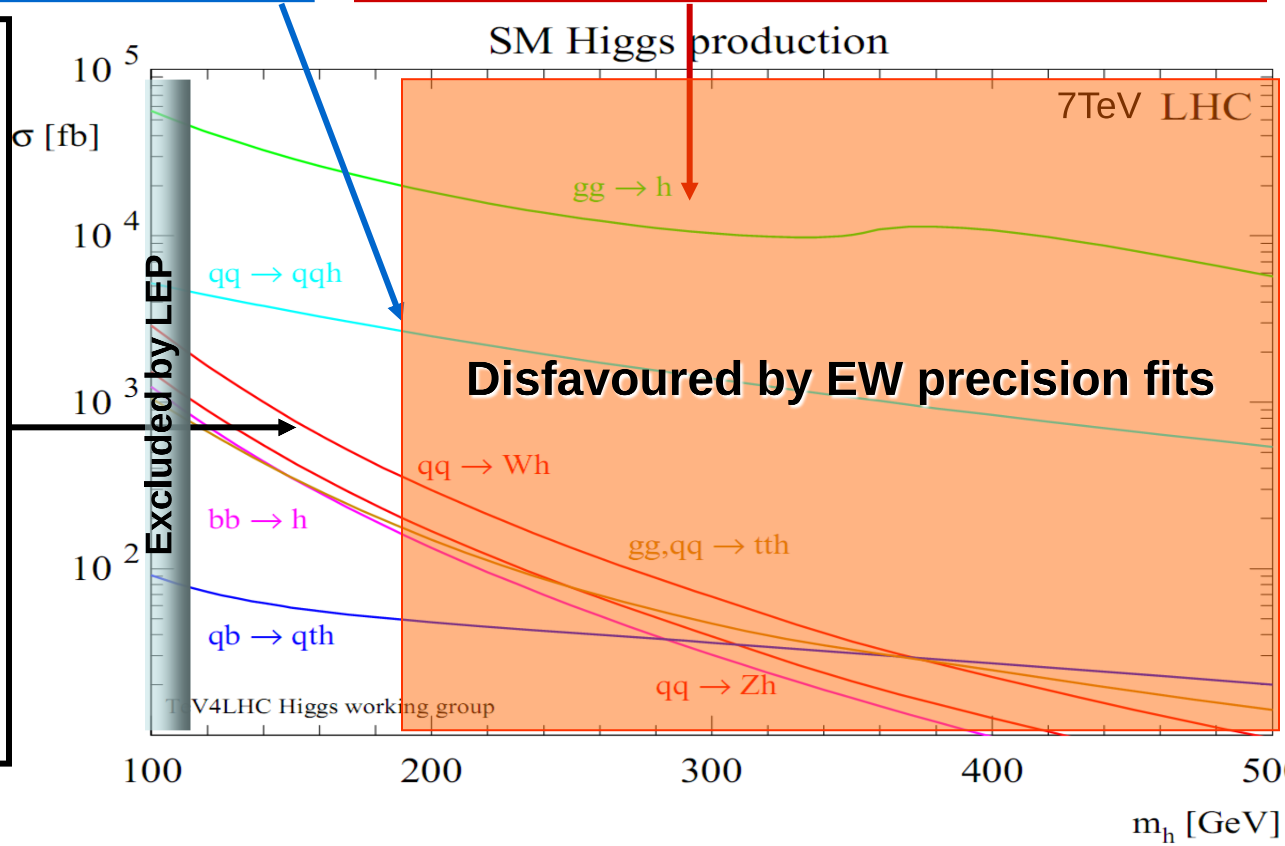

SM Higgs production at the LHC

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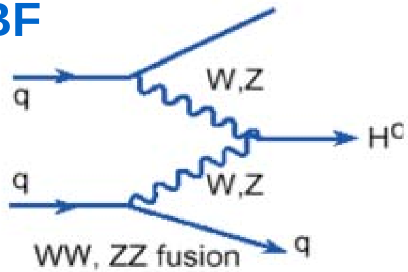

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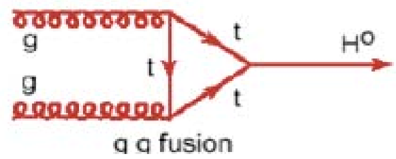

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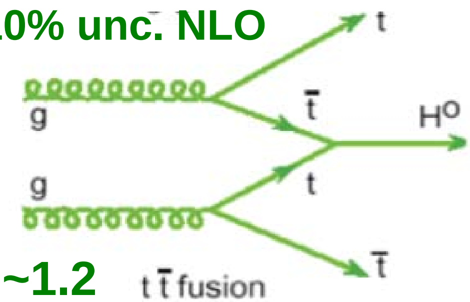

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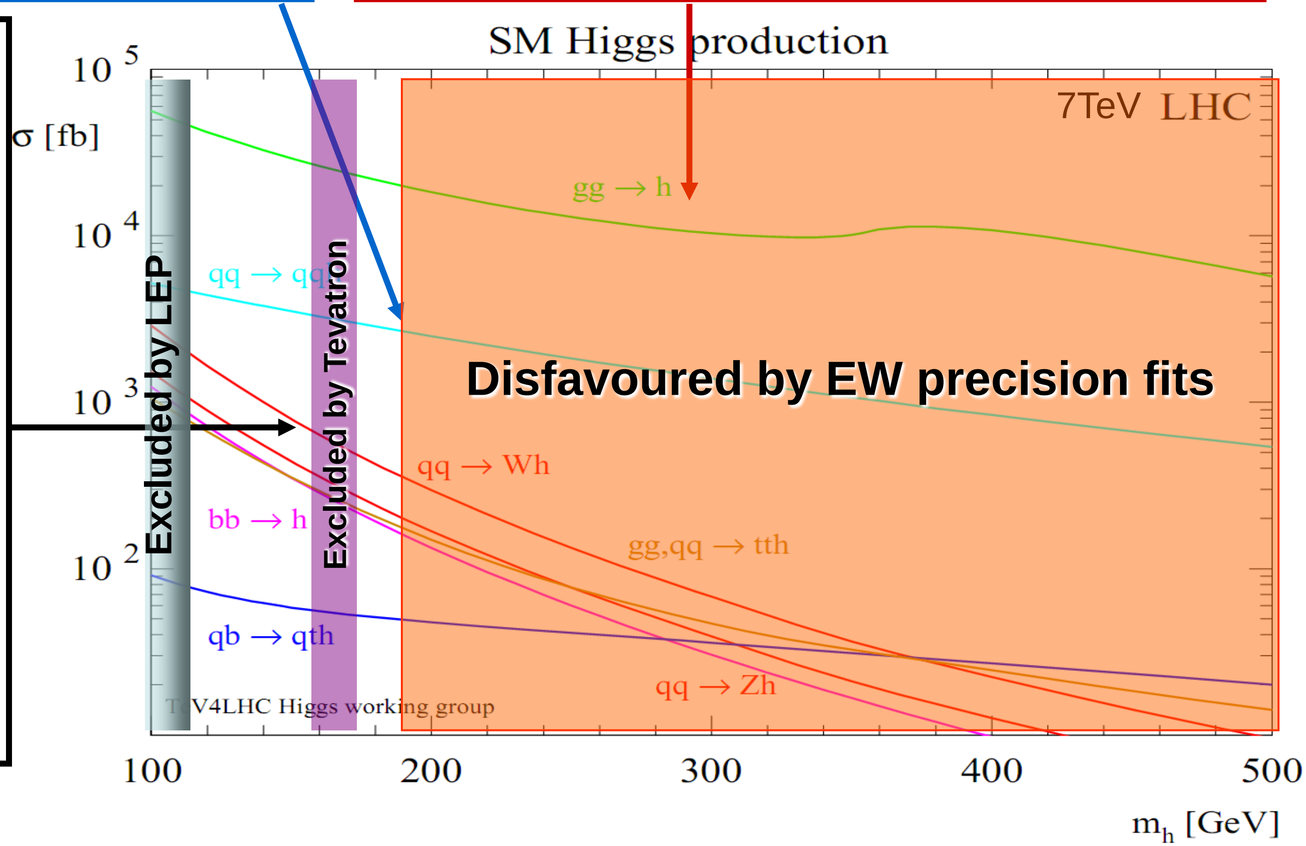
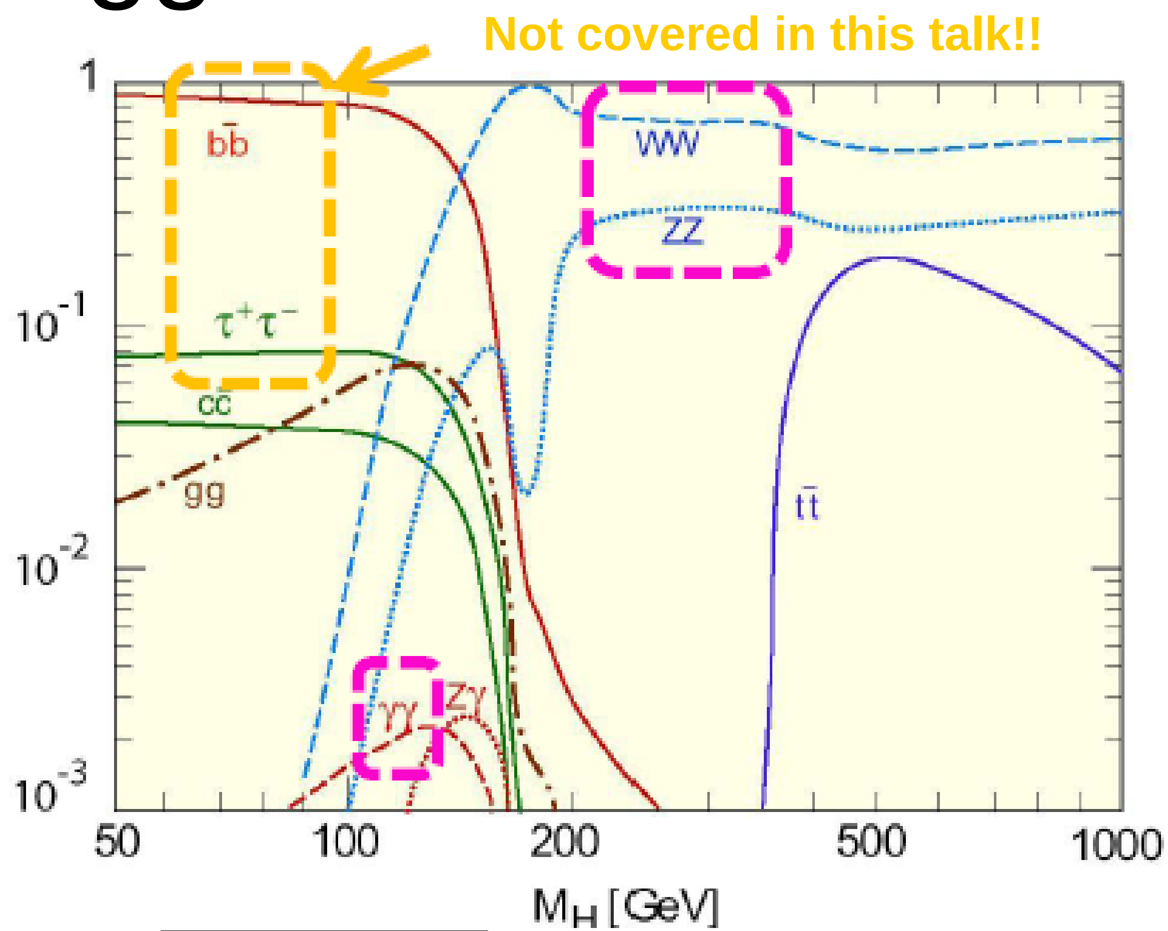


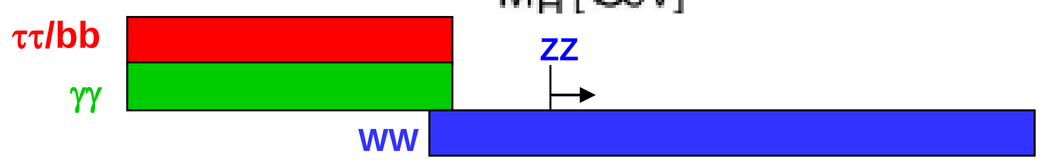
SM Higgs decays

They set the main search channels:

- **At low mass (M_H< $2M_Z$)**
  - **Dominant bb; huge QCD background**
  - **H→ττ accessible through VBF**
  - **H→WW(*) accessible through gluon-gluon fusion and VBF**
  - **H→γγ has a low BR (decays through top and W loops); but due to excellent γ/jet separation and γ resolution is still very significant**
  - **H →ZZ*→4l also accessible**

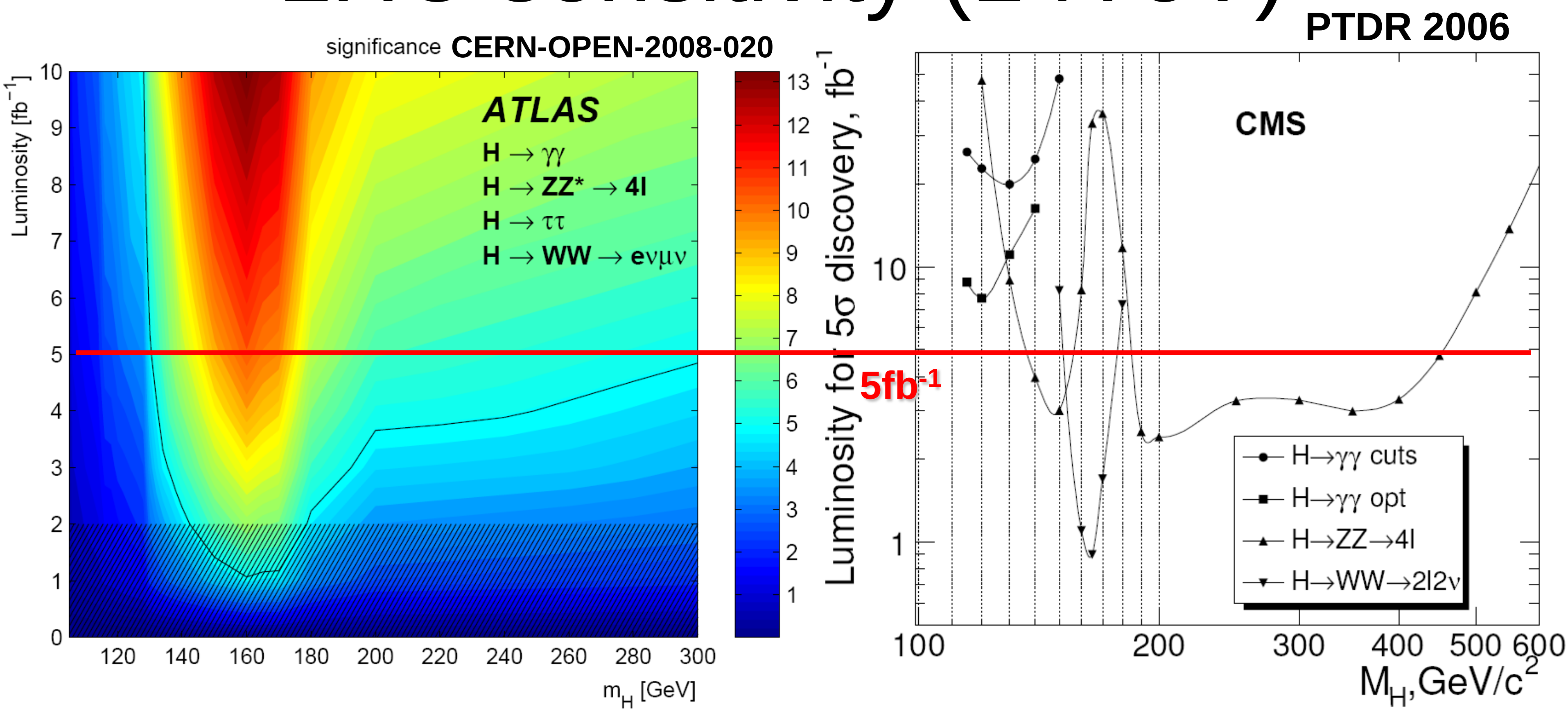


- **For higher masses**
  - **H→WW and H→ZZ→4l final-states**



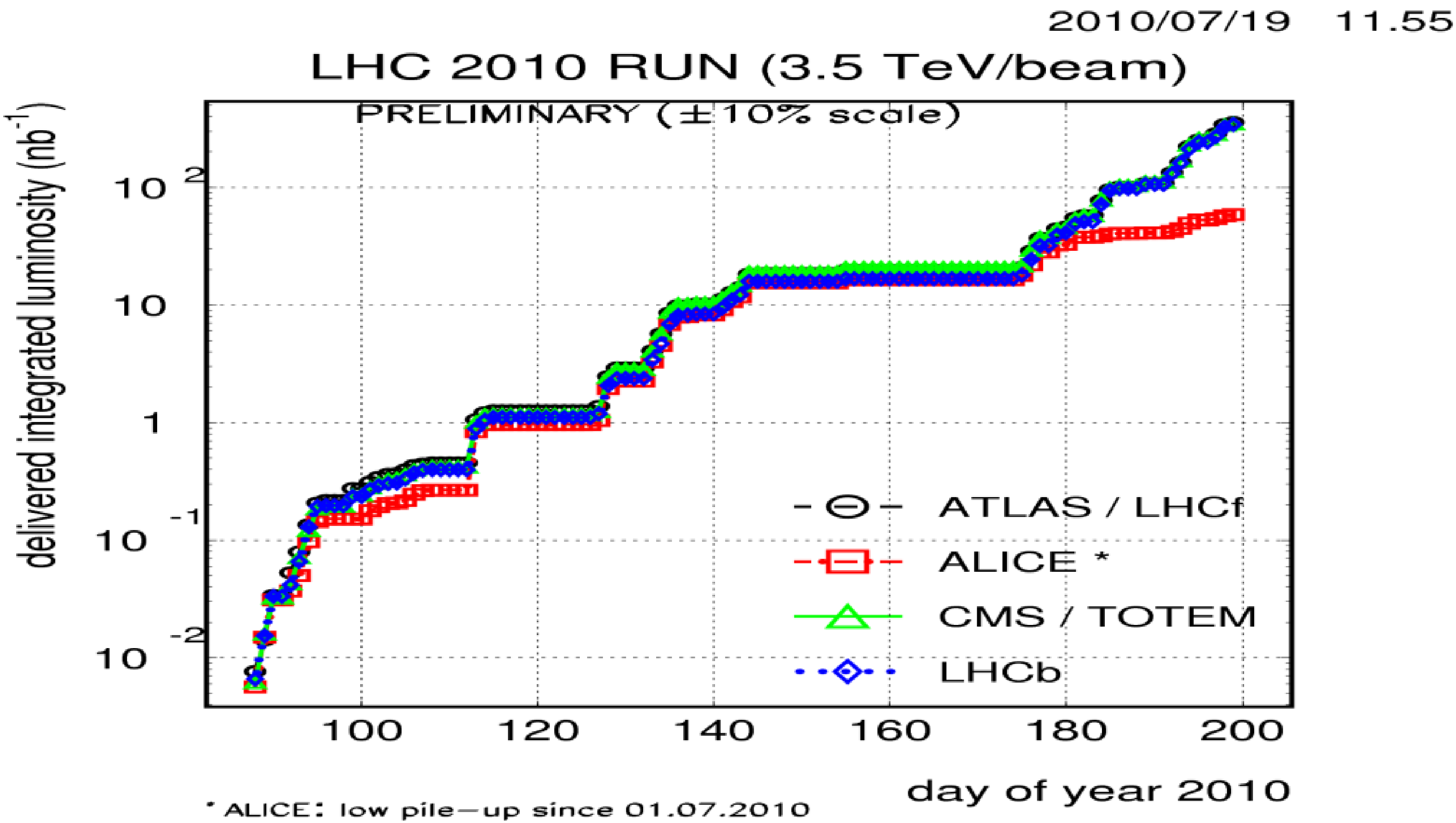
Decay branching ratios at NLO : Few % accuracy

LHC sensitivity (14TeV)



- ✓ **With 10 fb^{-1} (*normally* considered as one LHC year at low luminosity), 5σ discovery for m_H in [~115, ~500] GeV**
- ✓ **With 5 fb^{-1} 5σ discovery for m_H in [~130, ~450] GeV/c^2**
- ✓ **With 1-2 fb^{-1} H→ WW channel starts to play!!!**
- ✓ **Combining results from both experiments, around half of this luminosity**

What can LHC provide?



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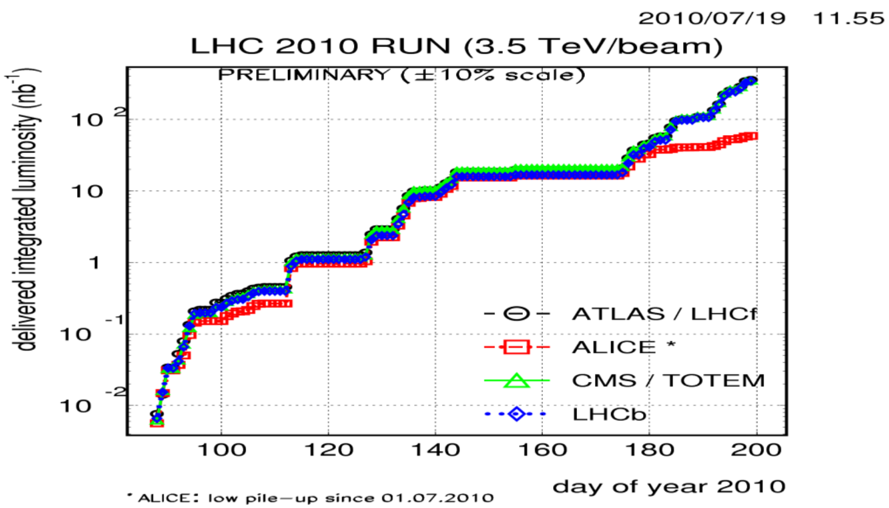

Summer 2010	End of 2010	Fall 2011
~1 pb^{-1}	~100 pb^{-1}	1 fb^{-1}

- QCD, b measurements
- W, Z cross sections
- Electroweak program
- Early ttbar observation
- Early searches, mainly Exotica

7 TeV Collisions

- + top physics program
- + broad search program: Mainly Exotica, SUSY

- + Higgs program

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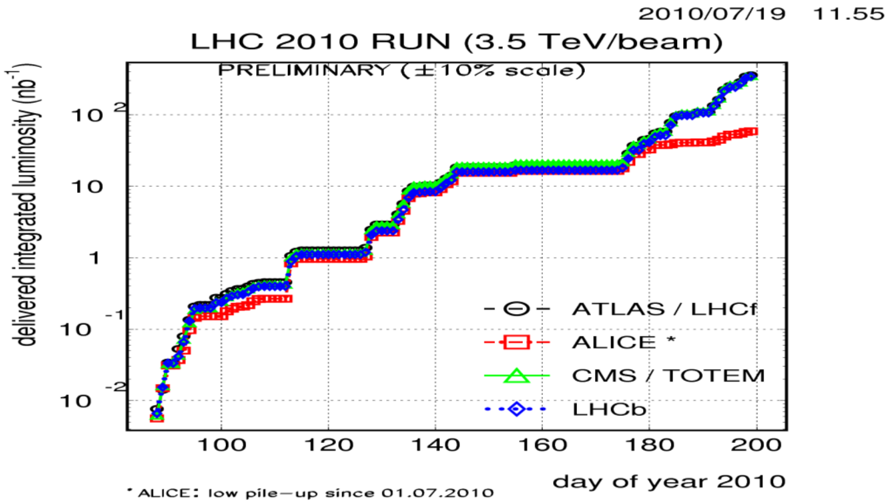

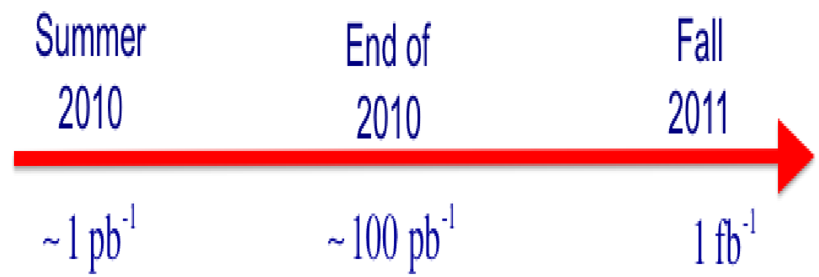

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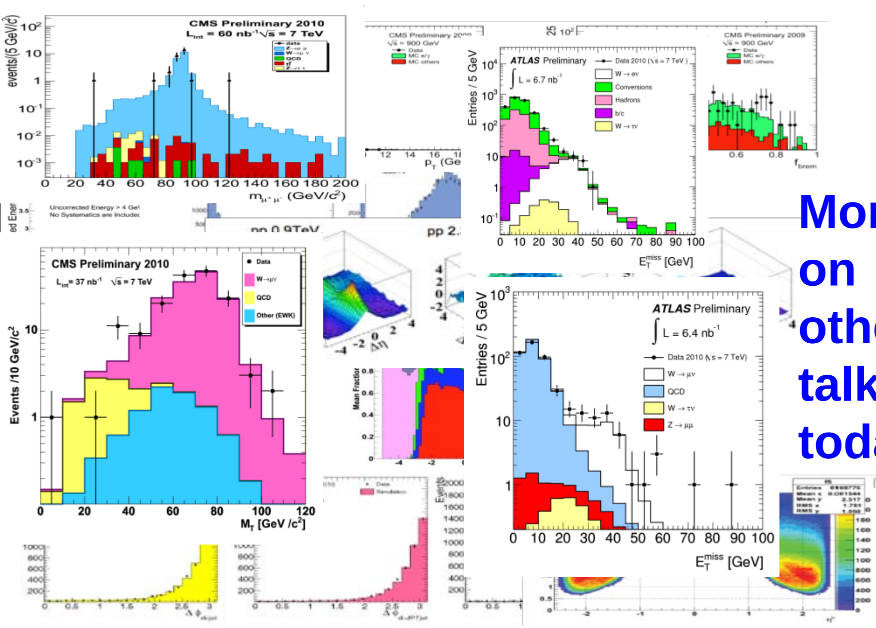
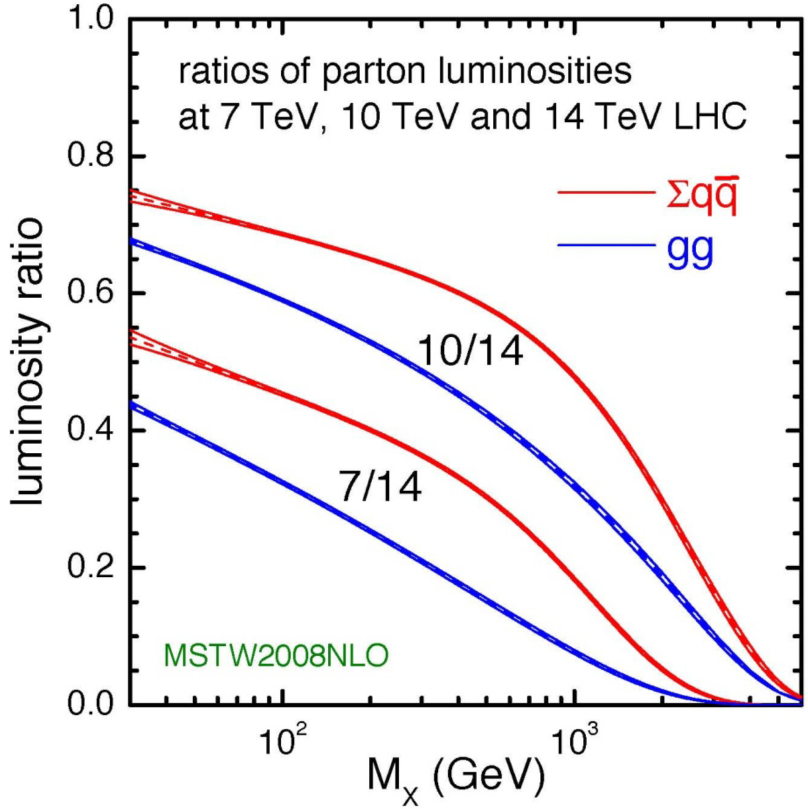
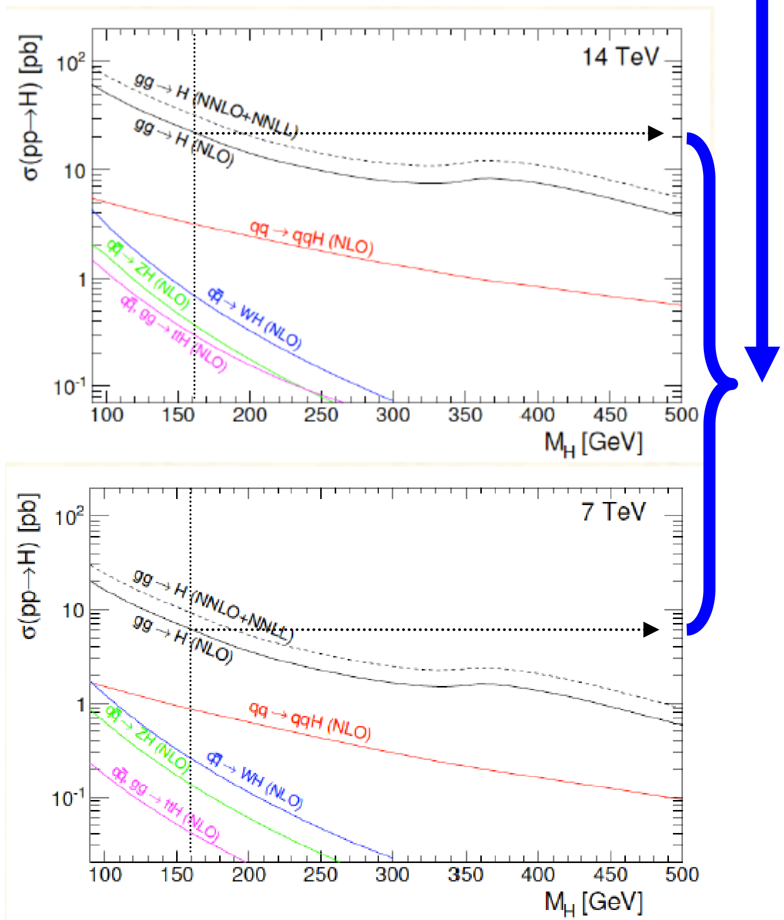


More on other talks today!

Impact of reduced LHC energy

Typically, σ(tt) at 7/14 is ~0.18, while for m_H~160 GeV/c^2 is ~0.28 for gg->H, and similar for VBF



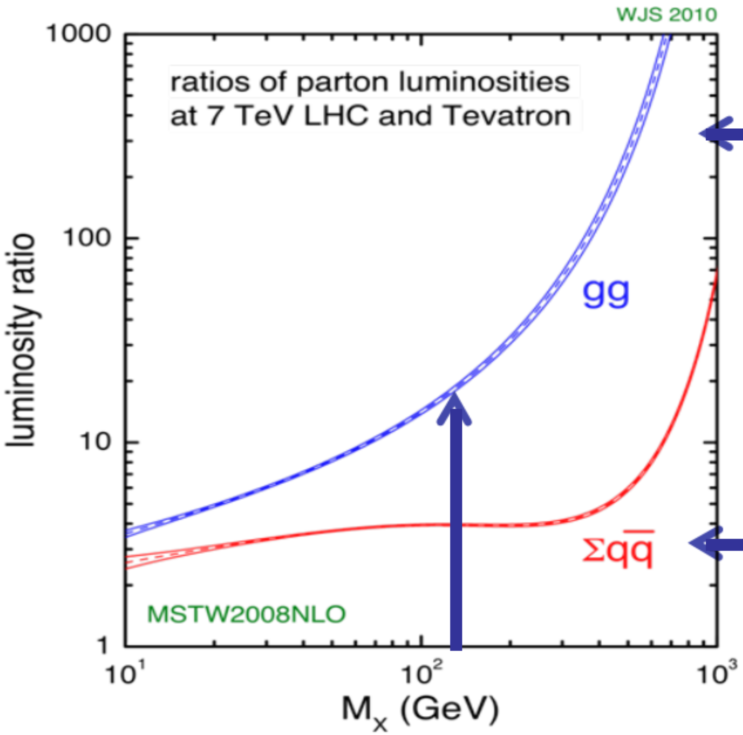


LHC vs. Tevatron

Higgs searches in **ATLAS** and **CMS** at the LHC will go in parallel with the Tevatron experiments **CDF** and **DØ**

Tevatron end 2011: 2 TeV, ~10 fb^{-1}/exp.
LHC end 2011: 7 TeV, ~1 fb^{-1}/exp.

LHC



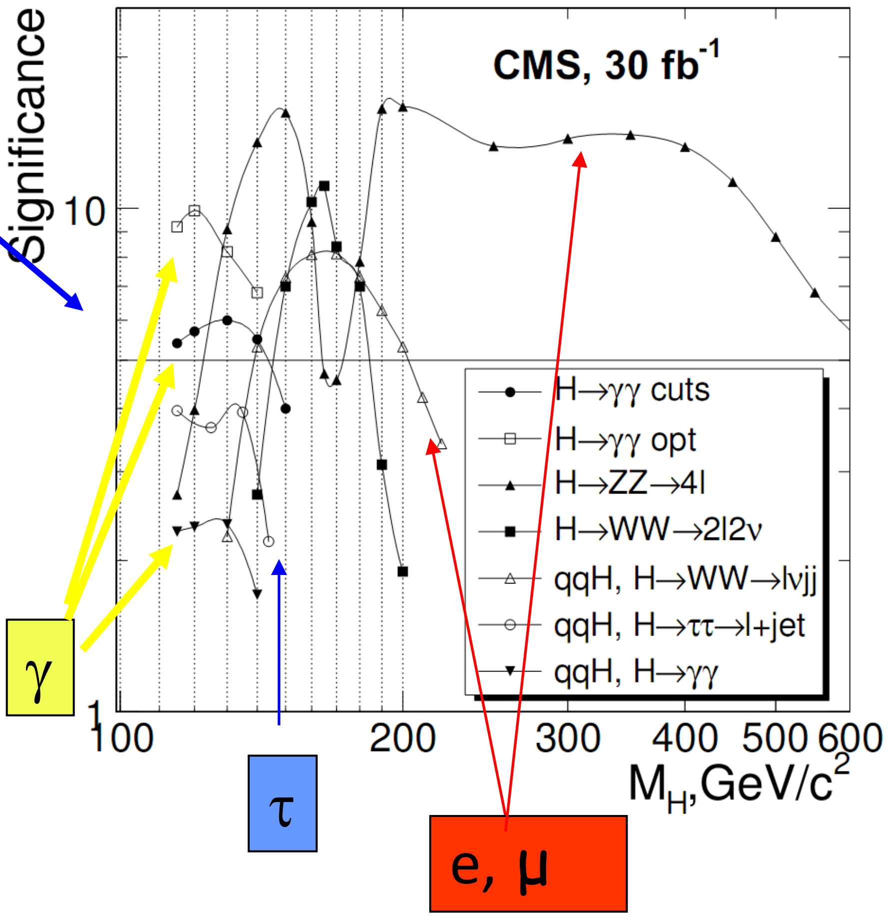
- **For M_X > 140 GeV, the gg luminosity is <u>15 times higher</u> than at the Tevatron while the bkgds. for H->WW/ZZ are produced mainly through qqbar**

- **For M_X < 140 GeV, the S/B for LHC Higgs-strahlung searches is not as favorable: backgrounds come from ttbar, W/Z+bbar (gg-fusion processes); Need to use the $\gamma\gamma$ mode, where the QCD backgrounds are large, or try the complicated VBF to $\tau\tau$ or boosted WH.**

Prospective SM Higgs Searches ATLAS/CMS

Both experiments work in a wide range of Higgs decay channels

Public results available at different √s: CMS ATLAS (links to public results)



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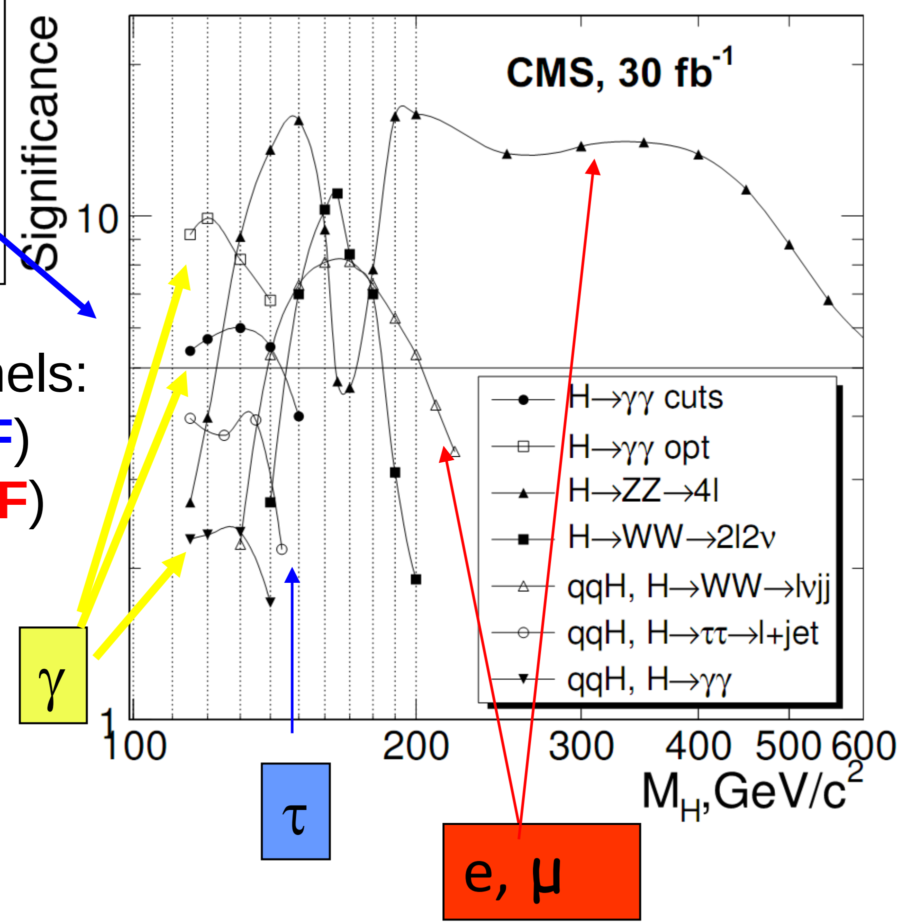
7 TeV Projections for the main channels:
ATLAS: PHYS-PUB-2010-009 (**NLO GGF**)
CMS : CMS-NOTE-2010/008 (**NNLO GGF**)



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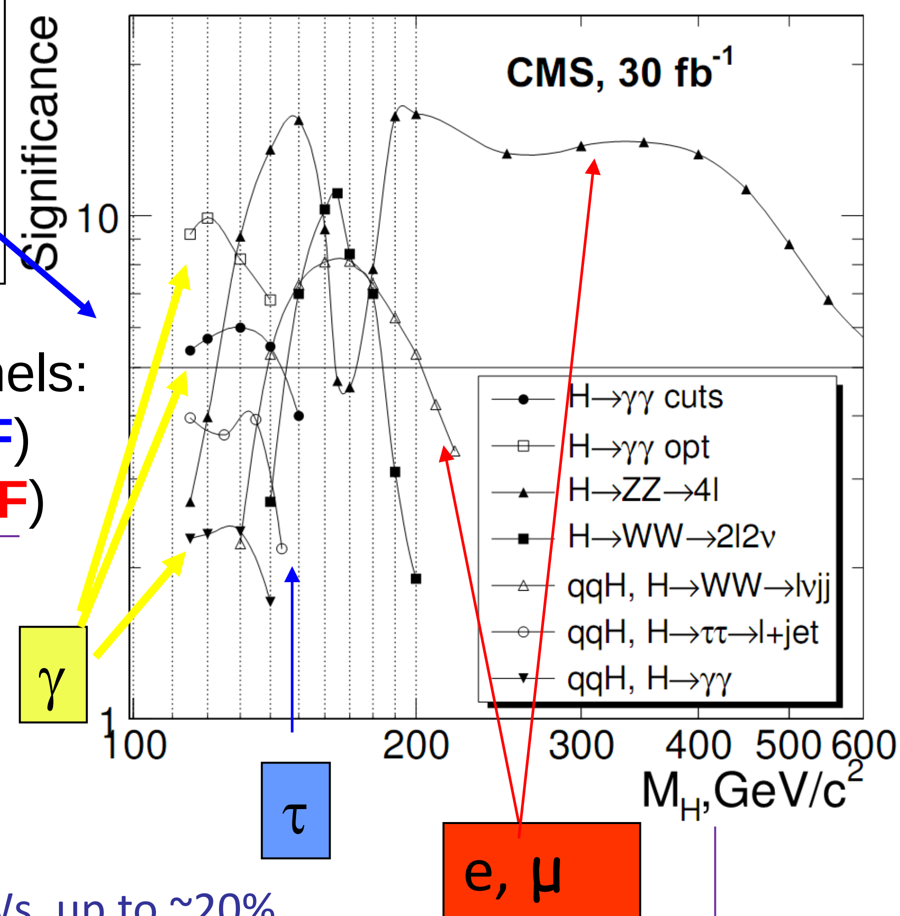
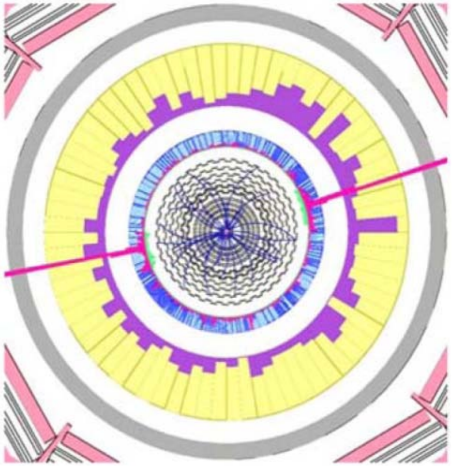


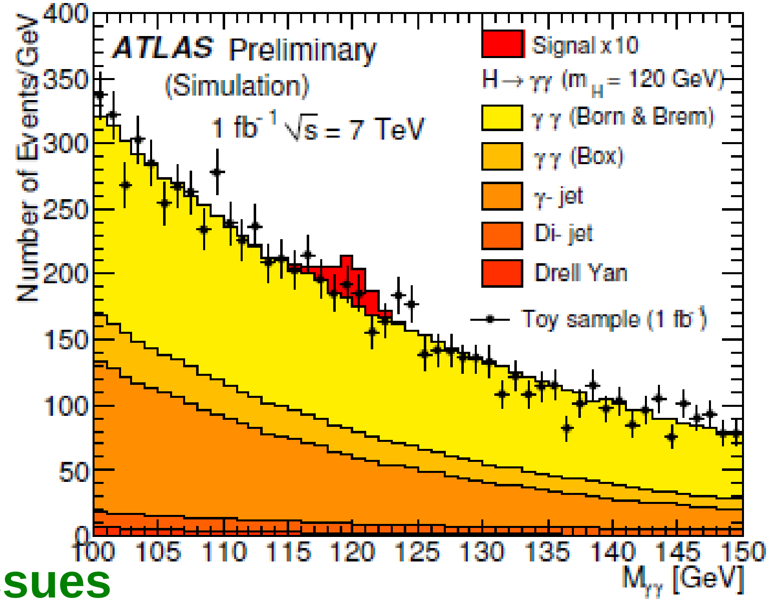
These are **NOT** new analyses done with 7 TeV MC and new detector simulation/reco software.

- From public studies at 10/**14 TeV** (**∫L ~1-30 fb^{-1}**)
- Re-scale signal and background event counts by the ratio of **7 TeV / 14(10) TeV** cross sections/pdf
- Project for **∫L 1 = fb^{-1}**
- No corrections for higher acceptance at smaller √s, up to ~20%
- No corrections for future improvements in reconstruction (efficiencies, resolution)
- Systematic uncertainties also rescaled conservatively, and possible correlations taken into account. Uniform statistical analysis: derive exclusions with modified frequentist (CLs) and significance with profile likelihood

$H \rightarrow \gamma\gamma$



- **Very clear signature**
- **Low-mass region (110-140 GeV/c^2)**
- **High lumi required**



Background assessed from data sidebands:

$\gamma\gamma$, $\gamma\gamma$+jets (irreducible) **γ+jets, jets, DY**

Experimental issues

- **Electromagnetic calorimeter calibration**
- **Requires excellent γ/jet separation**
- **Good mass resolution needed (~1.5 GeV/c^2)**
- **Vertex reconstruction**

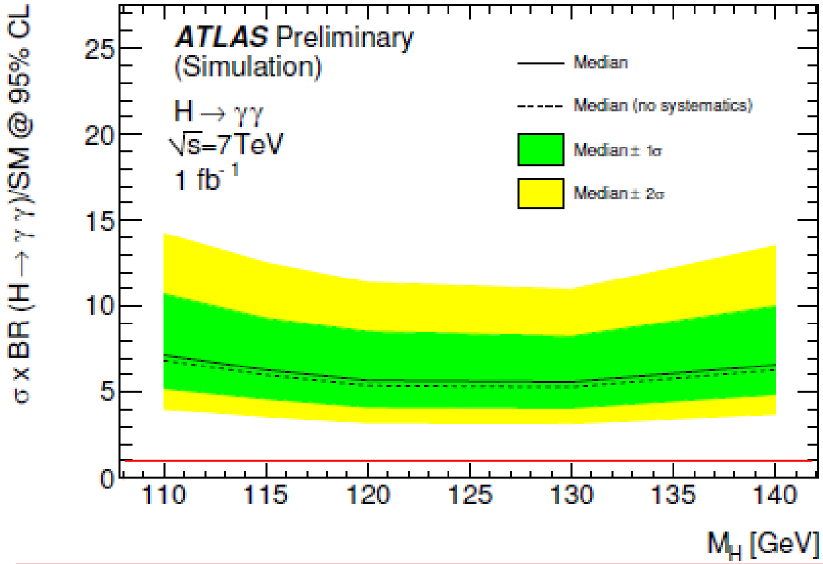
CMS

- Cut-based or MVA
- Event-by-event kinematical Likelihood Ratio

ATLAS

- Search for **$H \rightarrow \gamma\gamma$** and **$H \rightarrow \gamma\gamma$ + jets**
- **Unbinned maximum-likelihood fit**

Results H → γγ



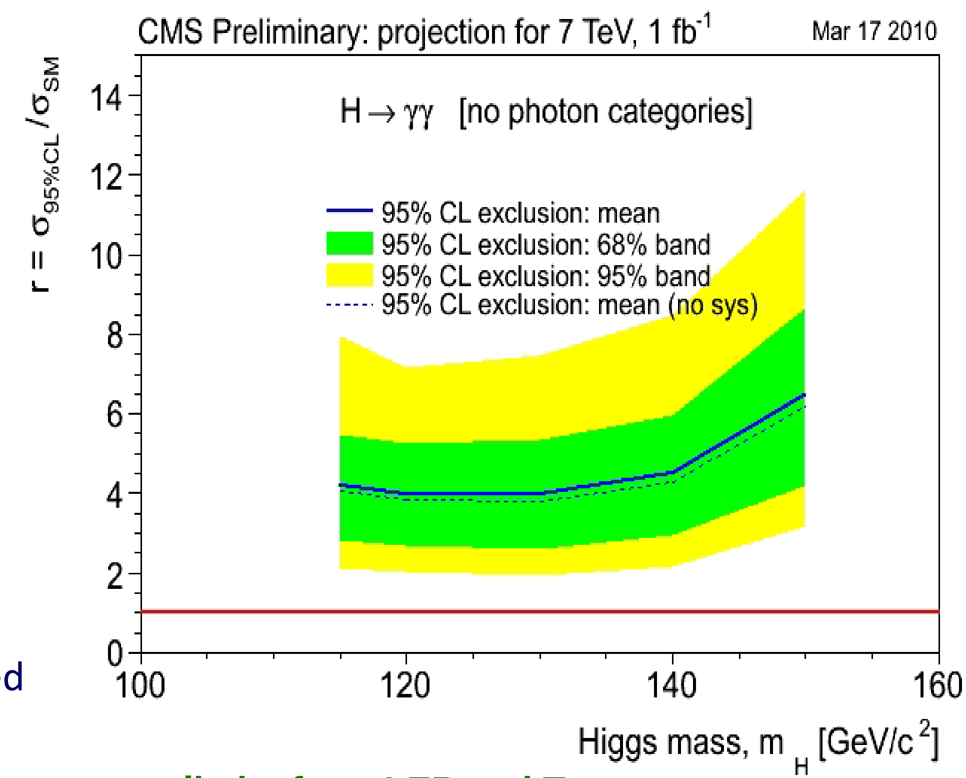
ATLAS (Reference **CERN-OPEN-2008-020**@14 TeV)
- Profile likelihood method is used
- Expected exclusion is set using the signal-plus-background probability only

The SM Higgs cannot be excluded anywhere in the mass range

CMS (Reference PTDR @14 TeV)
- Counting in a mass window
- No photon categories.

No exclusion either.

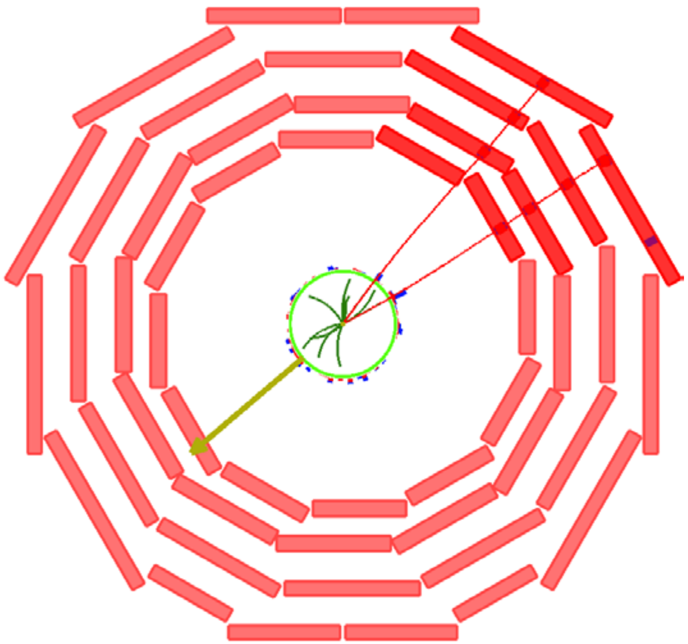
A fermio-phobic Higgs* with:
m_h<110 GeV would be excluded, as for this mass range, the yield $\sigma(pp\rightarrow h_{fph})xBR(h_{fph}\rightarrow\gamma\gamma)$ is >4



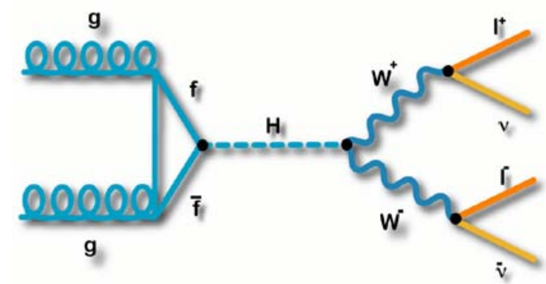
*The limit on the anomalous production is expected to be about 4 times $\sigma(pp\rightarrow H_{SM})xBR(H_{SM}\rightarrow\gamma\gamma)$.

The projected exclusion reach is comparable to the current limits from LEP and Tevatron

$H \rightarrow WW^* \rightarrow 2l2\nu$



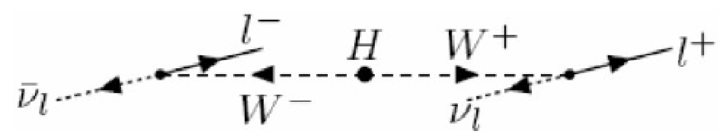
- **Discovery channel** for a SM Higgs boson in a wide mass range



- Branching ratio close to 1 in the region:

$$2m_W < m_H < 2m_Z$$

- Clear **experimental signature**:

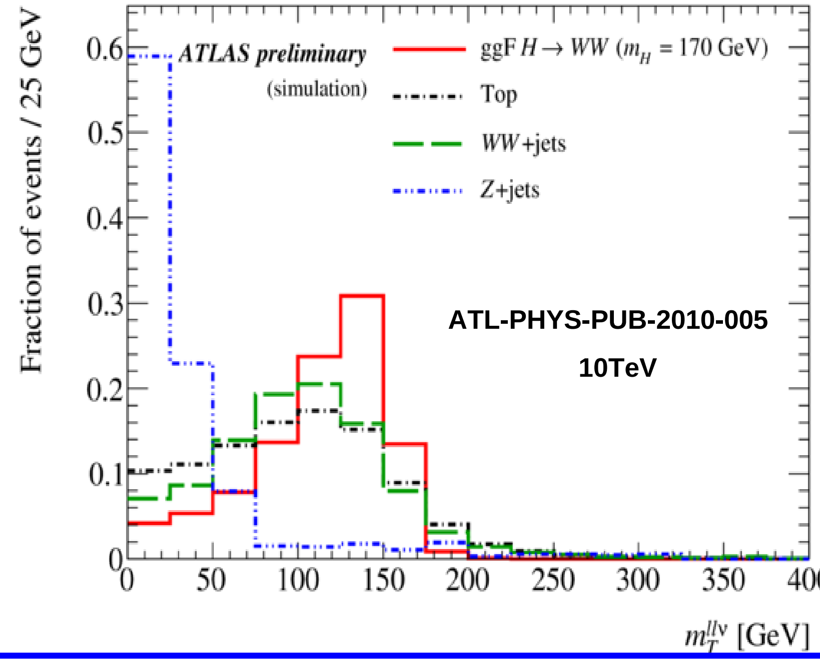


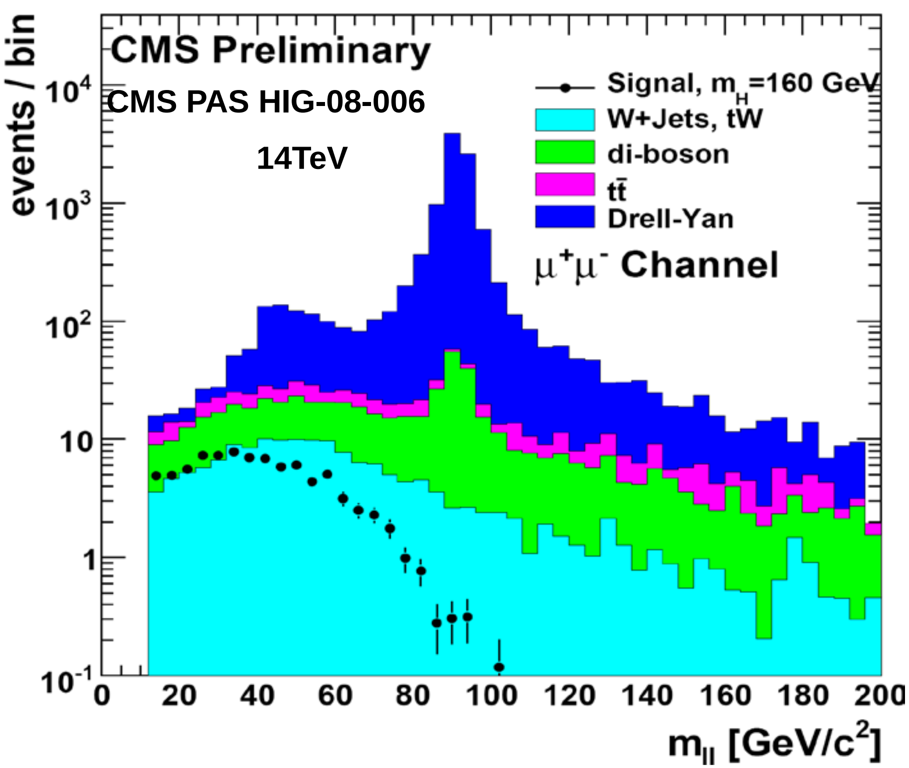
  - 2 high PT leptons with opposite charge and a small transverse opening angle
  - Missing ET
  - No jets (GGF) or two forward jets with rapidity gap (VBF)

Backgrounds:
Real or fake multi-lepton final states + missing ET:
'irreducible' **WW (WZ, ZZ), ttbar (tW), DY, W+jets…**

H → WW* → 2l2ν

- **μμ, eμ, ee final states**
- **No mass peak, syst. very important**
- Excelent **knowledge of backgrounds** mandatory: control regions & data-driven methods



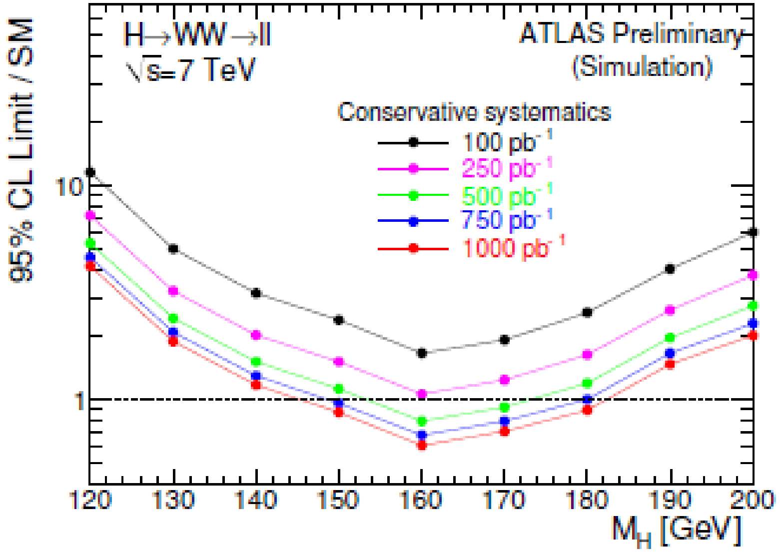


ATLAS
- Three event selections:

H+0 j;H+1 j and H+2 j analyses
- Use of the transverse mass

CMS
- *H+0j* (+ independent VBF analysis)
- Sequential cut-based analysis: 3 final states
- Multivariate analysis: all together

Results $H \to WW^* \to 2l2\nu$



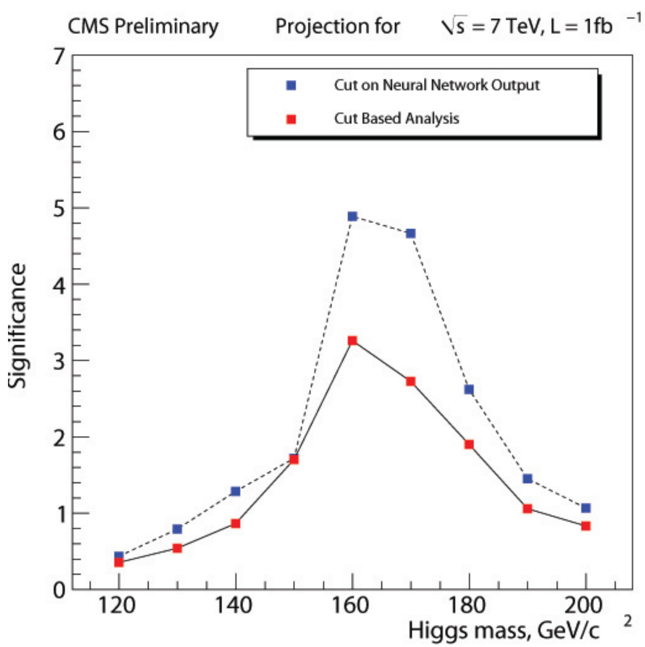
ATLAS (Ref. ATL-PHYS-PUB-2010-005 @10TeV)

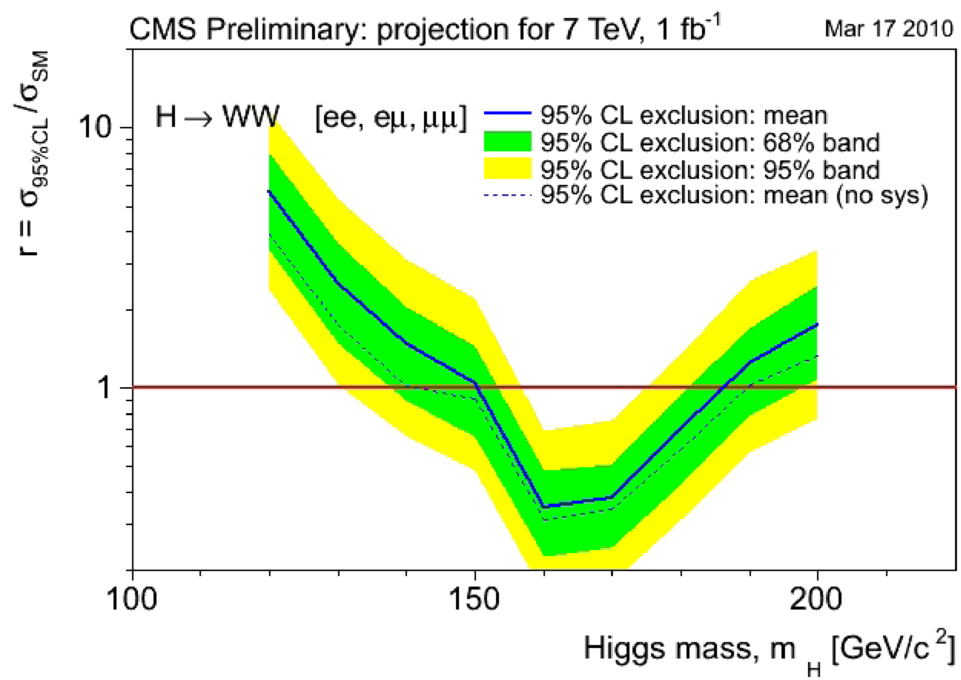
- A minimum of $\int Ldt$ = **250pb^{-1}** is required to be sensitive to the SM Higgs boson
- Exclusion 95%CL: **$145<m_H<180$ GeV/c^2**

CMS (Reference: CMS PAS HIG-08/006 @14TeV)

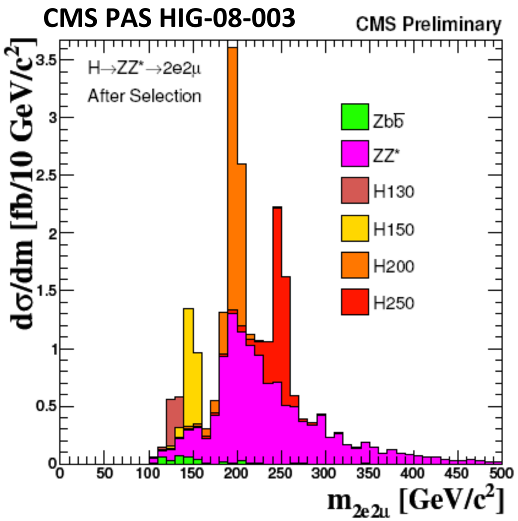
- Counting above a MVA-output cut
- Exclusion 95%CL: **$150<m_H<185$ GeV/c^2**

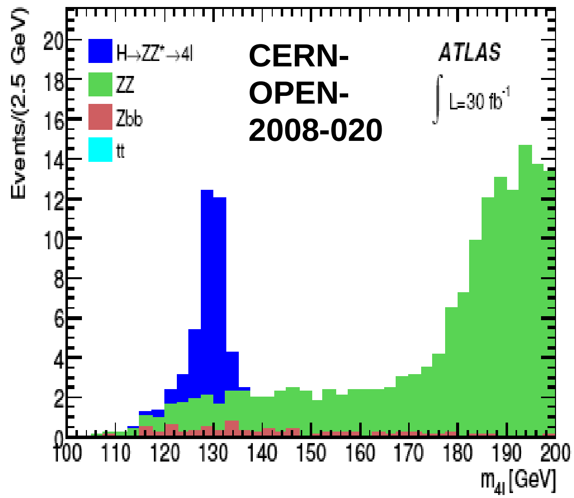
Discovery sensitivity (~5σ): **$160<m_H<170$GeV/c^2**





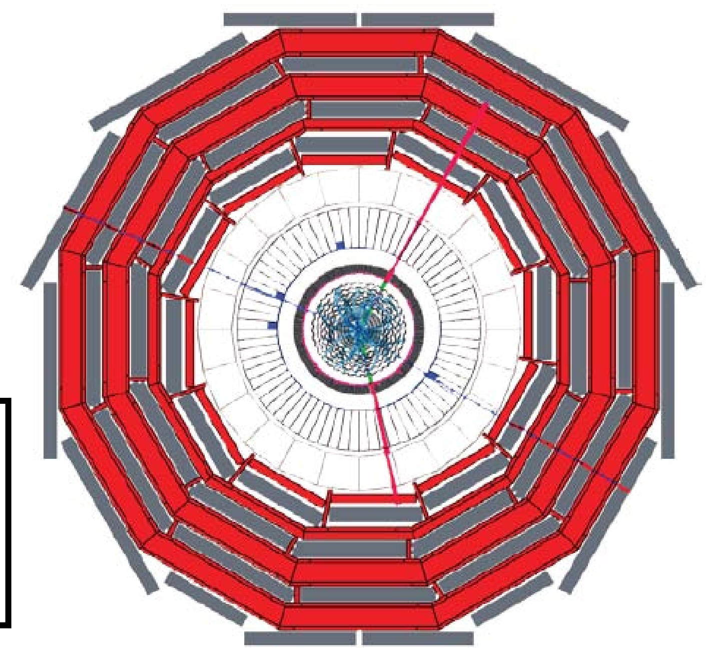
H → ZZ*→ 4l





- **'Golden' Higgs decay**: experimentally cleanest signature for discovery.
- **Narrow 4-lepton invariant mass peak** on top of a smooth bck.
- Wide mass range analysis

- 2 pairs of same flavour, opposite-sign leptons (**4e, 4μ, 2e2μ**)
- **Higgs mass reconstruction**
- Lepton isolation & impact parameter cuts
- Background estimation by fit on sidebands



Backgrounds:

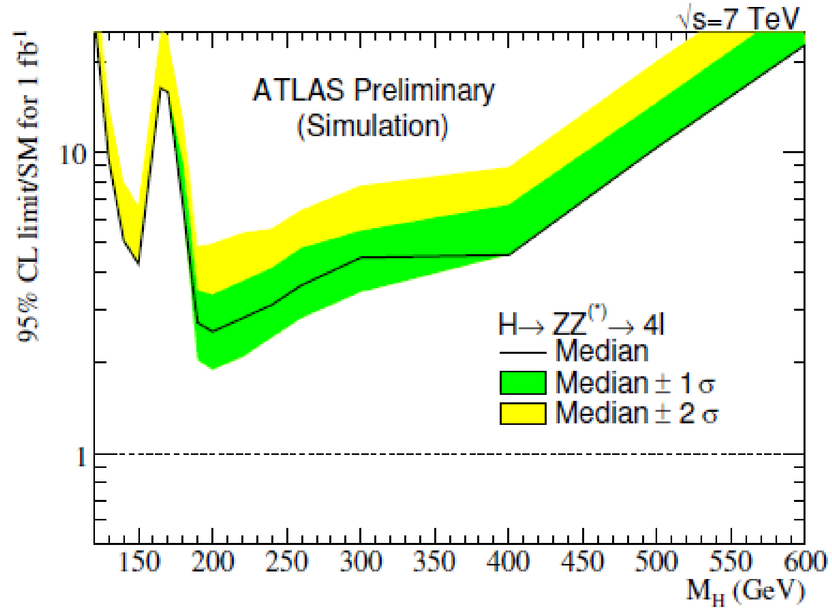
Irreducible: **ZZ*** dominant (after isolation)

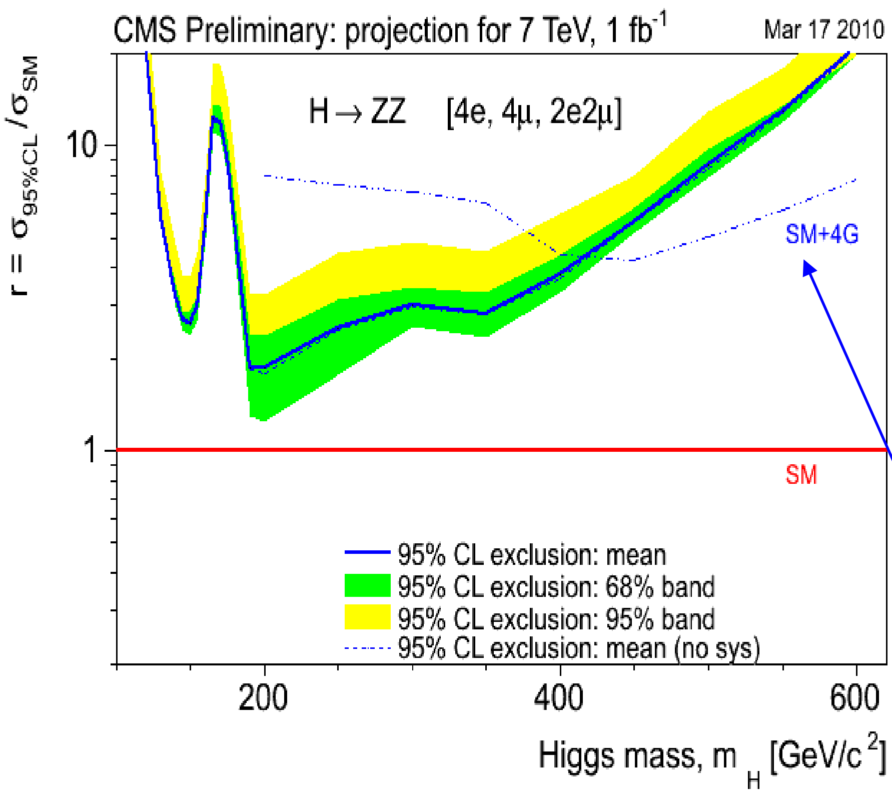
Reducible: **Zbb, tt, ZW, Z + X**

Results H → ZZ*→ 4l

ATLAS (Reference @10TeV analysis)

- SM Higgs boson cannot be excluded for any mass value
- Highly sensitive in the high mass region (**200 GeV/c² < m_H < 400 GeV/c²**)





CMS (Reference: PAS HIG-08/003 @14TeV)

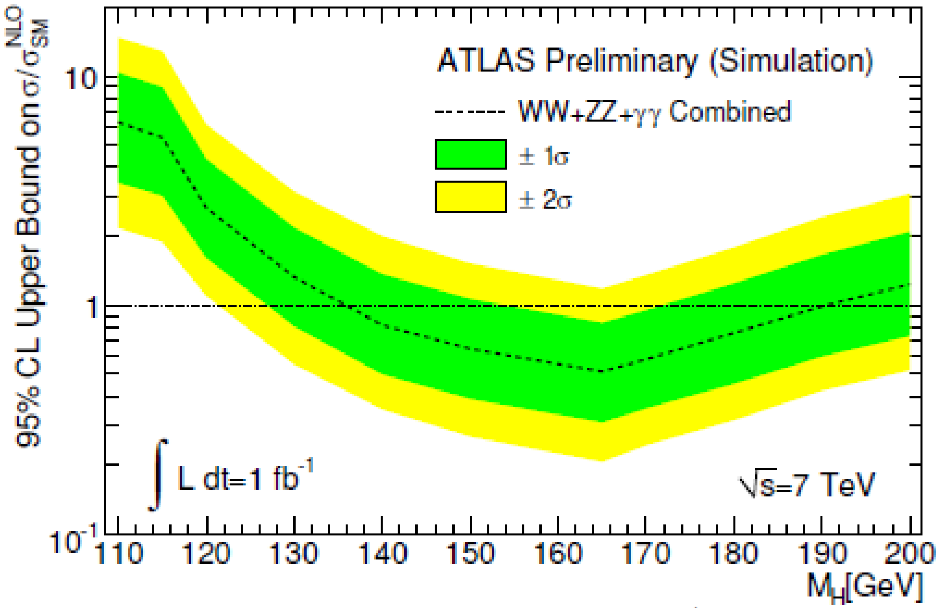
- Counting in a 4l-mass window
- SM Higgs boson cannot be excluded anywhere in the mass range considered.

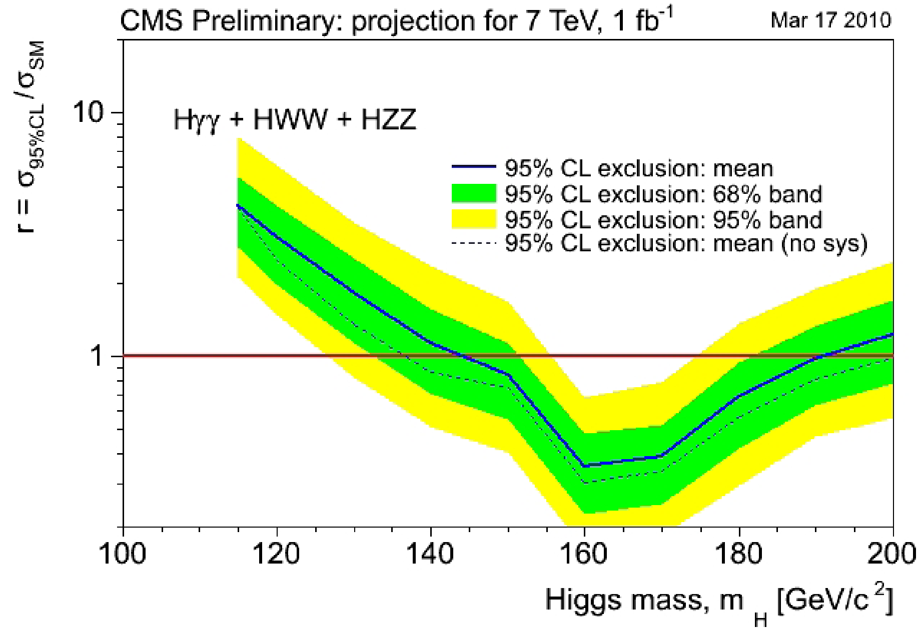
In the 4th generation model* the Higgs with a mass: **m_H<400 GeV/c²** would be excluded

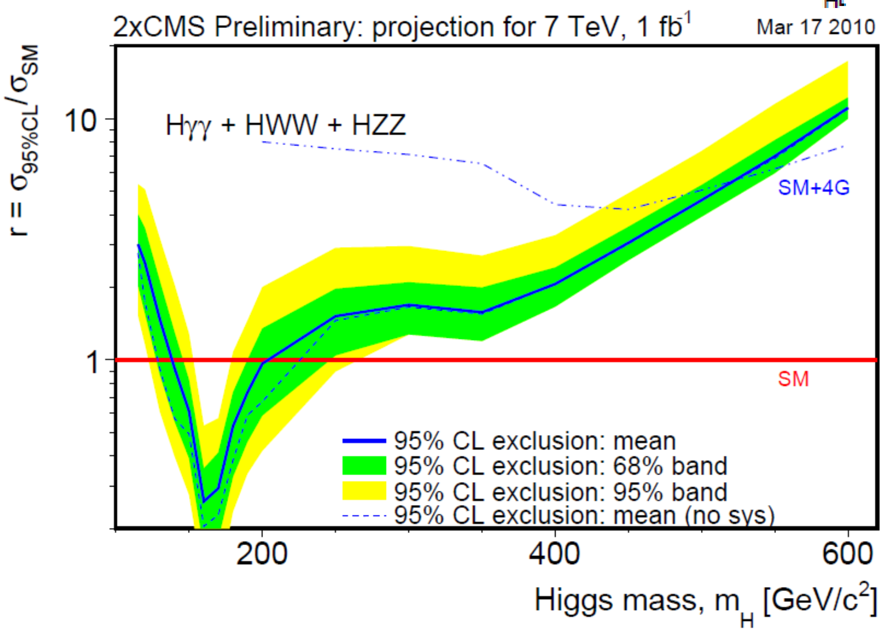
An extra doublet of quarks would make the gg→H production rate ~7-9 times larger, regardless of how massive the two extra quarks might be.

arXiv:0706.3718v1 [hep-ph]

SM Higgs Combination at 7 TeV







2xCMS :

Conservative and indicative projected exclusion limits assuming twice amount of data (ATLAS + CMS)

Exclusion: $140<m_H<200$ GeV/c^2

SM Higgs +4th fermion generation: $m_H<500$ GeV/c^2

Conclusions

- The **performance of the ATLAS and CMS experiments** in collision data has been **excellent** since the start of the data taking and many of the main physics objects to be used in the Higgs analyses were already checked and are performing quite well.
  - **O(100 nb^{-1}) were enough already to start exploring Standard Model processes, and W and Z**,
  - **and soon O(100 pb^{-1}) top and early searches will become possible**.
- With **$\int L \sim 100\ pb^{-1}$ to 1 fb^{-1} at $\sqrt{s}$ = 7 TeV** CMS and ATLAS experiments will start to do Higgs Physics at the LHC
  - This may likely happen **from beginning 2011**
- At 7 TeV **with enough luminosity O(1 fb^{-1})**, ATLAS and CMS will begin to explore a sizable range of SM Higgs mass:
  - **SM Higgs discovery sensitivity : [160-170] GeV/c^2**
  - **SM Higgs exclusion range : [140-200] GeV/c^2**
  - **Low mass SM Higgs searches require higher $\int L$ and $\sqrt{s}$**

First Higgs seen in ATLAS and CMS!!!

These are conservative 7TeV projections of result estimates

We hope to do it better than expected!!!

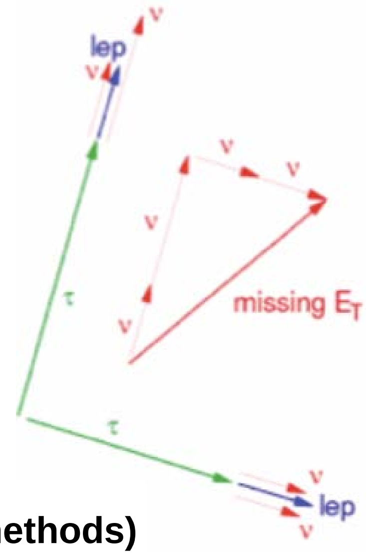
The higher energy and luminosity LHC runs, starting in 2013, will provide the opportunity for the experiments to test the whole mass range and finally observe and measure (or exclude) the SM Higgs boson

Backup slides

VBF H→ττ

Experimental issues

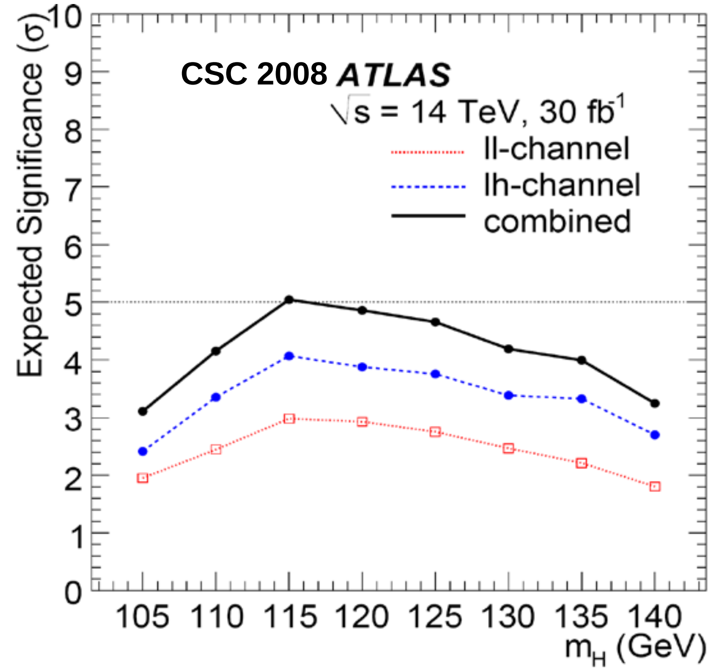
- Very significant channel for low masses
- Important for studying the coupling of Higgs to leptons
- Three final states lepton-lepton, lepton-hadron, hadron-hadron
- Triggers for the fully hadronic mode are under investigation
- Mass reconstruction via the collinear approximation: breaks down when the two taus are back-to-back!!

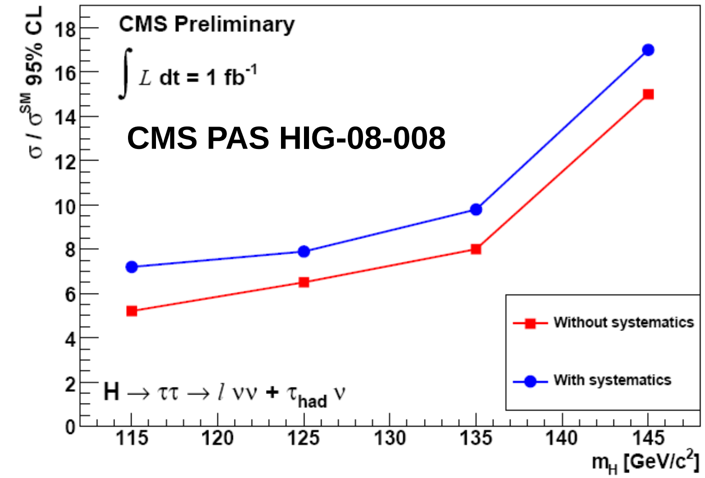


- Mass resolution limited by MET (~8–10 GeV)

Relevant items for analysis:

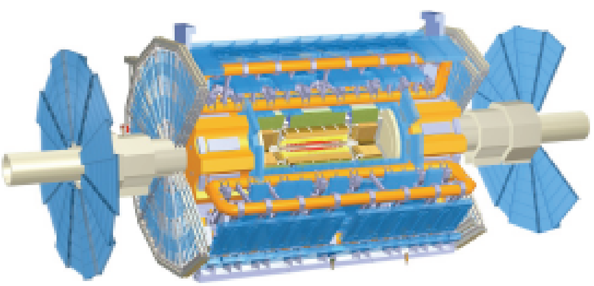
- Tau tagging (Likelihood, NN methods)
- Z+jets background (especially for low masses)
- tt rejection (b-jet ID and veto for lepton-lepton)

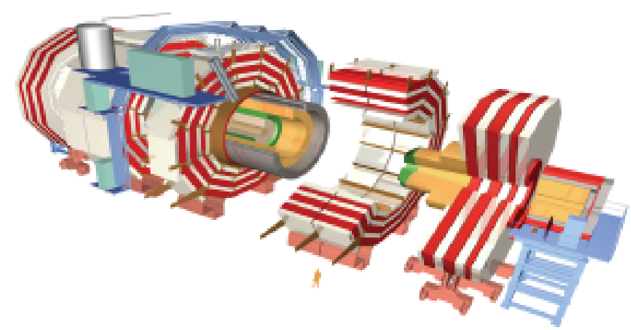




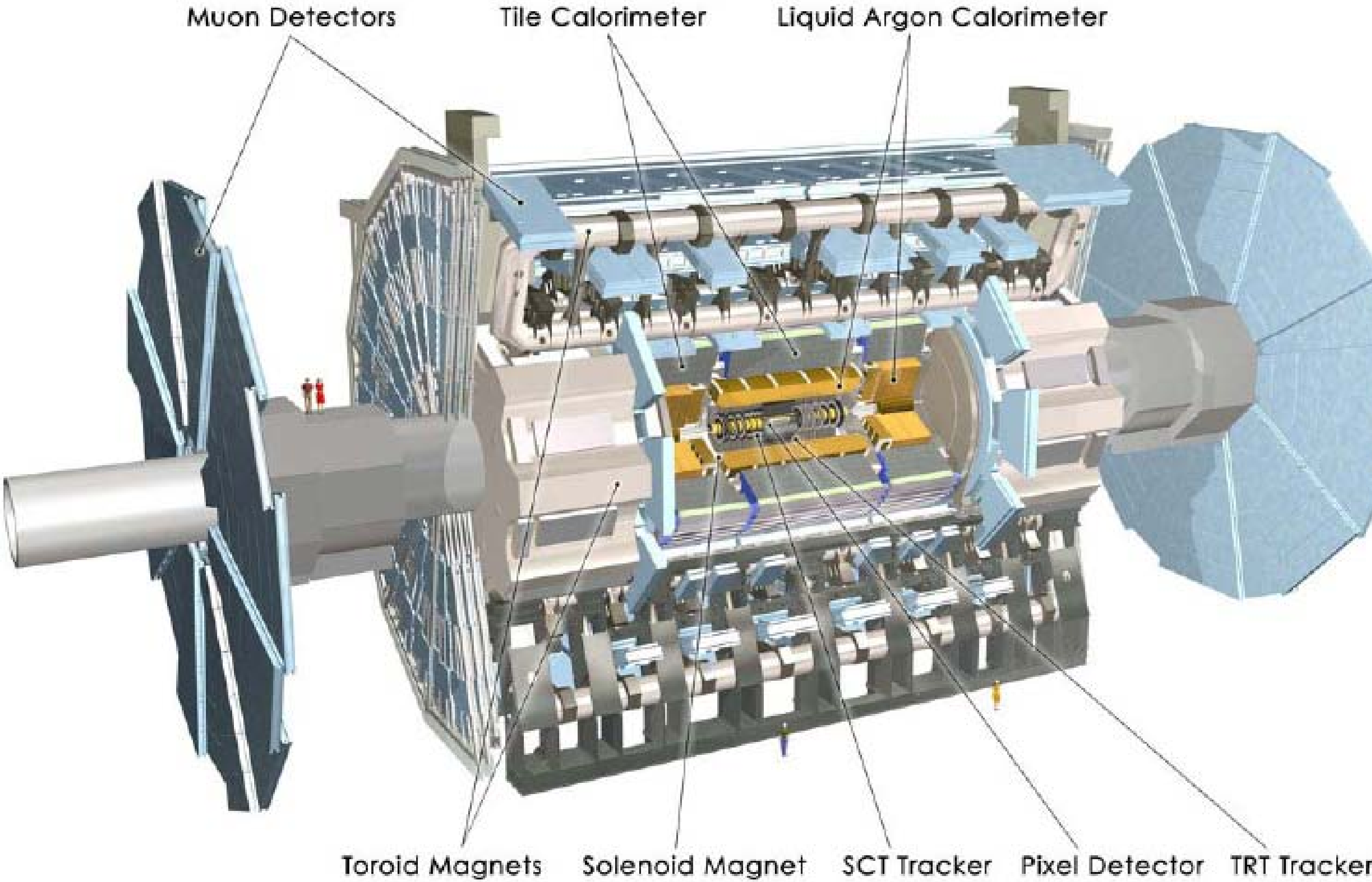
ATLAS vs CMS

	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 $\sigma/p_T \approx 5x10^{-4}p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5x10^{-4}p_T + 0.005$
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)

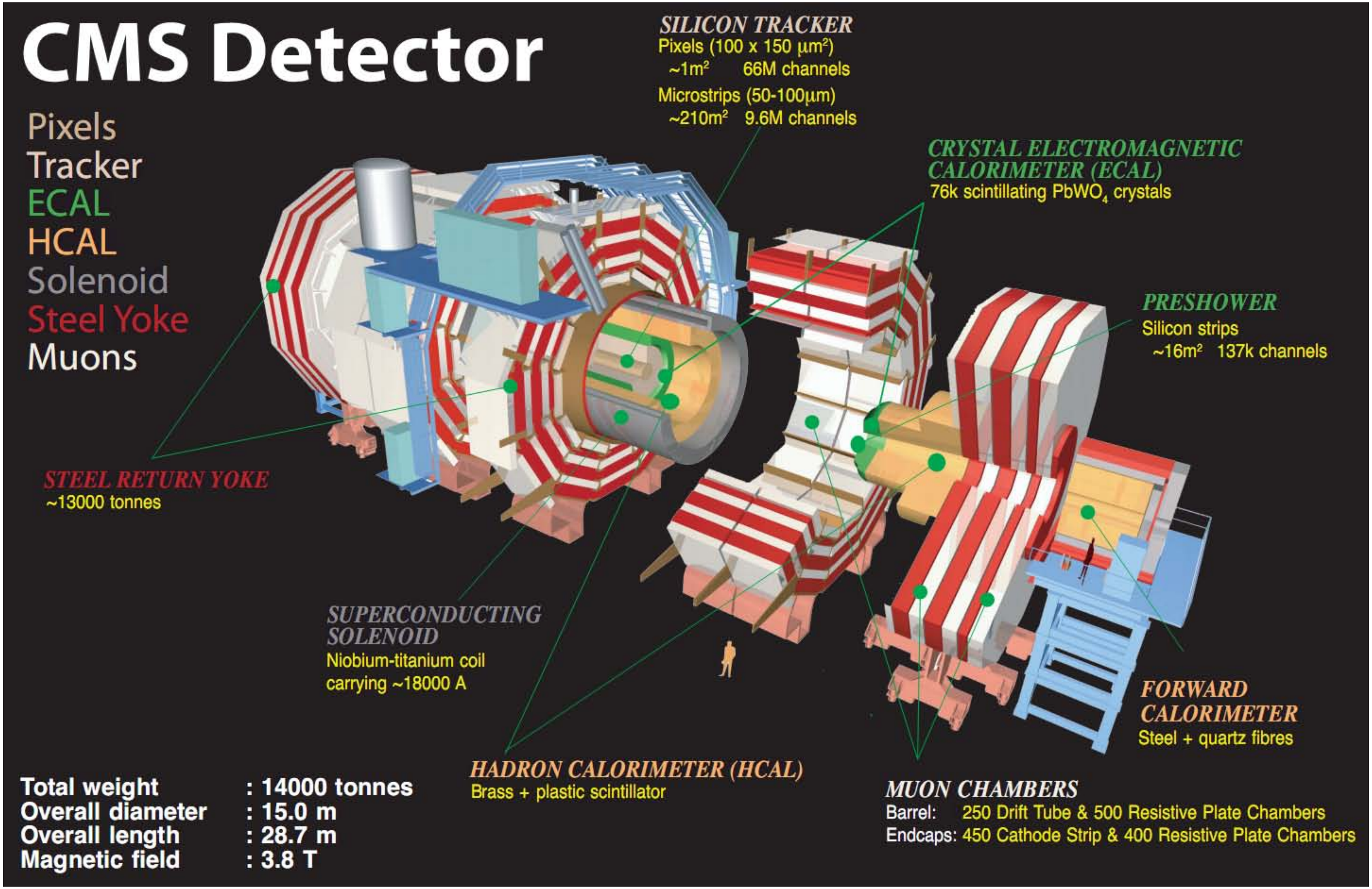




ATLAS


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

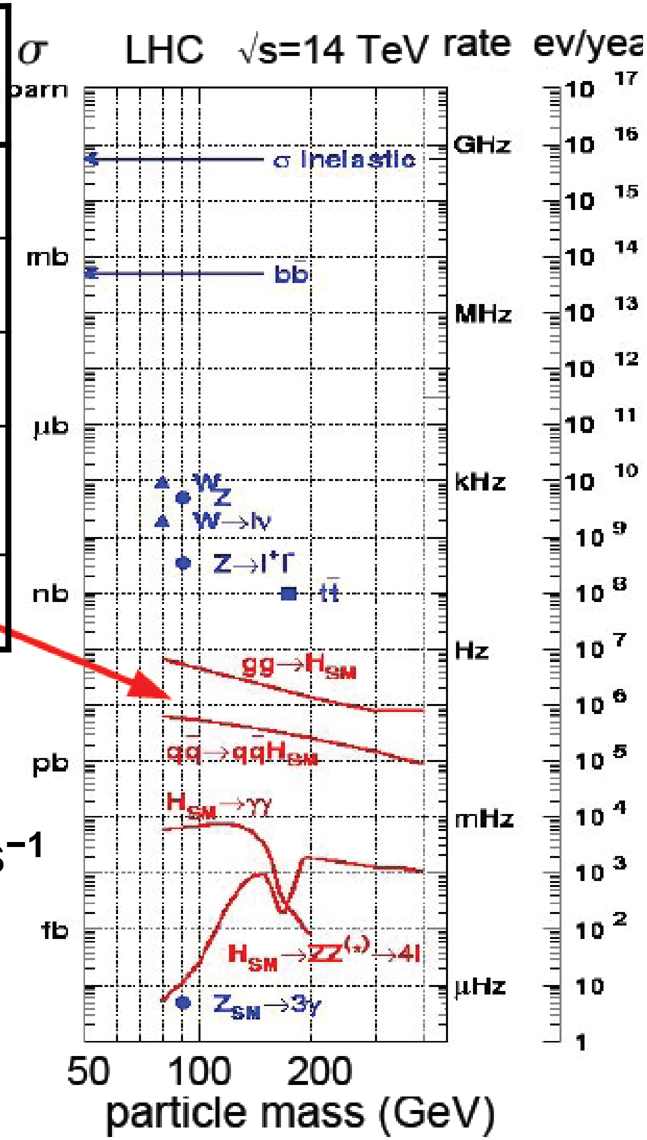
CMS

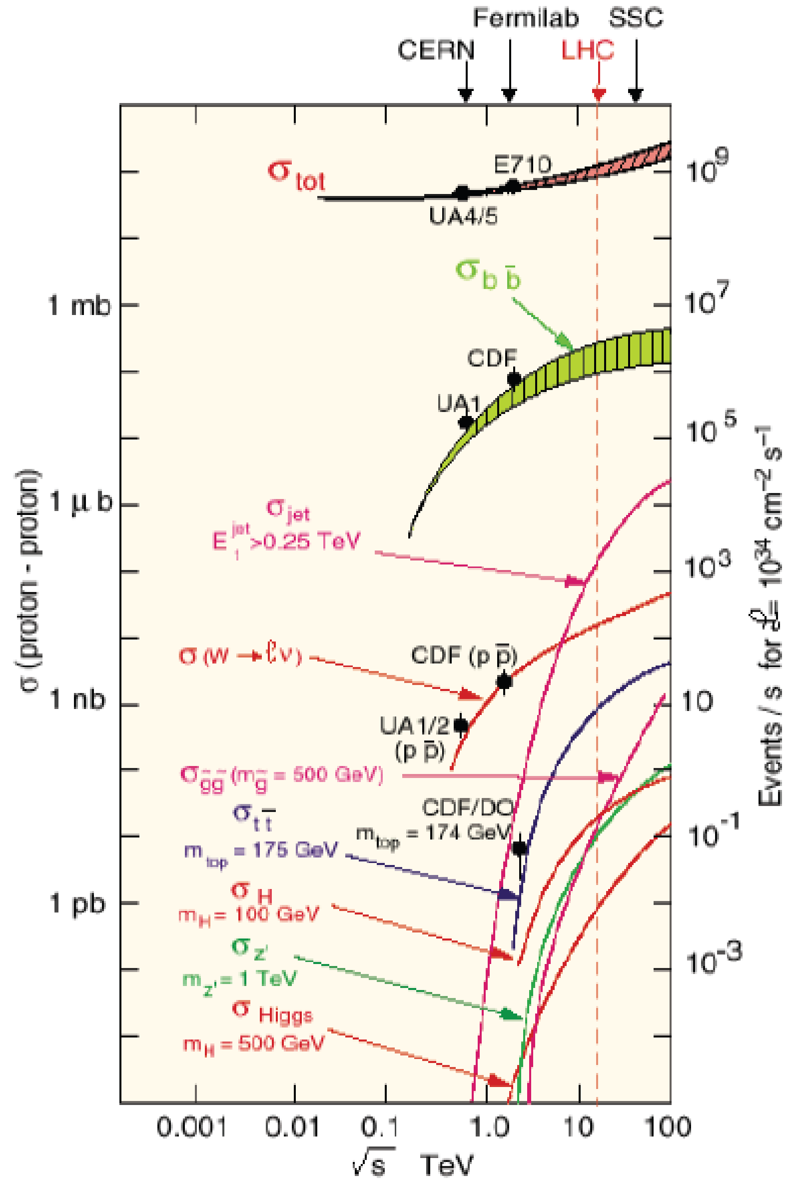

CMS Detector
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² 66M channels
Microstrips (50-100μm)
~210m² 9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² 137k channels
STEEL RETURN YOKE
~13000 tonnes
SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A
FORWARD CALORIMETER
Steel + quartz fibres
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
MUON CHAMBERS
Barrel: 250 Drift Tube & 500 Resistive Plate Chambers
Endcaps: 450 Cathode Strip & 400 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Production rates at LHC

Process	Ev/s	Ev in 10fb[-1]
$W \to e\nu$	15	10^8
$Z \to ee$	1.5	10^7
ttbar	1	10^9
bbbar	10^6	10^{13}
H130	0.02	105

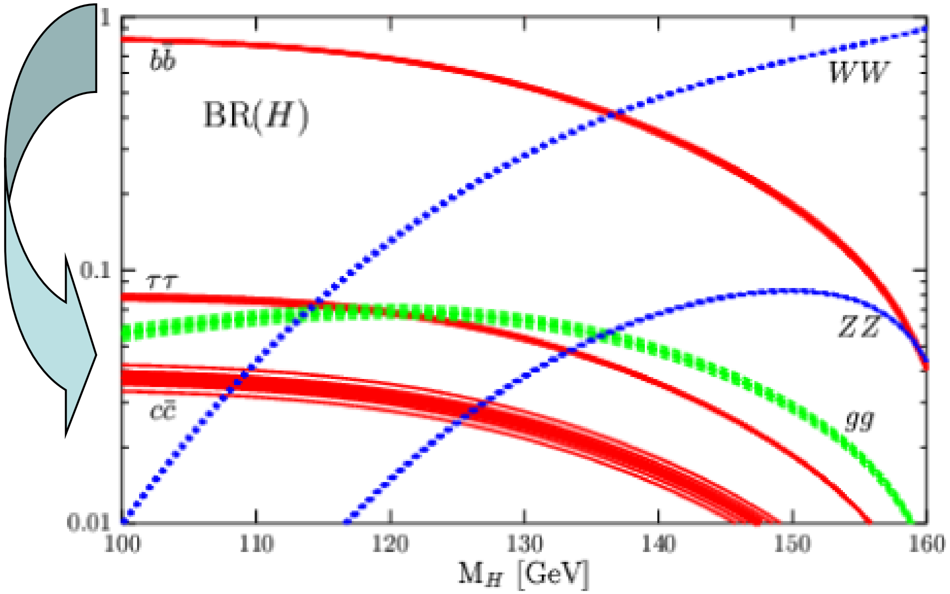
LHC $\mathcal{L}$=10^{33}cm^{-2}s^{-1}

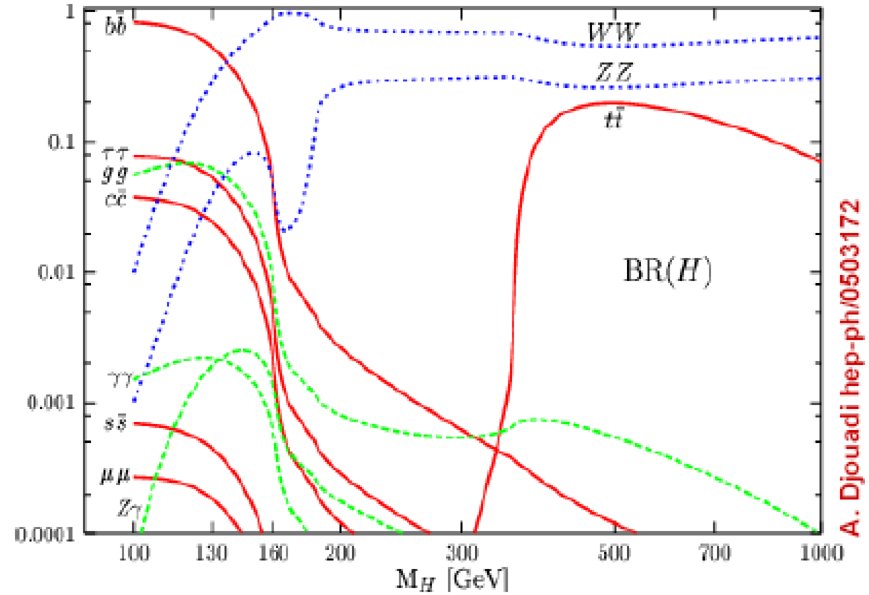




SM Higgs decays

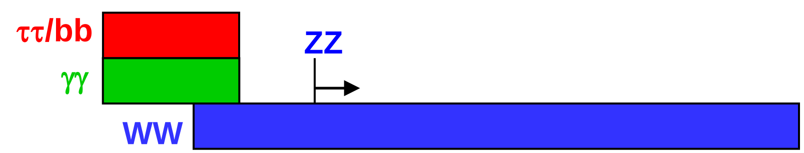
Including quark mass uncertainties (t, b, c) and $\alpha_s(M_Z)$





- **At low mass (M_H< $2M_Z$)**
  - **Dominant bb; huge QCD background**
  - **H→ττ accessible through VBF**
  - **H→WW(*) accessible through gluon-gluon fusion and VBF**
  - **H→γγ has a low BR (decays through top and W loops);**

  but due to excellent γ/jet separation and γ resolution is still very significant
  - **H →ZZ*→4l also accessible**
- **For higher masses**
  - **H→WW and H→ZZ→4l final-states**



Decay branching ratios at NLO : Few % accuracy