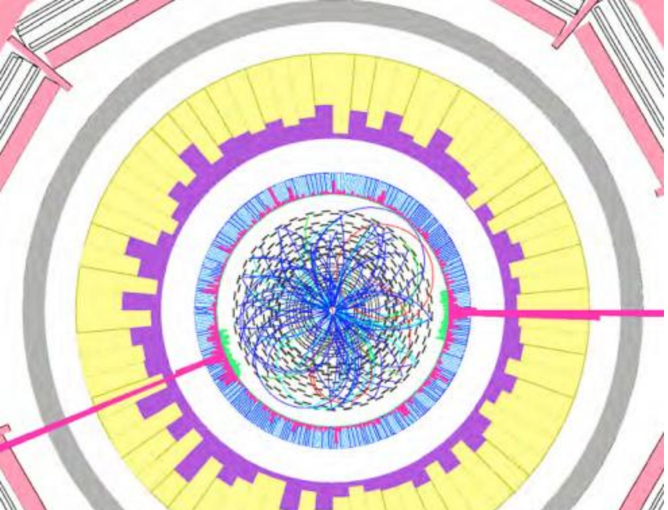
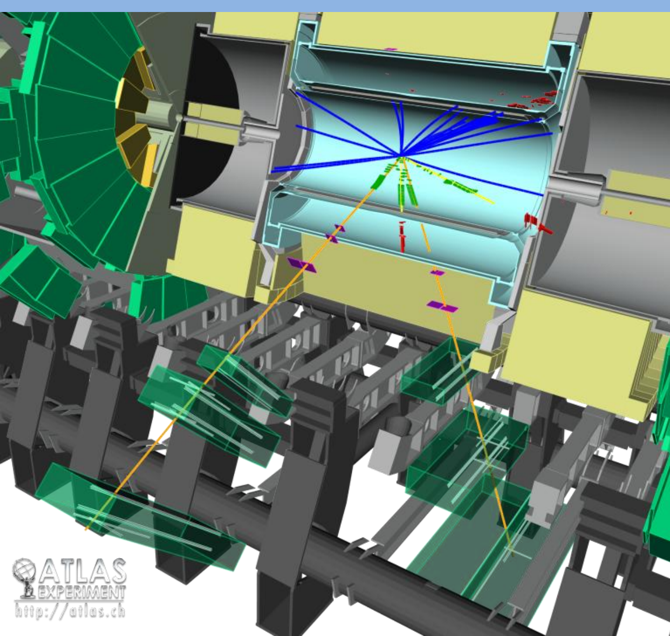


Royal Holloway
University of London

Pedro Teixeira-Dias

Higgs Overview



UK HEP Forum – Cosener's House, 20/9/2010

Overview

LHC data taking at high energy started in 2010

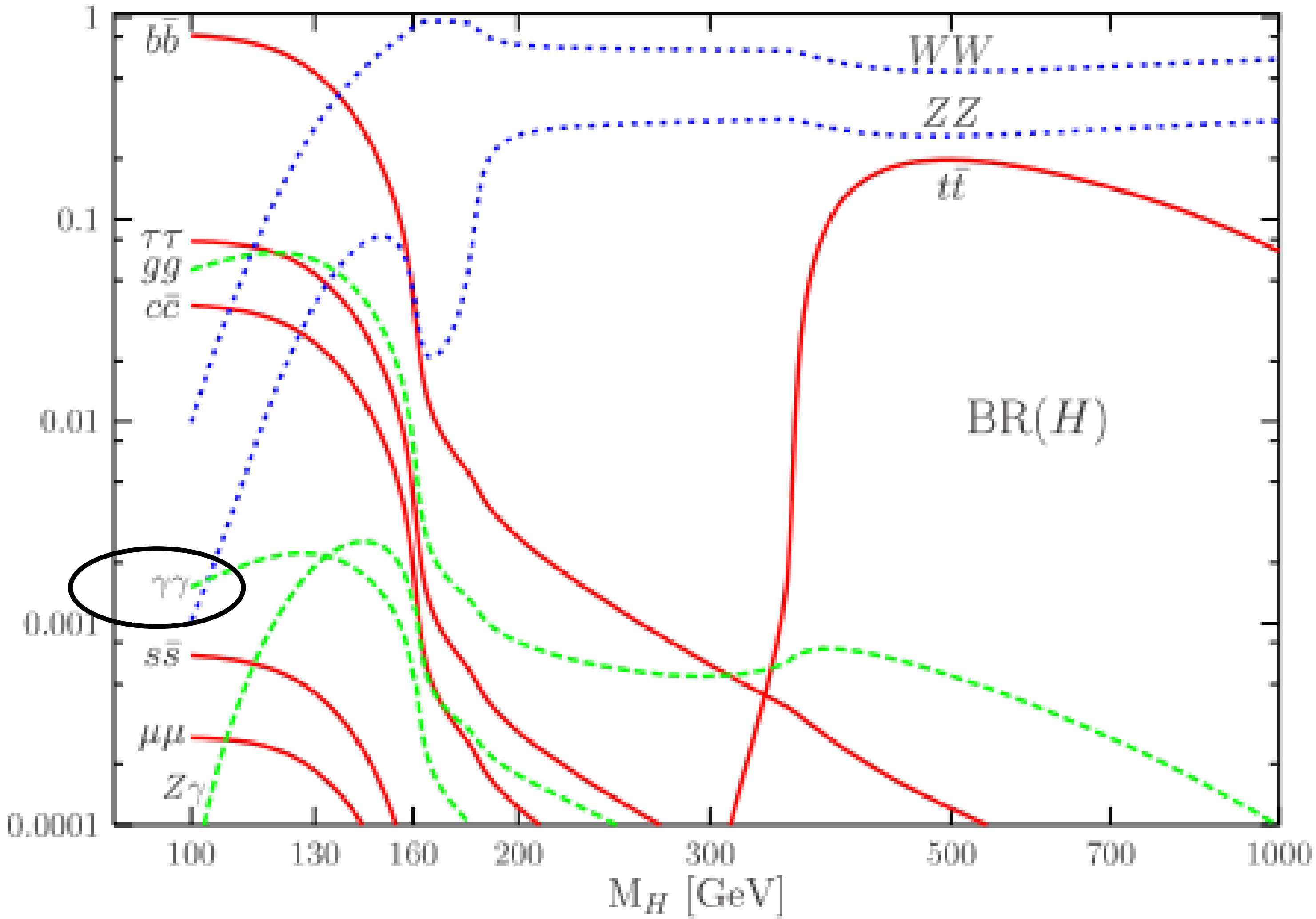
First results presented this summer at

- ICHEP 2010, 22-28 July
- Higgs Hunting, 29-30 July

In this talk I will review recent Higgs developments and projections for the near future:

- Introduction: SM Higgs production and decay
- SM Higgs searches at the TeVatron
- Theoretical interlude
- LHC: operations at 7 TeV
- SM Higgs sensitivity (and MSSM Higgs, too)
- Conclusions

SM Higgs decays: branching ratios

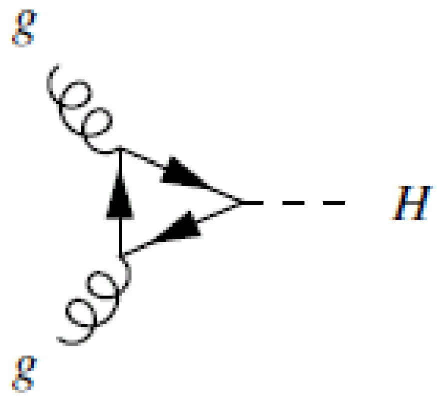


Main decays used in Higgs searches:

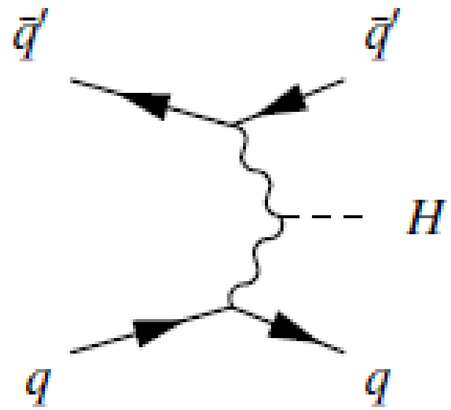
- m_H < 140 GeV: bb, $\tau\tau$, and $\gamma\gamma$
- m_H > 140 GeV: WW dominates, with ZZ a distant 2nd

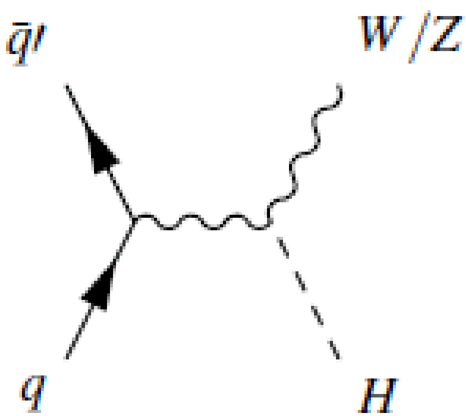
SM Higgs production

Gluon fusion (GF)
Dominant production mode

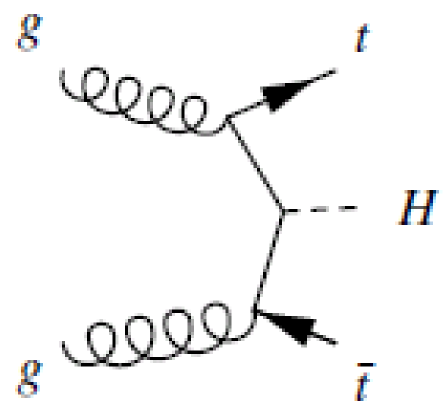


Vector boson fusion (VBF)
Characteristic "tag jets" signature





Higgsstrahlung

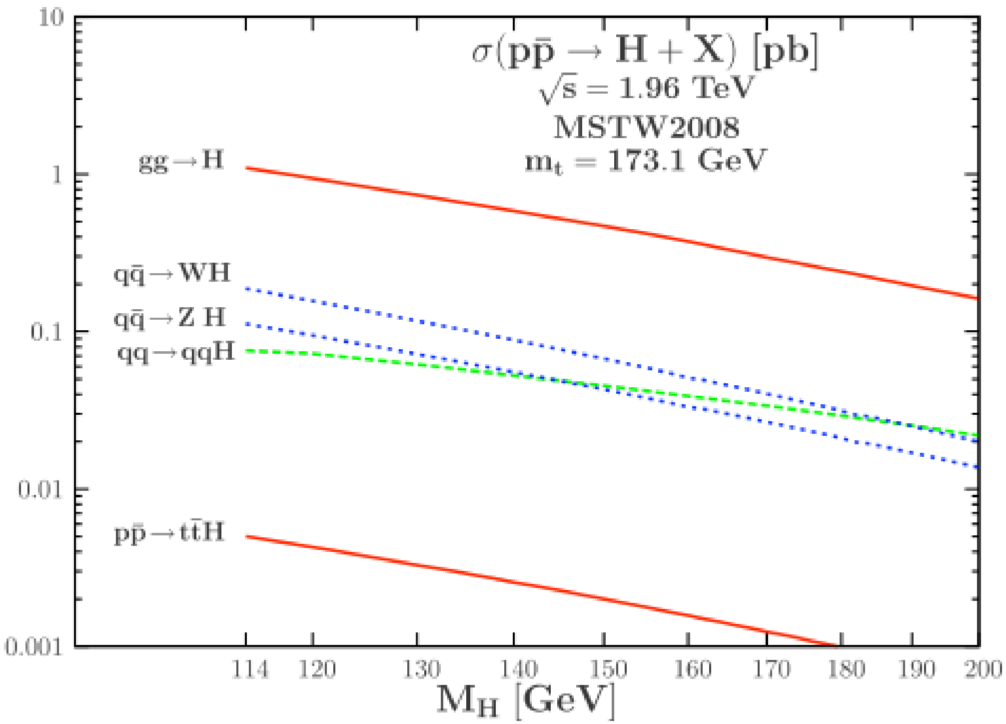


Associated production
with a pair of top-quarks

HIGGS HUNTING AT THE TEVATRON

Higgs at the TeVatron

Higgs boson production cross-sections



Overall search strategy

Low Higgs mass

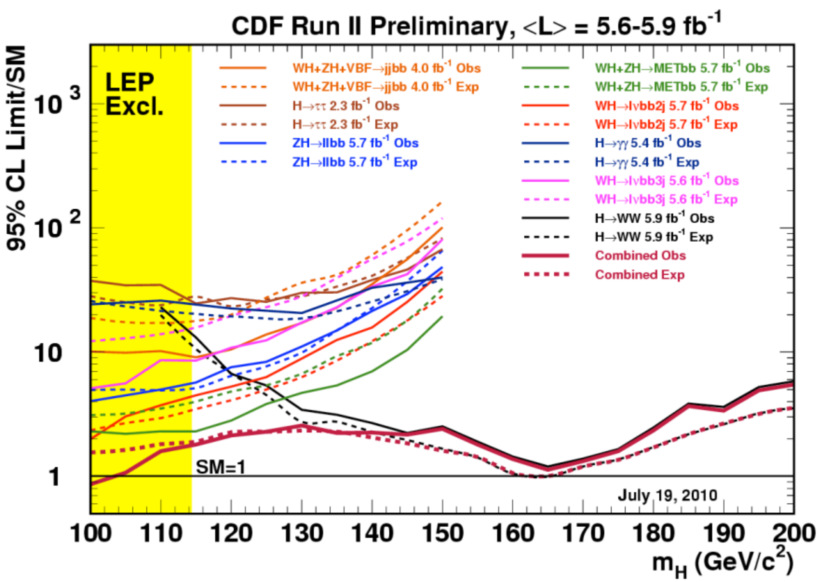
- H→bb decay dominates (…can't use GF)
- pp→WH,ZH→ℓνbb, ννbb, ℓℓbb
- Main backgrounds are W+jets, Z+jets

High Higgs mass

- H→WW is main decay (→leptons!)
- gg→H→WW most important (m_H>125 GeV)

Analysis of most channels is divided into sub-channels for improved s/b

Higgs at the TeVatron

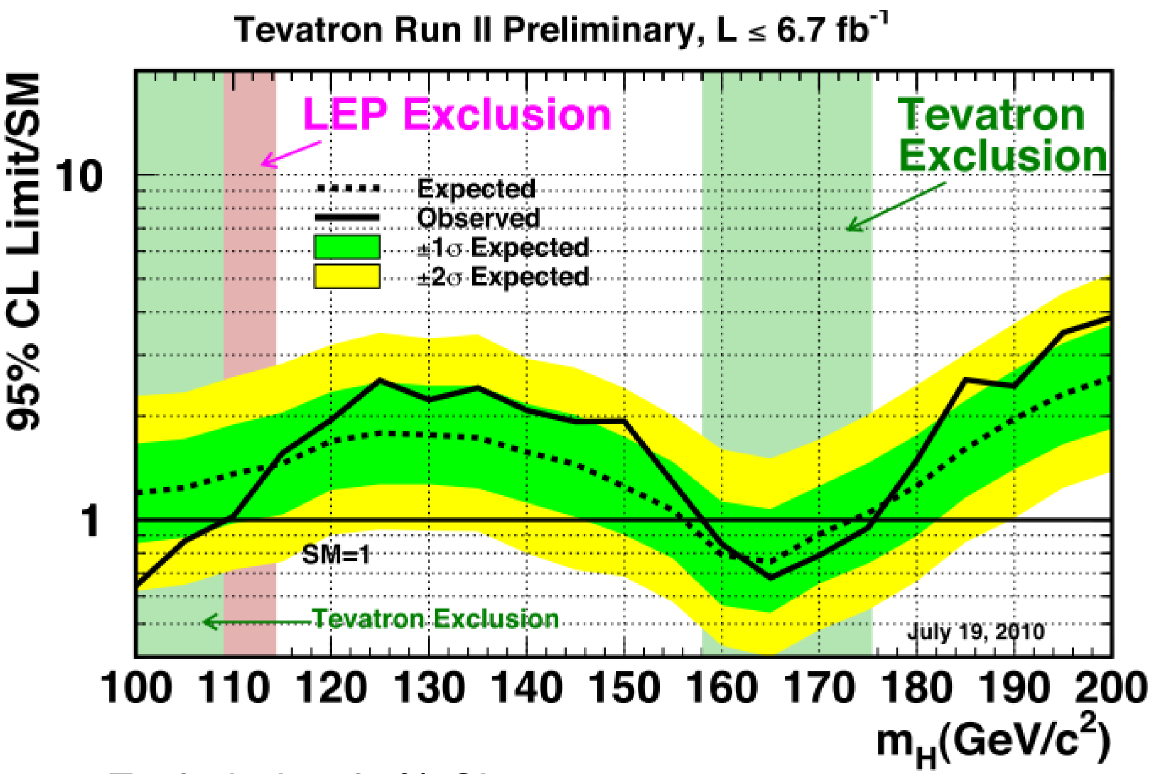


- But in practice have expanded list of searches: *"no channel too small"*
- H→ττ, H→γγ also included
- D0 even includes tt(H→bb) !

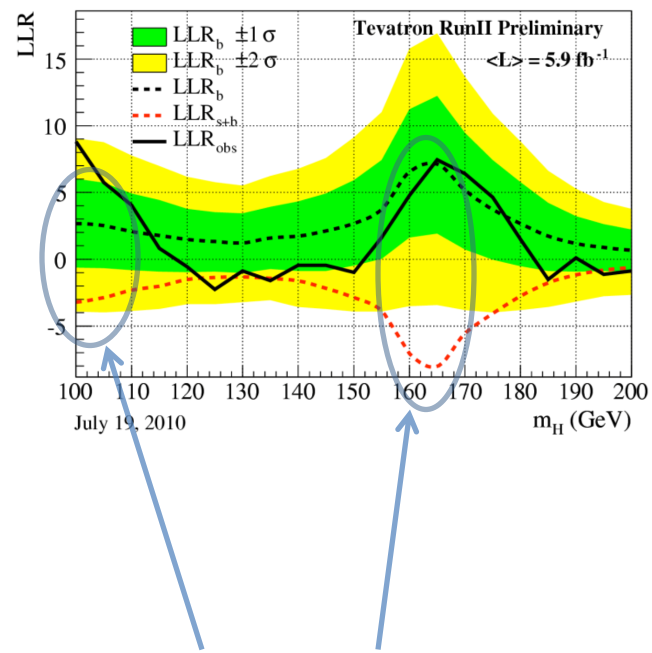
Channel	Expt	Dataset now	Increase since Nov. 2009 combination
H → WW	D0	6.7	24%
H → WW	CDF	5.9	23%
WH → lνbb	CDF	5.7	30%
WH → lνbb	D0	5.3	6%
ZH/WH→METbb	CDF	5.7	60%
ZH/WH→METbb	D0	6.4	23%
ZH → llbb	CDF	5.7	40%
ZH → llbb	D0	6.2	45%
H → γγ	CDF	5.4	New!
H → γγ	D0	4.2	0%
H → ττ	CDF	2.3	15%
H → ττ	D0	4.9	0%
ZH/WH→qqbb	CDF	4	100%
ttH	D0	2.1	0%

Ben Kilminster, ICHEP 2010

Higgs at the TeVatron



Log likelihood ratios: b, s+b



Larger sensitivity

- Excluded at 95% CL
  - $158 < m_H < 175$ GeV (4x previous exclusion)
  - In the absence of signal: expect $156 < m_H < 173$ GeV
  - At m_H=115 GeV: 1.5 x $\sigma_{SM\ Higgs}$
- Approved to end 2011. Request 3 more years (“Run III”)

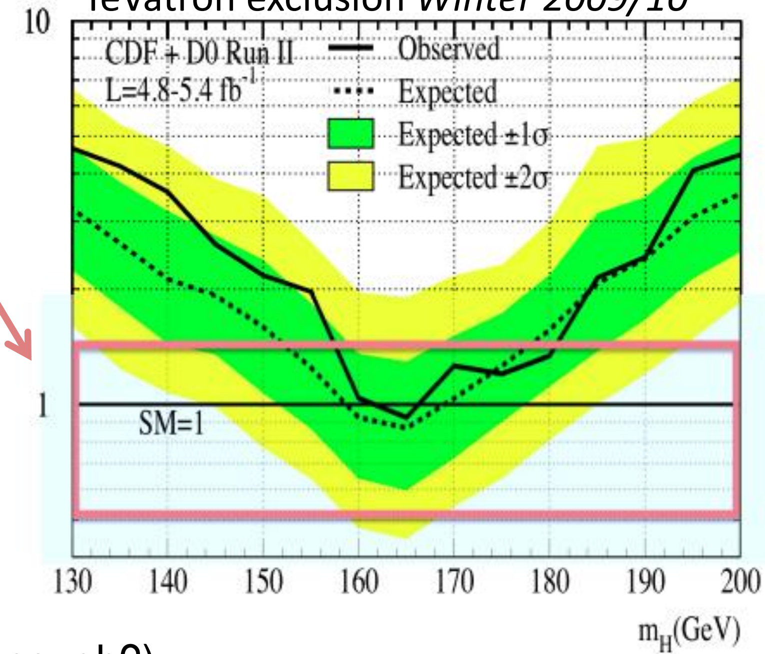
THEORETICAL INPUTS

Theoretical input to searches

SM Higgs limits are not purely experimental…
eg input of $\sigma_{\text{SM Higgs}}$ (line at R="1")

- "Predictions for Higgs production at TeVatron and associated uncertainties"
  (Baglio & Djouadi, [hep-ph] 1003.4266, 1009.1363)
- Bottom line: authors estimate unctty. in $\sigma(gg\rightarrow H)$ (~40%) is twice as large as what was used in latest TeVatron combination
- Main issues:
  - Uncertainty from scales μ_R,μ_F (variation not large enough?)
  - PDF uncertainties, and incorporation of uncertainties on both α_S^{th} + α_S^{exp}
  - how to combine above errors
- Over the Summer, work has been done by both sides to discuss + address issues… but debate still rages on
- LHC 7 TeV is also being given the "Baglio & Djouadi treatment" ($\Delta\sigma/\sigma \approx$ -25% $\leftrightarrow$ +30%)

TeVatron exclusion *Winter 2009/10*



Theoretical input to searches

Theoretical inputs (event generators, PDFs, cross-sections for signals and backgrounds , Higgs BRs, etc) are crucial to searches

⇓

vital that theorists and experimentalists work together on this

LHC Higgs "Cross Section" Working Group

Meetings: April 2010 (Freiburg), July 2010 (CERN), November 2010 (Bari)

https://twiki.cern.ch/twiki/bin/view/LHCPhysics

LHC Higgs WG

R Tanaka

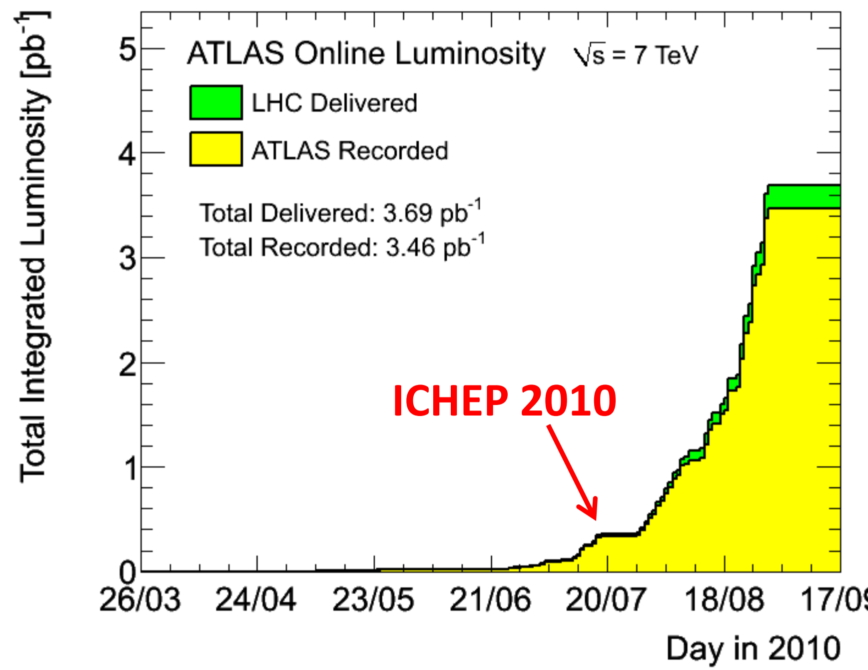
LHC

LHC operations in 2010

LHC operations: impressive so far

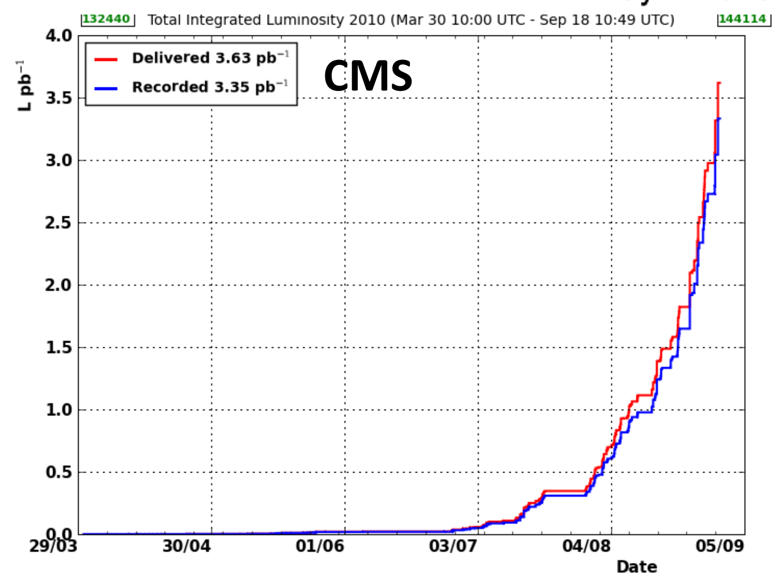
2010

- Start of 7 TeV pp collisions: end of March
- L = ~~10^{27}~~, ~~10^{28}~~, ~~10^{29}~~, ~~10^{30}~~, 10^{31} $cm^{-2}s^{-1}$
- Already attained max p/bunch: 10^{11}
- Late August: collided 36 x 36 bunches (delivering ~0.5 /pb/day)
- Target: 10^{32} $cm^{-2}s^{-1}$ < end of year



ATLAS + CMS

- data collection and detector commissioning going impressively well
- each experiment now has ~3.5 /pb of high quality data

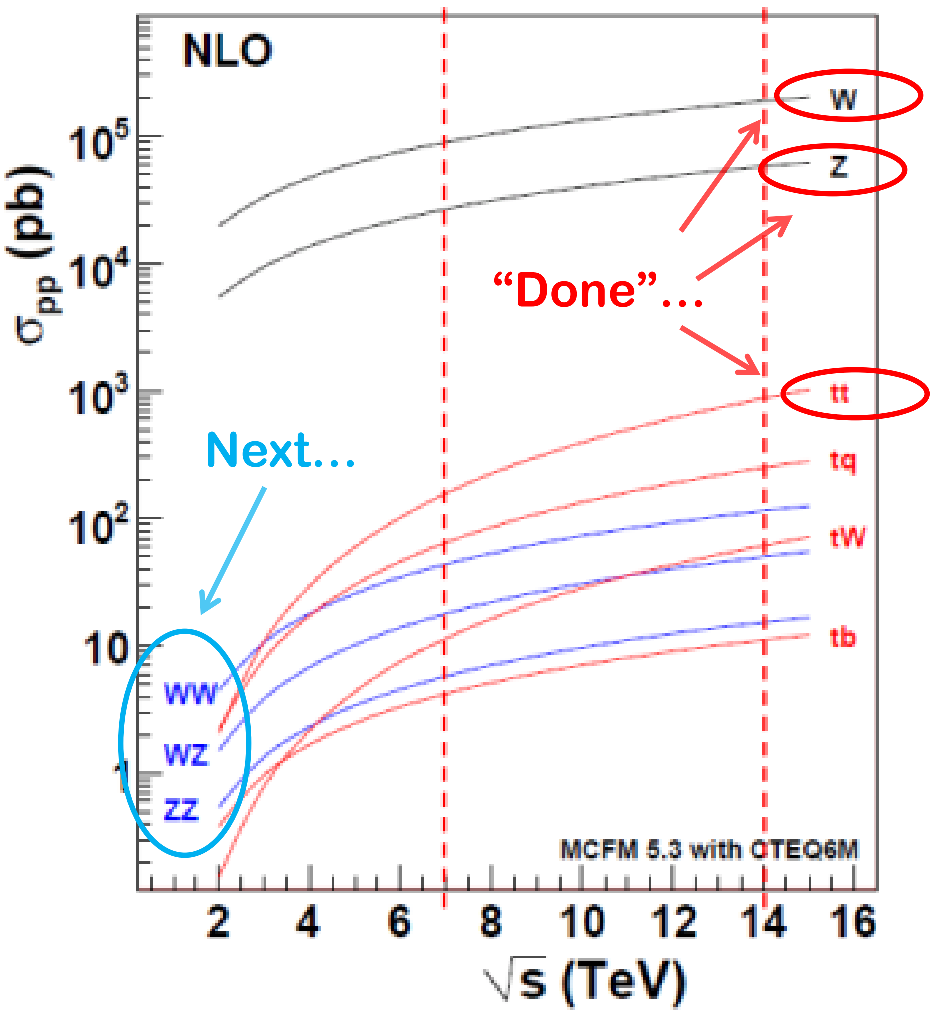


2011: aim for $L_{int} \geq 1$ /fb /expmt
2012: shutdown
2013: collisions at 14 TeV

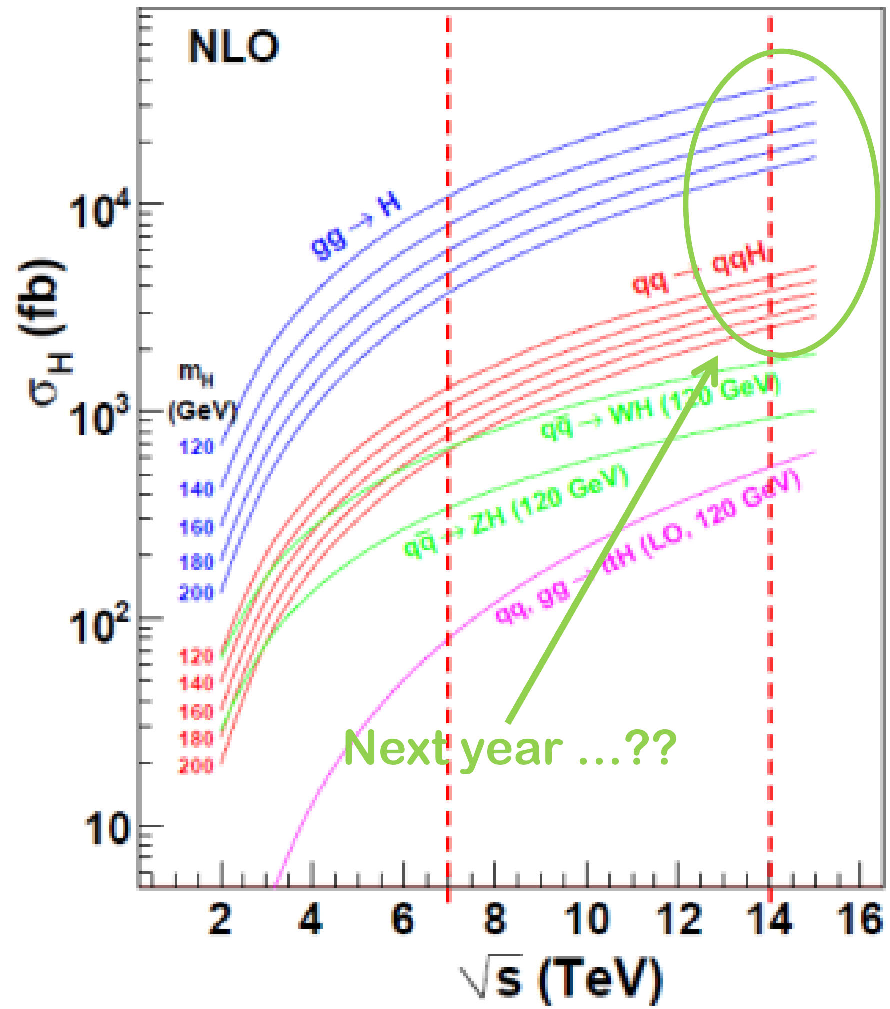
LHC production cross-sections

Rediscovering the Standard Model

SM processes (pb)

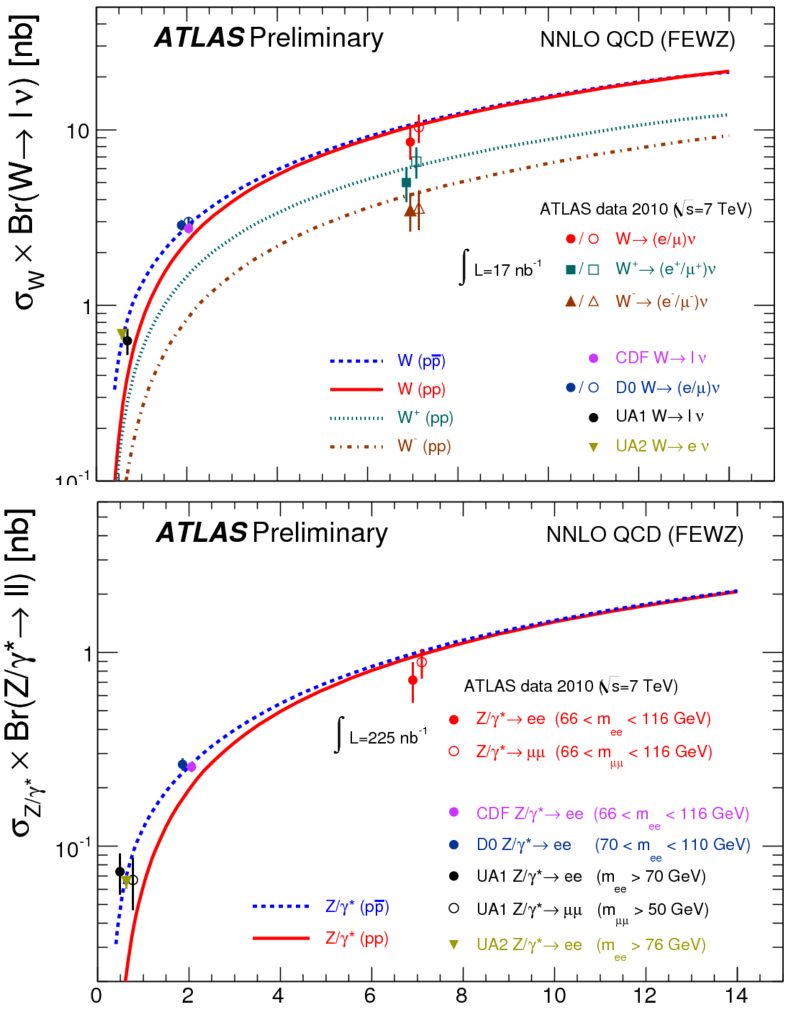


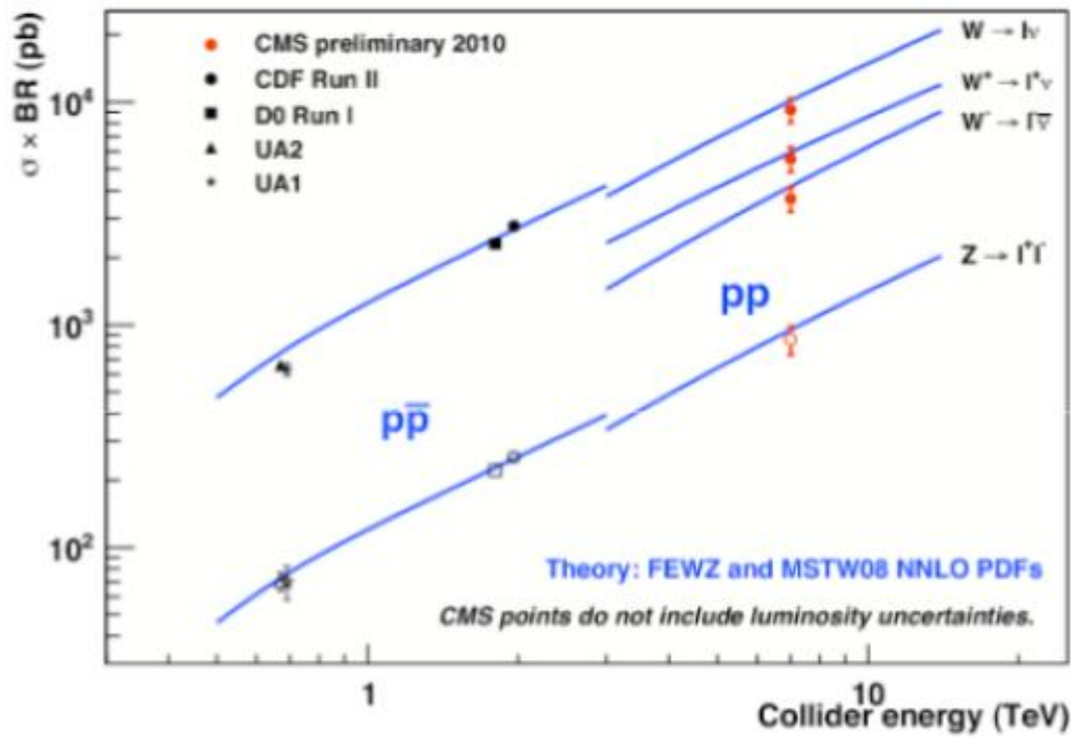
SM Higgs (fb !)



W & Z cross-sections measurement

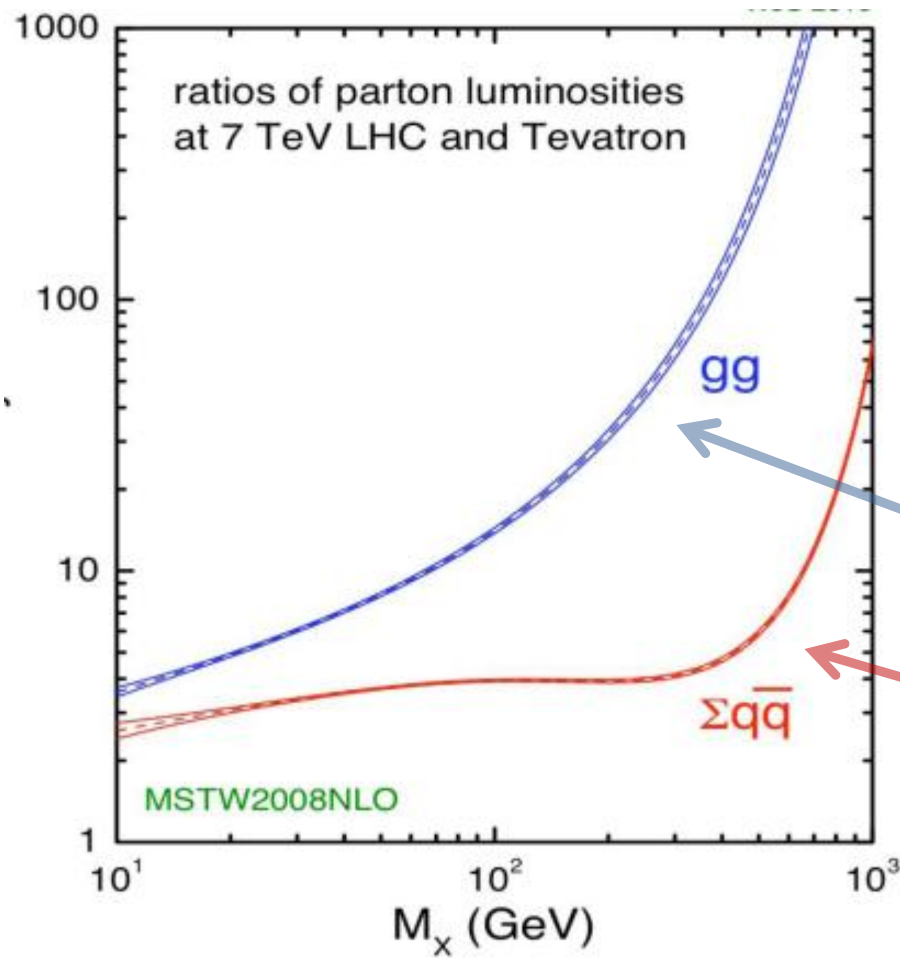
Detector commissioning going very well (and rapidly) on all fronts:
tracking, calorimetry, particle id, jets, missing E_T, b-tagging.





Higgs: from the TeVatron to the LHC

Clearly, the 7 TeV LHC should be a significant step up in Higgs sensitivity



Parton luminosities for gg/qq → X

For M_X >140 GeV, the gg luminosity is > 15 times larger at LHC: good news for gg→H→WW/ZZ.

In addition, dominant backgrounds are produced via qq.

gg→H→WW/ZZ

qq→WW/ZZ

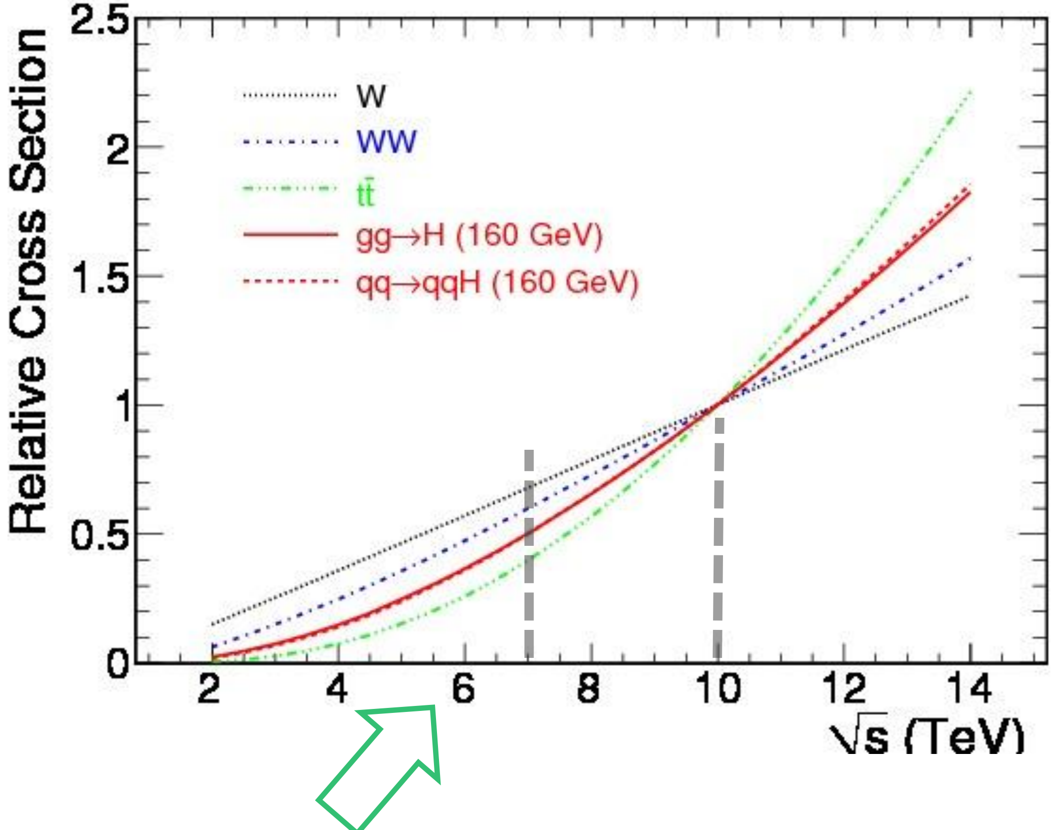
LHC 7 TeV: Higgs sensitivity

Projected Higgs exclusion sensitivity for 1/fb of data at 7 TeV LHC

- Method used by ATLAS + CMS:
  - No new analyses developed for $\sqrt{s}$=7 TeV
  - Instead rely on full simulation studies at $\sqrt{s}$=10/14 TeV and rescale signal and background cross-sections to $\sqrt{s}$=7 TeV.
  - ATLAS uses GF NLO; CMS uses GF NNLO (~30% higher)
  - Acceptances, efficiencies unchanged (verified to be the same – or even slightly higher – at 7 TeV)
  - Errors rescaled/re-evaluated for 7 TeV and 1/fb
  - 10/14 TeV studies optimised for discovery, instead of exclusion: room for improvement
  - Limit setting (incorporating uncertainties) using profile likelihood method (ATLAS) and CL_S method (CMS)
- References: ATL-PHYS-PUB-2010-009, CMS NOTE 2010/008

Effect of 10/14 TeV → 7 TeV

Some signal and background cross-sections as function of √s, normalised to √s=10 TeV

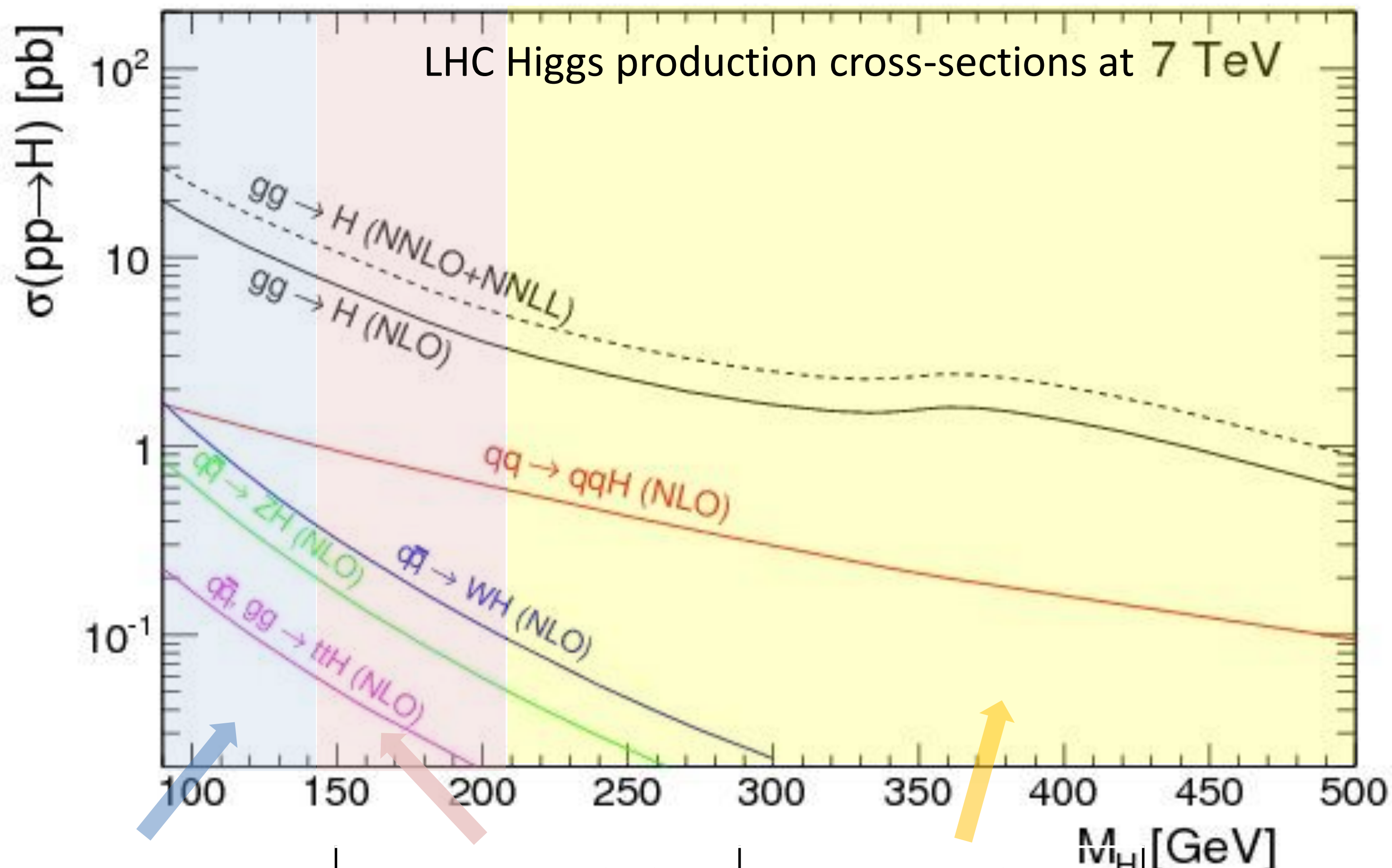


Cross sections depend strongly on √s…:

e.g., from 10 ⟶ 7 TeV

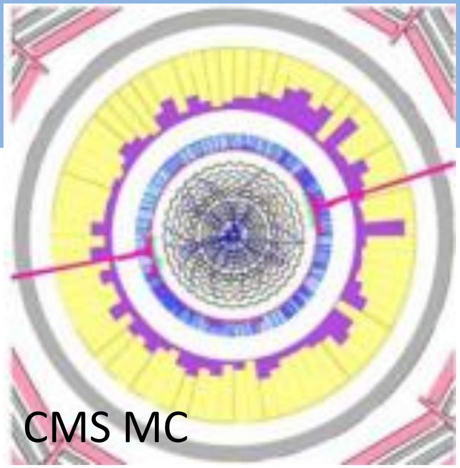
- GF + VBF signals (m_H=160 GeV) drop to 50%
- tt, WW and W backgrounds drop to 30-60%

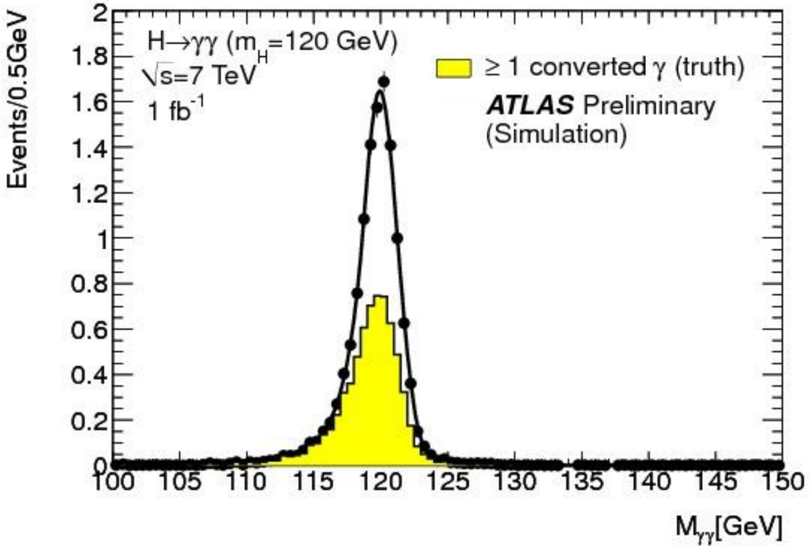
LHC Higgs search strategy

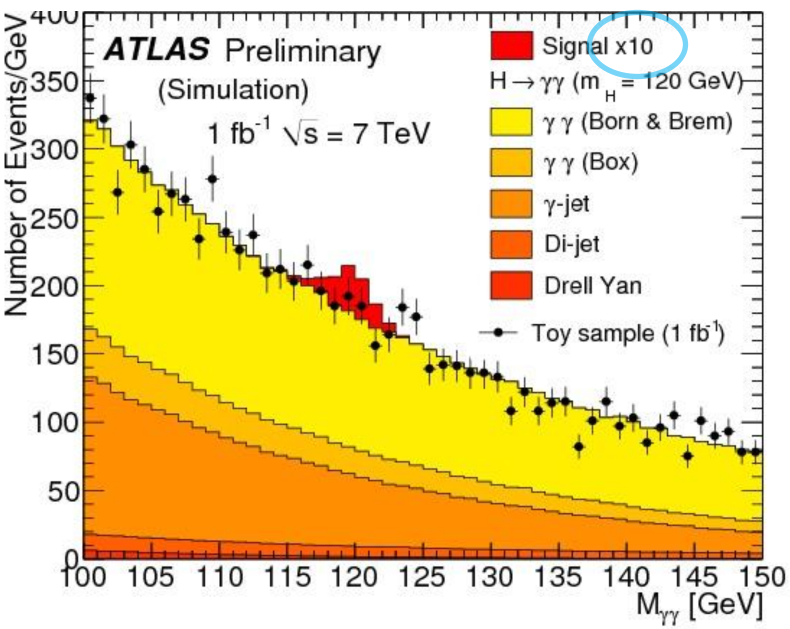


$H\to\gamma\gamma$	**$H\to WW\to\ell\nu\,\ell\nu$**	$H\to WW\to\ell\nu\,qq$
$qq(H\to\tau\tau)$	**$H\to ZZ\to\ell\ell\,\ell\ell$**	
$tt(H\to bb)$	$H\to ZZ\to\ell\ell\,\nu\nu$	$H\to ZZ\to\ell\ell\,bb/qq$
$W/Z(H\to bb)$		

$H\rightarrow\gamma\gamma$







- very clear signature
- excellent mass resolution: CMS 0.7% - ATLAS 1.1%

→ narrow di-photon resonance

BUT

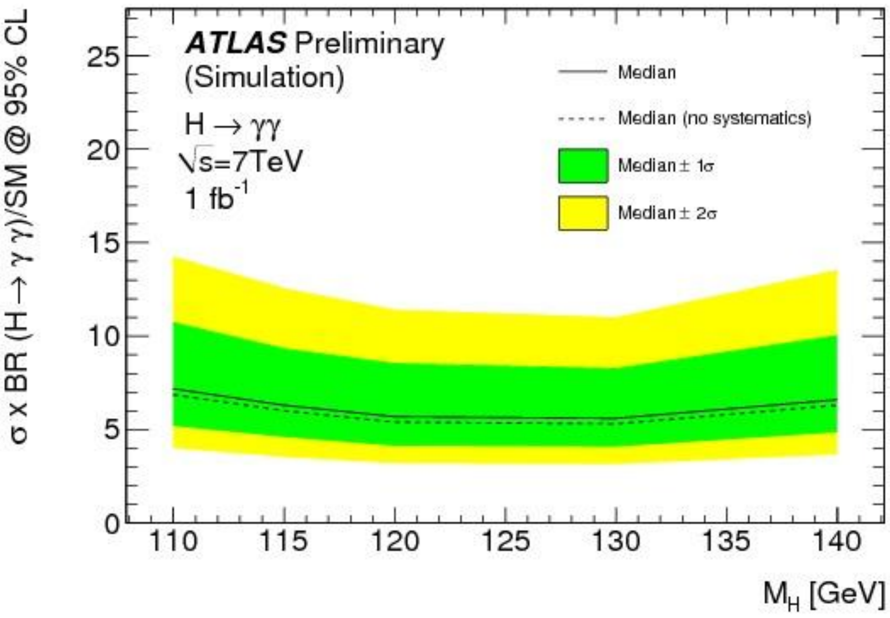
- low signal yield: $B(H\rightarrow\gamma\gamma) \sim 10^{-3}$
- high background rate ($\gamma\gamma$, γj)

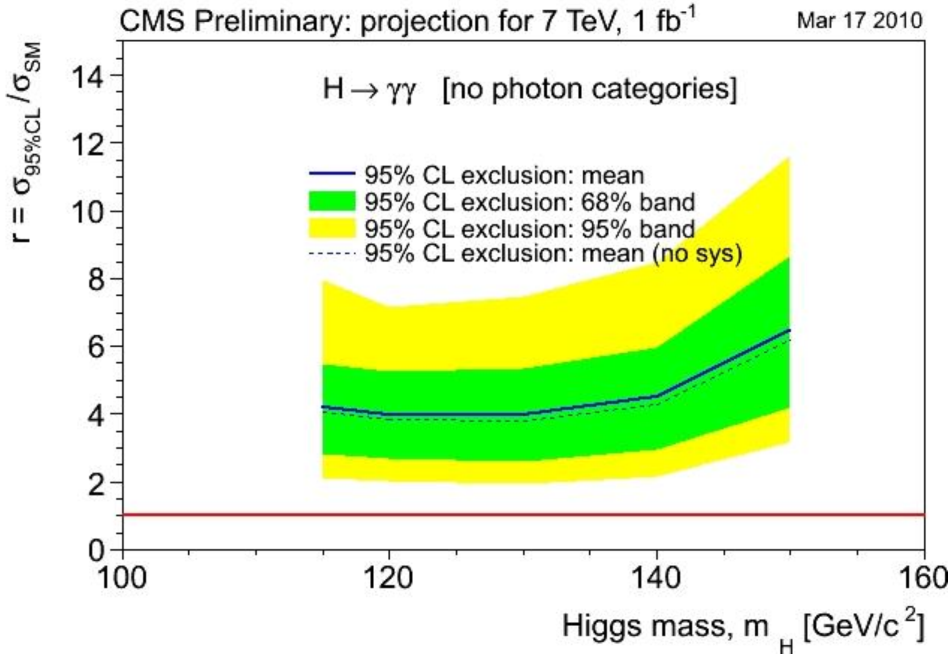
NEED

- excellent ECAL calibration
- high γ identification efficiency
- γ conversion recovery
- γ/jet discrimination

H→γγ

Ratio of 95% CL upper limit on σ x B(H→γγ) and the SM rate





- No exclusion with this channel stand-alone
- Limits are better than current H →γγ TeVatron limits (~ 20 x SM)

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

Powerful channel: $H \to WW$ has largest BR around $m_H \sim 2m_W$

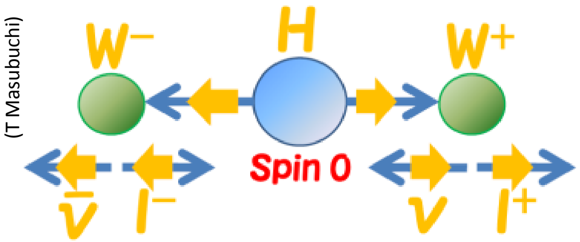
- di-lepton signature (include ee + eμ + $\mu\mu$) and missing E_T
- ATLAS analyses H+0/1/2jets (GF+VBF)
- CMS uses a multivariate method
- backgrounds are WW, top (tt, single t, Wt), and W+jets
- no Higgs mass peak, due to νs!
  - systematics very important
  - detailed understanding of backgrounds is absolutely key: use sophisticated treatment of control regions; data-driven estimates

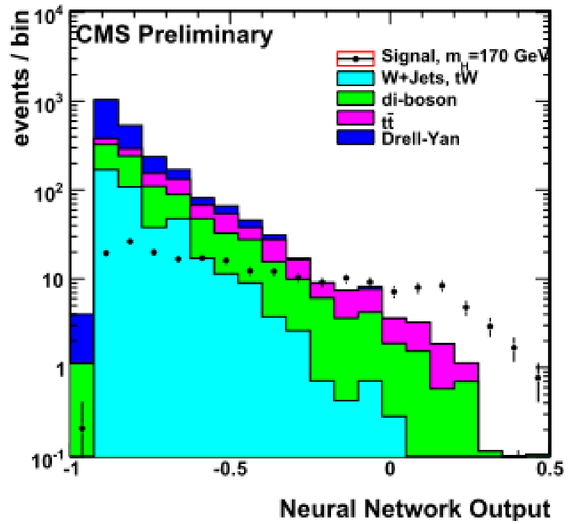
References: ATL-PHYS-PUB-2010-005 (10 TeV); CMS PAS HIG-08/006 (14 TeV)

H→WW→ℓν ℓν

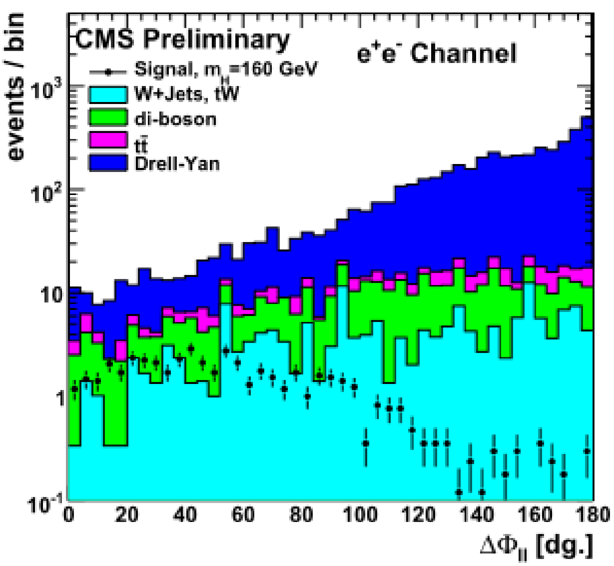
Explore azimuthal di-lepton correlation, due to resonant *scalar* decay

(T Masubuchi)

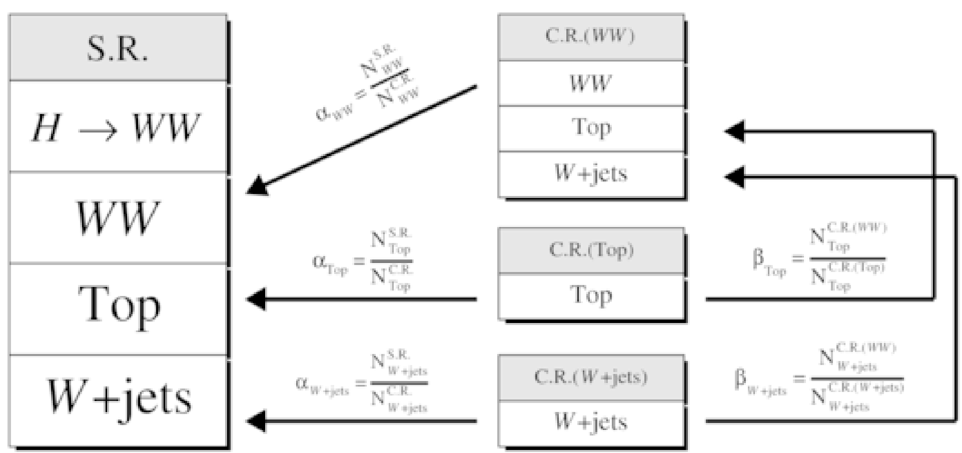




← CMS NN output

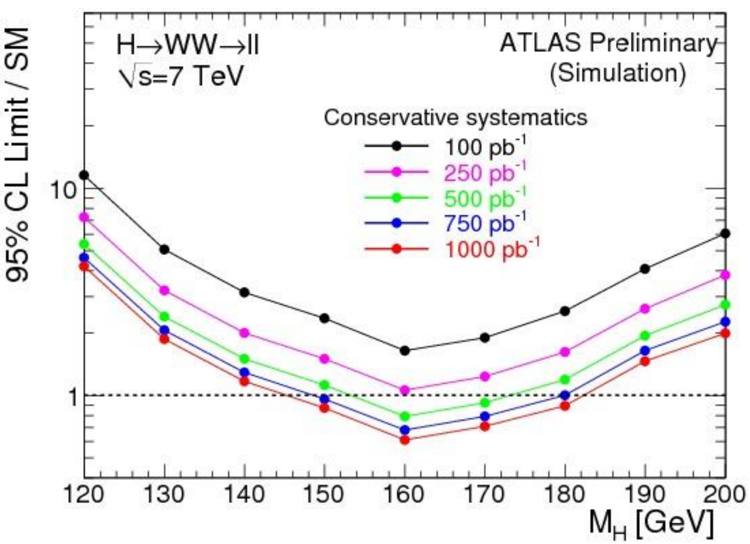


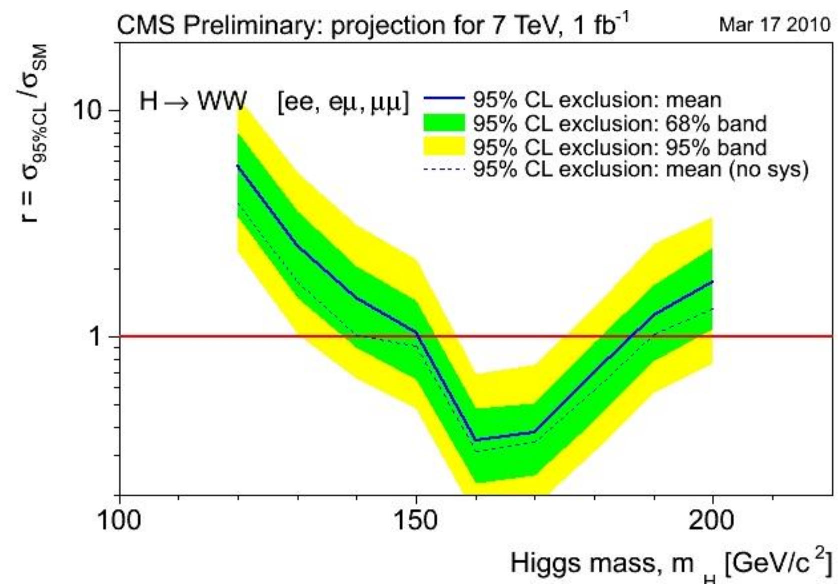
Determining background in signal region (ATLAS)



H→WW→ℓν ℓν

Ratio of 95% CL upper limit on σ x B(H→WW→ℓνℓν) and the SM rate



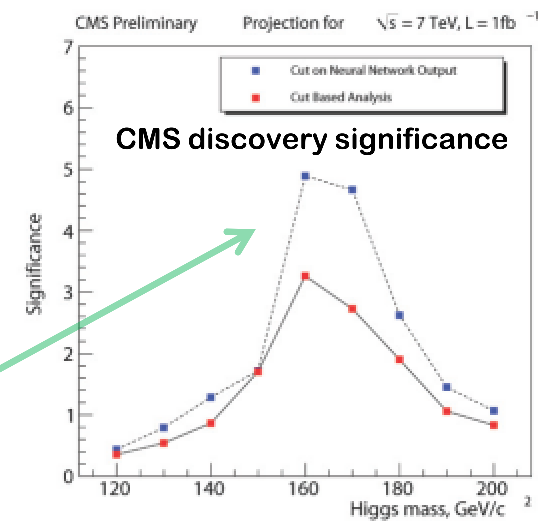


ATLAS

- sensitivity to SM starts with L = 250 /pb
- with L= 500 /pb would exclude same range as ICHEP 2010 TeVatron combination
- 145 < m_H < 180 GeV excluded (L=1 /fb)

CMS (L= 1 /fb)

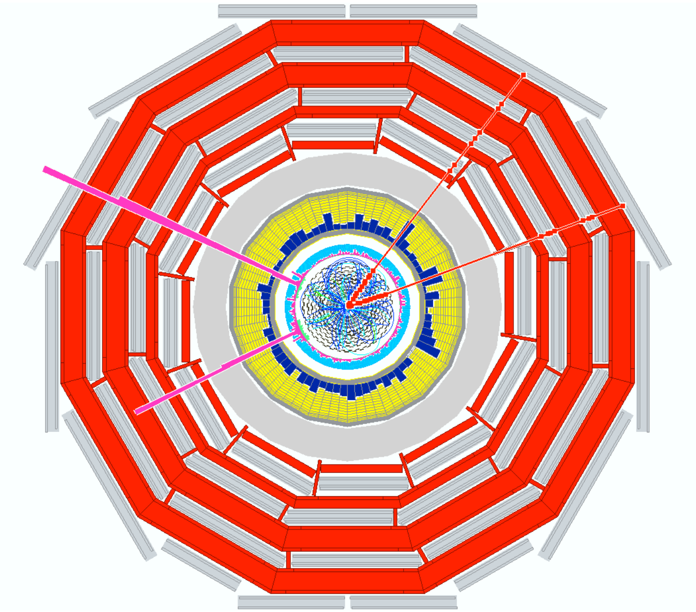
- 150 < m_H < 185 GeV excluded
- discovery sensitivity (significance > 4.5σ): 160 < m_H < 170 GeV



$H \rightarrow ZZ \rightarrow \ell\ell\ \ell\ell$

Very clear signature, low bgd: effective over a wide m_H range

- Four isolated high p_T leptons (4e, 4μ,2e2μ)
- Reconstruct narrow 4ℓ mass peak (m_Z constraint helps)



BUT

- low signal yield: $B(H\rightarrow ZZ) \times B^2(Z\rightarrow \ell\ell) < 10^{-3}$
- backgrounds: $ZZ^{(*)}$ dominates; Z+jets, tt, Zbb

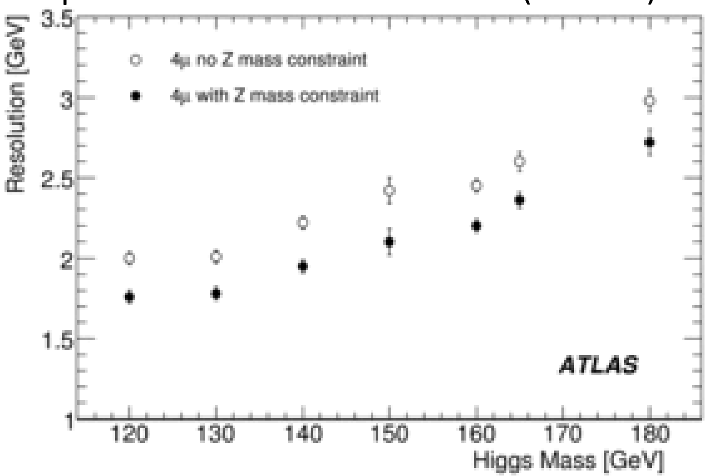
NEED

- high efficiency e/ reconstruction
- excellent lepton E and p resolution

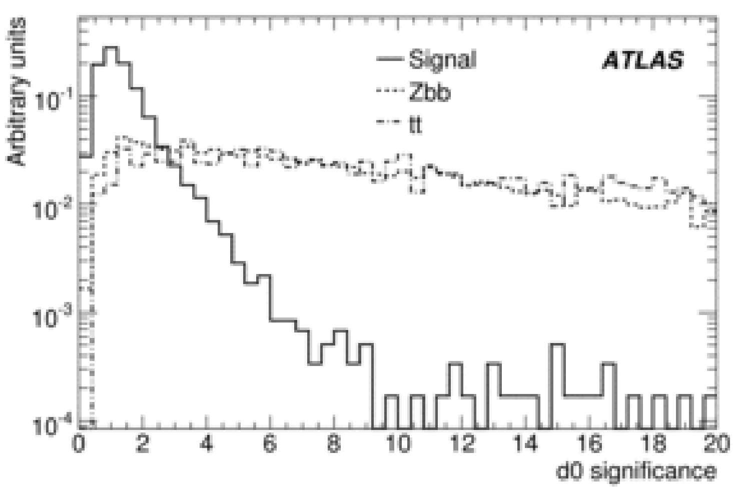
References: ATLAS CERN-OPEN-2008-020 (14 TeV); CMS PAS HIG-08/003 (14 TeV)

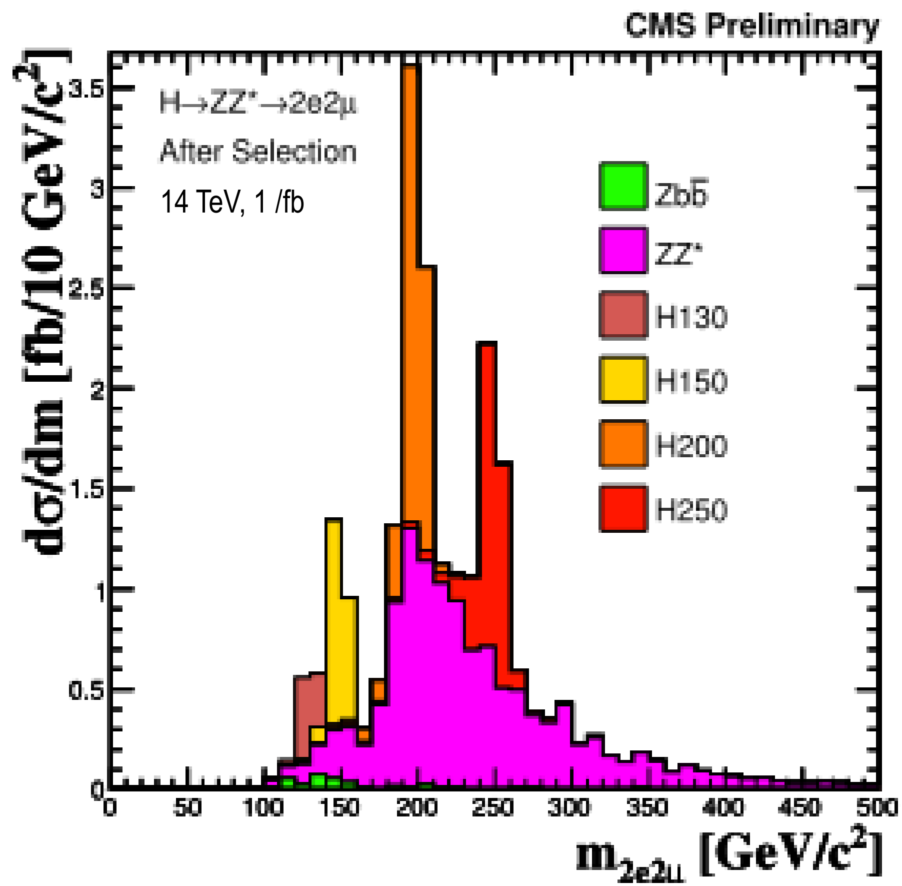
H→ZZ→ℓℓ ℓℓ

Z mass constraint:
improvement in mass resolution (10-20%)



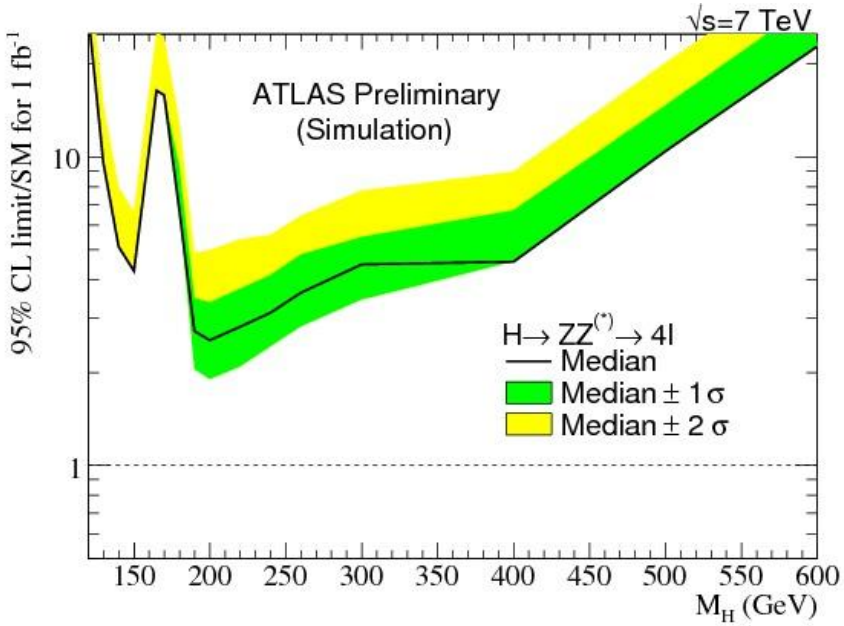
Impact parameter significance:
rejecting leptons from semi-leptonic B-decays

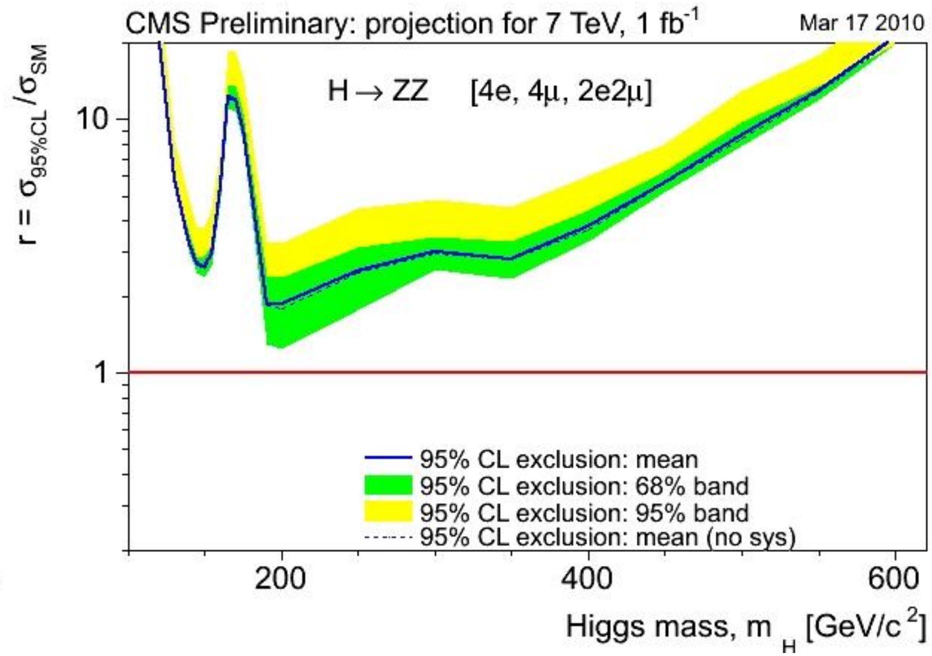




H→ZZ→ℓℓ ℓℓ

Ratio of 95% CL upper limit on σ x B(H→ZZ→ℓℓ ℓℓ) and the SM rate



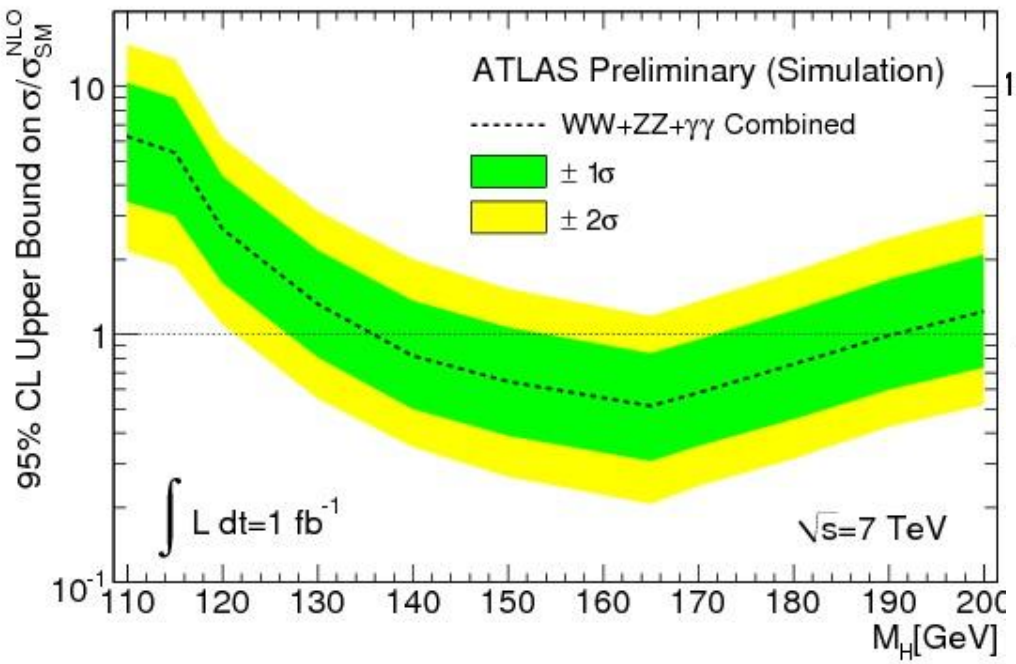


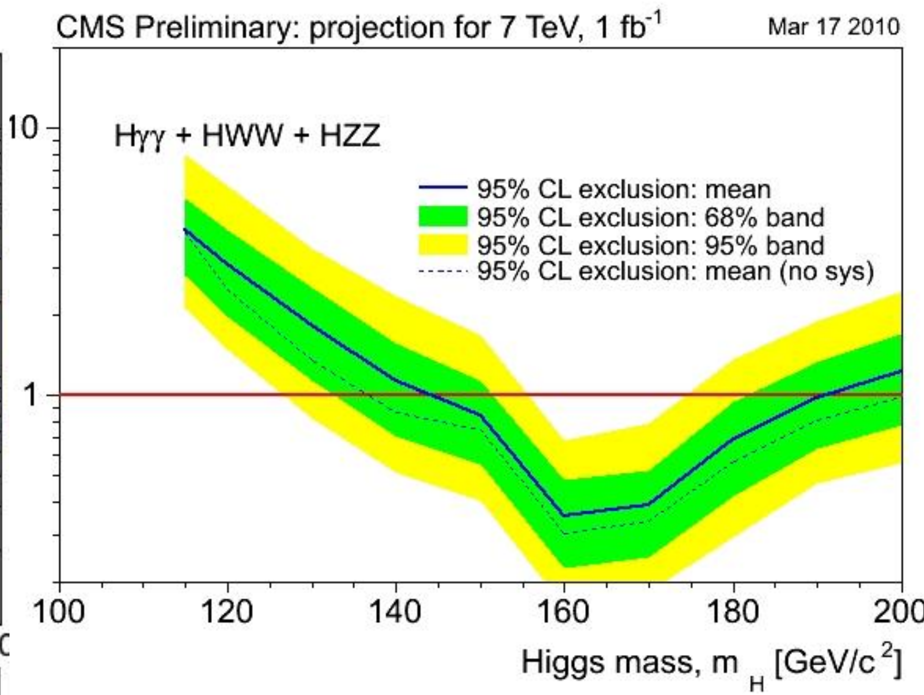
- No stand-alone exclusion
- But competitive sensitivity (< 4 x SM) in wide m_H region: 200 – 400 GeV

LHC 7 TeV combined results

95% CL upper bounds on cross-section (normalised wrt SM Higgs cross-section)

for 1/fb, and $H\rightarrow\gamma\gamma$ + $H\rightarrow WW\rightarrow \ell\nu\ell\nu$ + $H\rightarrow ZZ\rightarrow 4\ell$





$135 < m_H < 188$ GeV

$145 < m_H < 190$ GeV

- Both experiments combined (2 x CMS): **$140 < m_H < 200$ GeV** (95% CL excl.)
- Both experiments combined should exceed 5σ discovery potential for 160 – 170 GeV
- For low m_H will need more channels ($H\rightarrow bb$, $\tau\tau$), and higher $\sqrt{s}$

Subjets structure for Higgs search?

At the LHC: production of EW-scale particles ($W,Z,H,t\longrightarrow$jets) >> threshold

→ highly boosted/collimated decay products, with *measurable* **subjet structure;**

→ can be used to differentiate from QCD jets

Apply subjet analysis technique to WH+ZH ($H\longrightarrow bb$) at the LHC

- select events with very high p_T H and W,Z decay products
- cluster H decay products into a single fat jet
- iteratively decompose into **subjets** while checking for consistency with bbg
- two hardest subjets must b-tag
- subjets are "filtered" (cleanup contamination from underlying event)
- selected subjets are then used to reconstruct m_H: much improved mass resolution

- References: Butterworth et al, PRL**100** (2008)242001; ATL-PHYS-PUB-2009-088.

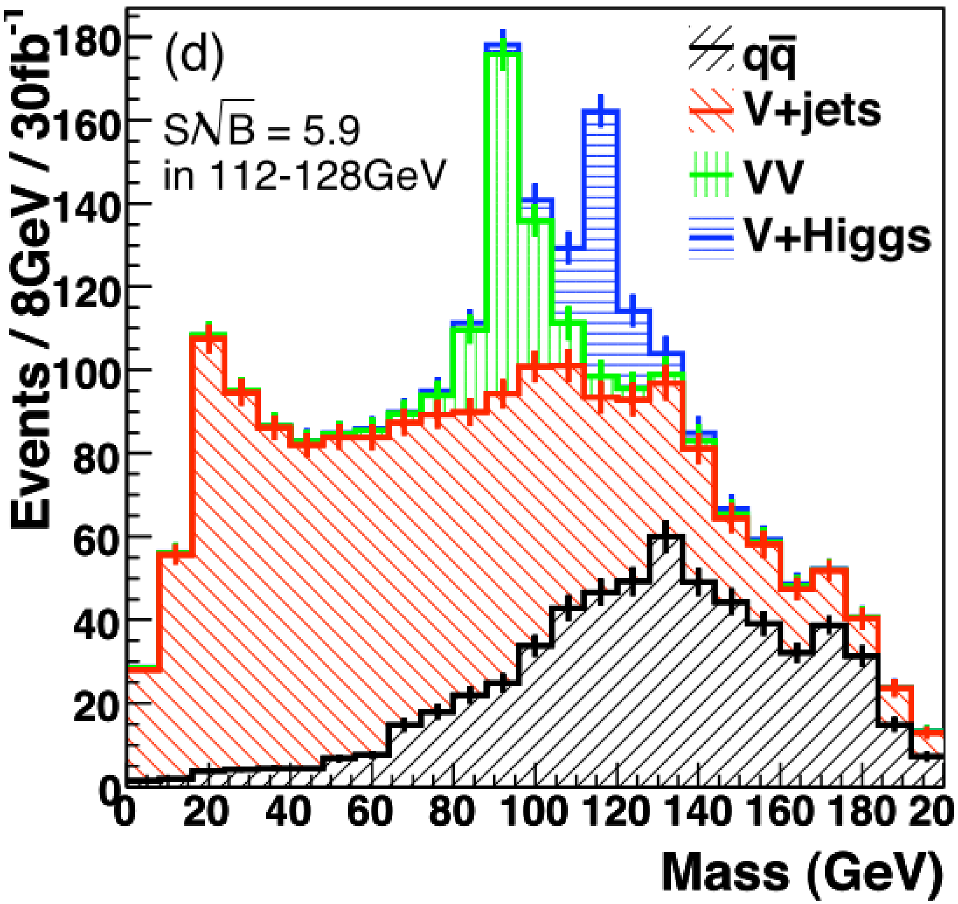
Subjets as Higgs search tool

LHC

J Butterworth – *Higgs Hunting 2010*

(WH→ℓν bb + ZH→ℓℓ bb + ZH→νν bb)

Combined particle-level result



- Note excellent Z peak for calibration
- 5.9 σ; potentially very competitive
- bb branching information critical for extracting Higgs properties
  - *"Measuring the Higgs sector" Lafaye, Plehn, Rauch, D.Zerwas, Duhrssen, arXiv:0904.3866 [hep-ph]*
- Studies within ATLAS are promising (14 TeV, ~4σ). 7 TeV nearly public.

HIGGS BEYOND THE SM

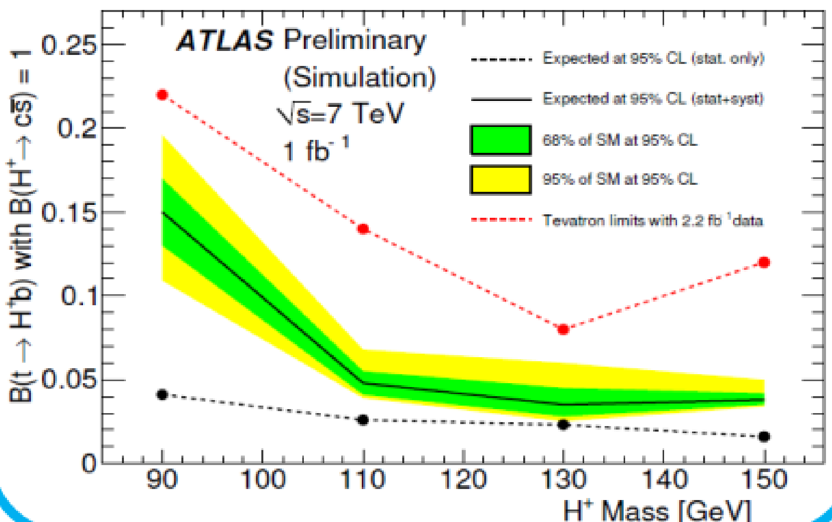
MSSM: $H^+ \rightarrow cs, \tau\nu$

ATLAS

- Light charged higgs ($m_{H+} < m_{top}$) can appear from top quark decay

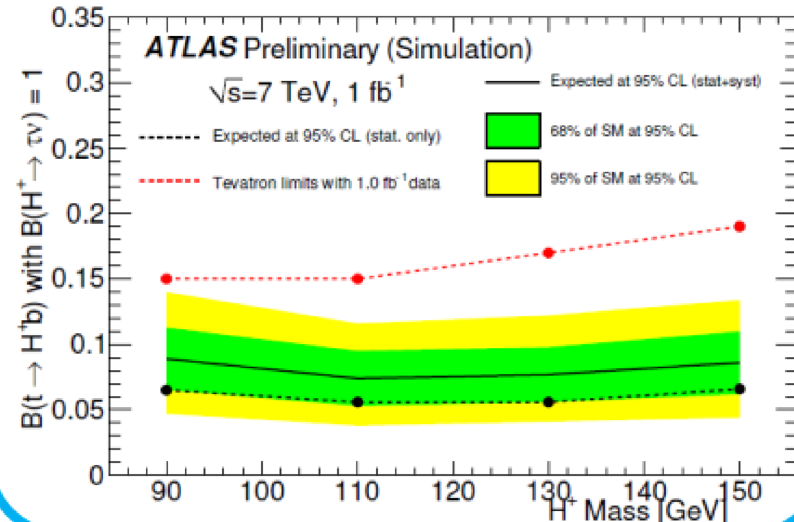
$H^+ \rightarrow c\bar{s}$ in semi-leptonic $t\bar{t}$ events

- lepton + MET + 4jets (with 2 b-tag)
- Reconstruct m_{H+} with 2 untagged jet
- Main background : ttbar (95%)
- Improve dijet mass resolution with leptonic W, top mass constraint



$H^+ \rightarrow \tau\nu$ in di-lepton $t\bar{t}$ events

- Use leptonic tau decay mode
- Two leptons + MET + 2 b-jets
- Main background : ttbar (90%)
- Look for excess close to -1 in helicity angle $\cos\theta_l^*$

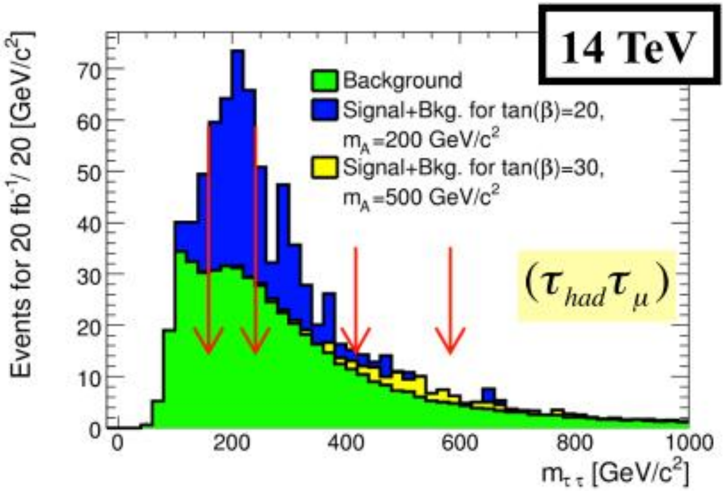


T Masubuchi – *ICHEP 2010*

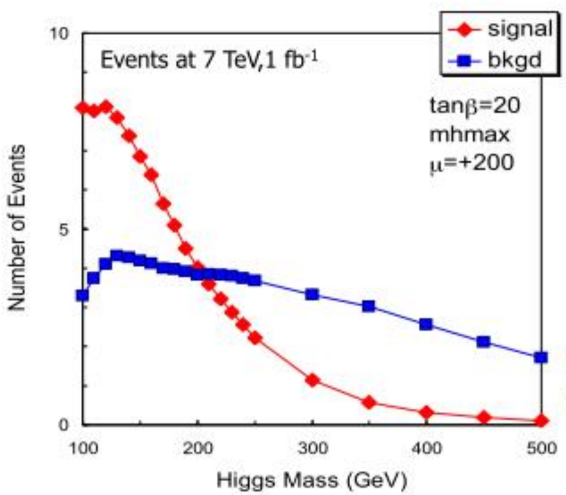
Better upper limit on branching ratio compared to current Tevatron results

MSSM Higgs pp→bbφ; φ→ττ

CMS

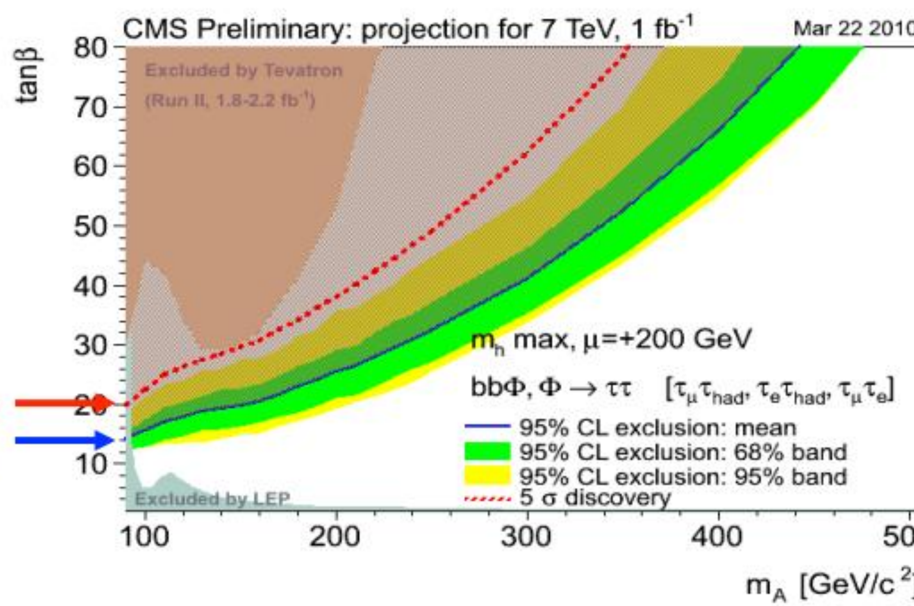


- – – Isolated pairs of $(\tau_{had}\tau_{\mu}),(\tau_{had}\tau_{e}),(\tau_{\mu}\tau_{e})$
- – – With MET, 1 tagged bjet, veto extra jets
- – – Build $\tau\tau$-mass using collinear approx
- – – Count events in sliding $\tau\tau$-mass window
- – – Dominant backgrounds: $t\bar{t}$, $Z+b\bar{b}$ & $Z+c\bar{c}$
  - -- assessed from data



discover

exclude



M Gataullin – *ICHEP 2010*

Conclusions and Outlook

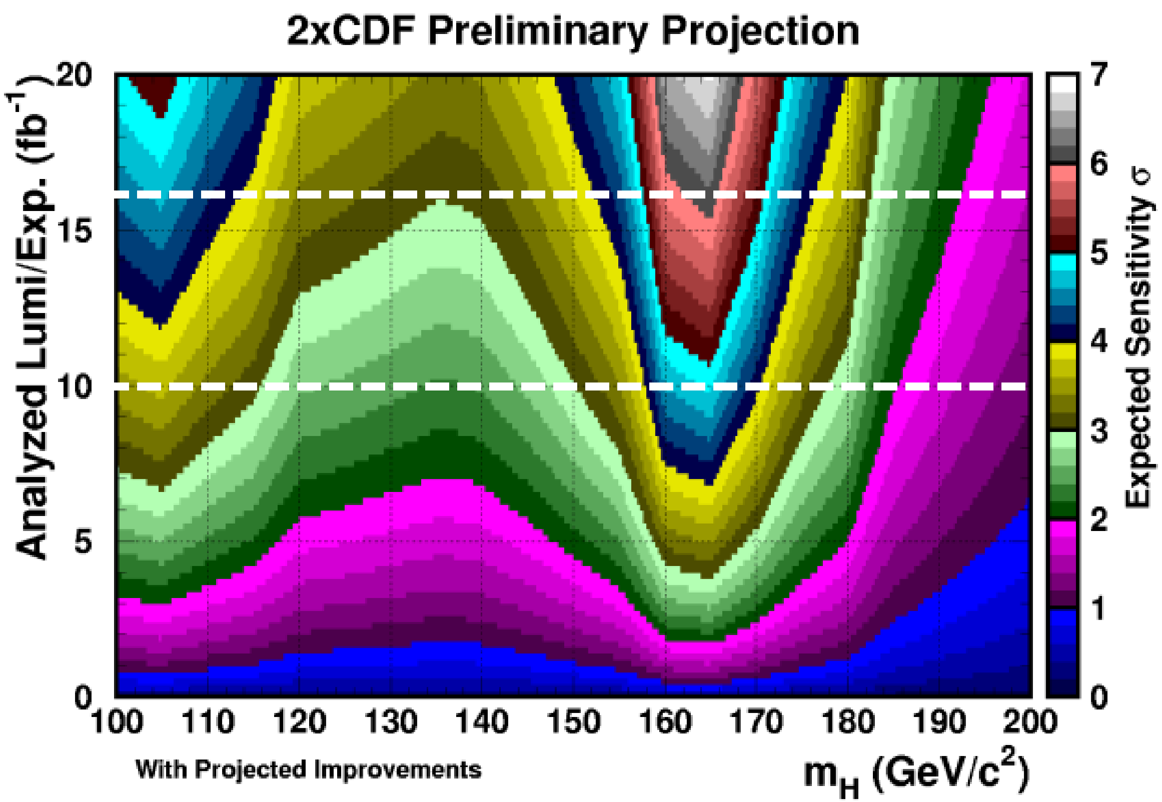
- TeVatron Higgs:
  - pushing on, with an impressive list of sophisticated searches
  - extended running for 3 more years proposed ("Run III")
- LHC:
  - machine and detectors operating extremely well
  - off to a good start! …but some major milestones still ahead of us
- LHC initial sensitivity to Higgs: expected early in 2011

This time next year we may have some real Higgs candidates… not just simulation!

Truly higgsciting times ahead!!

BACKUPS

TeVatron Higgs projections



Projections (based on 2 x CDF):

End 2011, 10 /fb

2.4σ expected across whole range

3σ at m_H=115 GeV

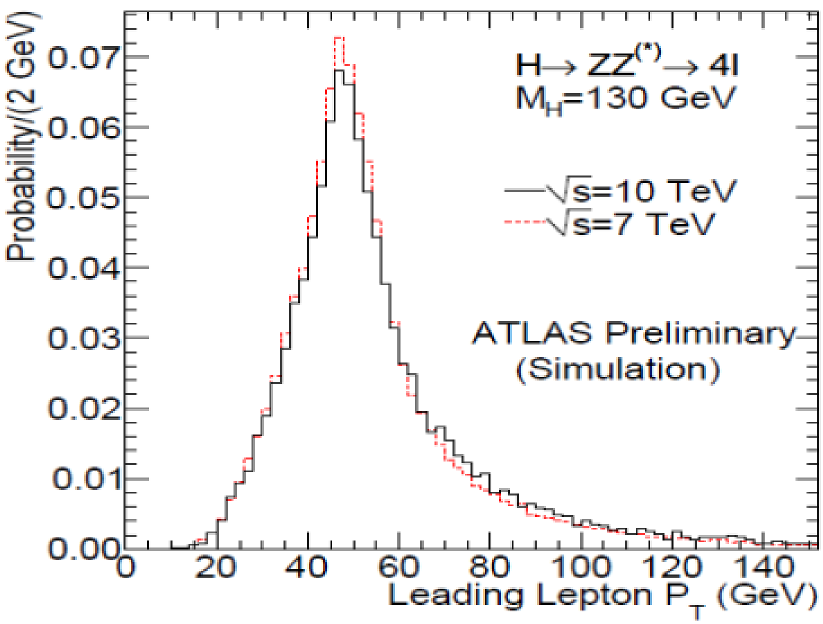
End 2014 (Run III), 16 /fb

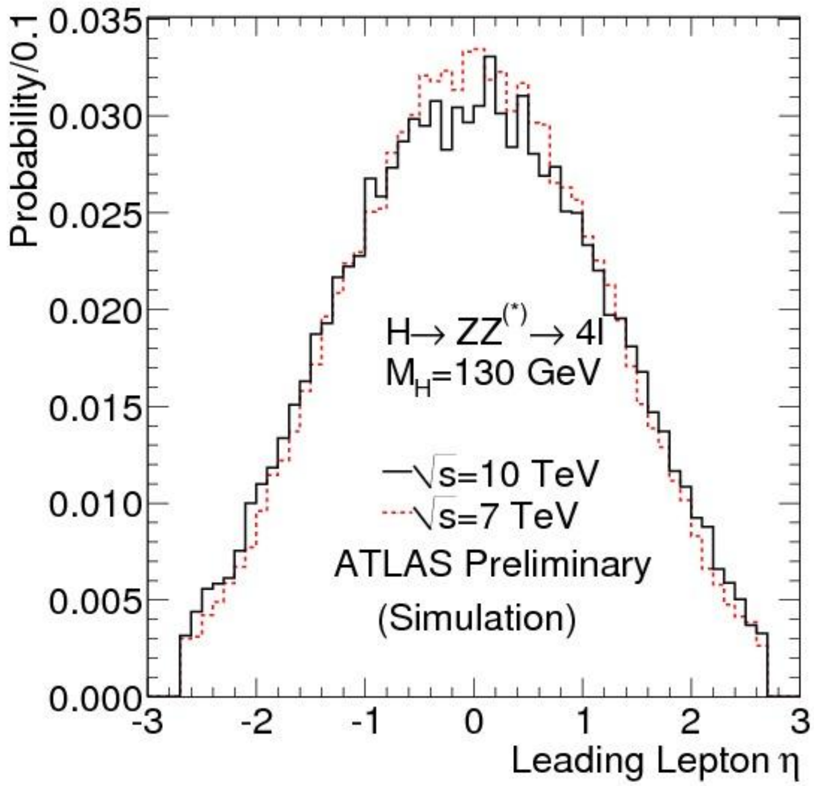
3σ expected across whole range

4σ at m_H=115 GeV

Rescaling effect on $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$

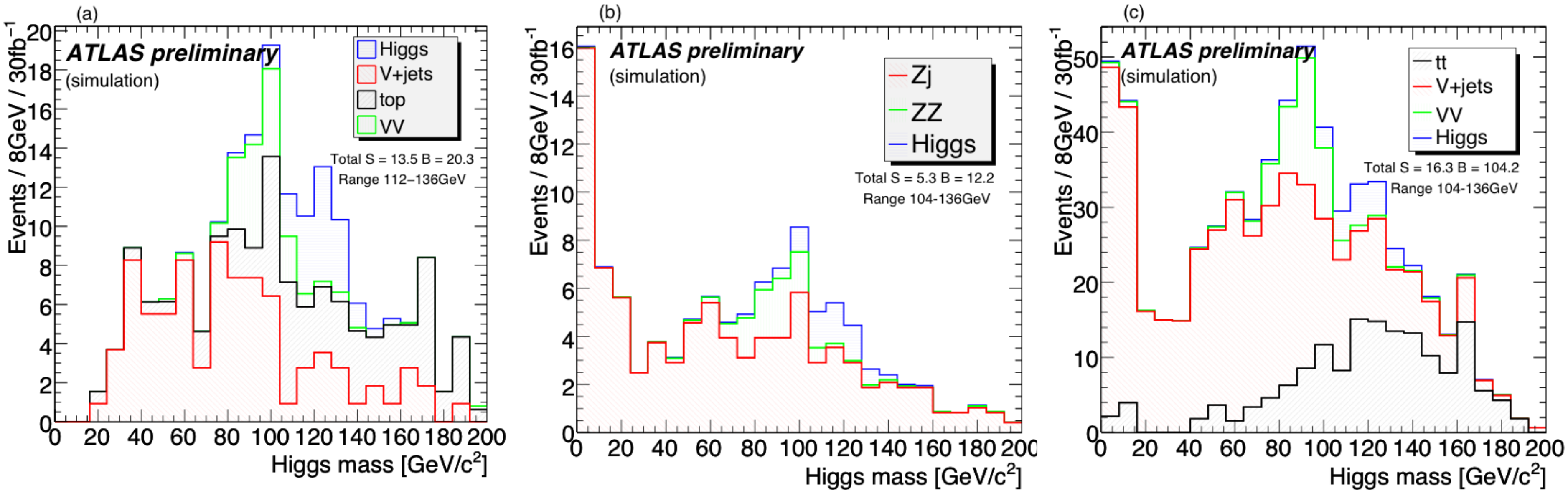
Acceptance of signal and irreducible ZZ background agree to within 2%





Fully simulated detector

- Included trigger, real ATLAS b-tagging algorithm, detailed tracking & calorimeter
- Also include Wt background omitted from initial study.
- Also included study of Wbb ME vs Wg->Wbb
- Slight degradation w.r.t particle level, but still very promising



Scale uncertainty

Higher orders (HO) guessed with μ_R, μ_F variation around central $\mu_0 = m_H$

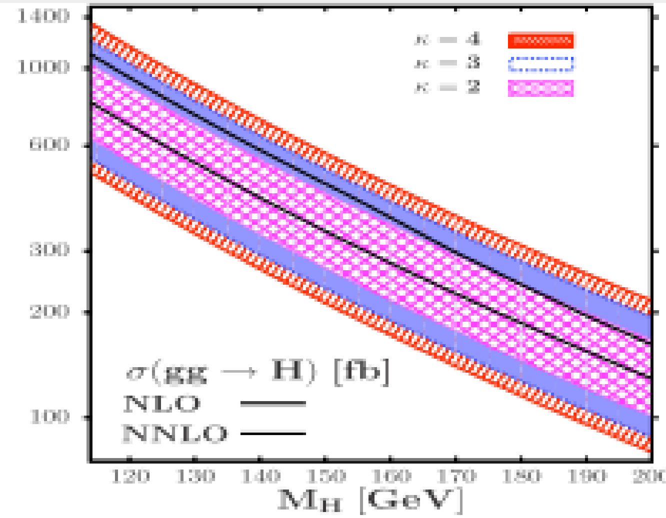
$$\frac{m_H}{\kappa} \leq \mu_R, \mu_F \leq \kappa m_H$$

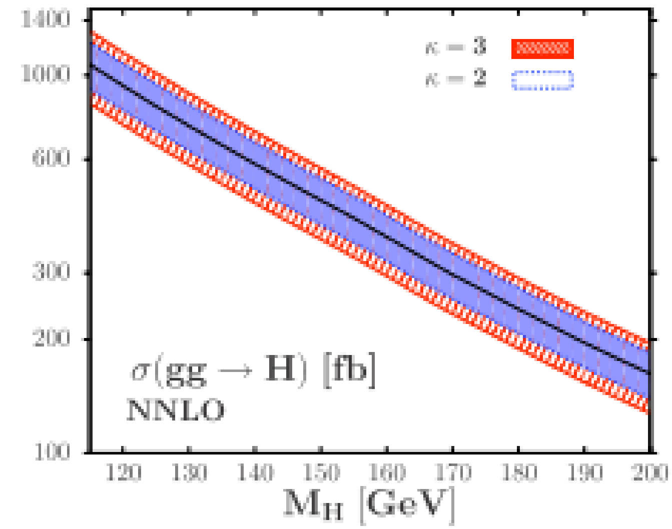
Small HO $\Rightarrow \kappa = 2$ enough (ex. $q\bar{q} \rightarrow HV$)

Large HO in $gg \rightarrow H$ ($K_{HO} \simeq 3$)
guess scale domain from $\sigma_{\rm NLO}$:
NLO band catches $\sigma_{\rm NNLO}$
$\Rightarrow \kappa = 3$ needed (at least) according to our criterium

NNLO $gg \rightarrow H$: $\simeq$ **20% scale variation**

($\neq$ 10% assumed by CDF/D0)





PDF and α_s^{exp+th} errors

Different sets of PDFs on the market

$\Rightarrow$ differents errors on individual PDF

+ different central values

All have $\sim 5-7\%$ error, but central ABKM is 25% smaller than MSTW/CTEQ !

Add PDF+$\alpha_s^{\rm exp}$ correlated error (MSTW dedicated set)

$\Rightarrow \alpha_s(M_Z) = 0.1171 \pm 0.0034$ (90%CL) error

Add $\Delta^{\rm th}\alpha_s = 0.002$ error with central fixed–α_s MSTW PDF sets

$\Rightarrow$ ABKM is now consistent with MSTW/CTEQ

$\sim$ **20% final error $\gg$ 5% PDF alone**