Higgs Boson Search Sensitivity in the $H \to W^+W^-$ Decay Mode at $\sqrt{s} = 7$ and 10 TeV

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Pheno 2010 - LHC Decade!

work in collaboration with:
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arXiv:1003.3875

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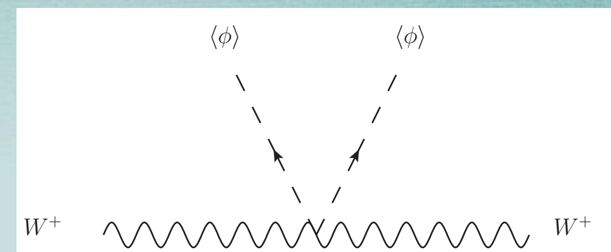
Introduction

- One of the primary goals of the LHC is to probe the mechanism for Electroweak Symmetry Breaking (EWSB)
  - What gives the W and Z bosons mass?
  - In the SM, it is the Higgs boson

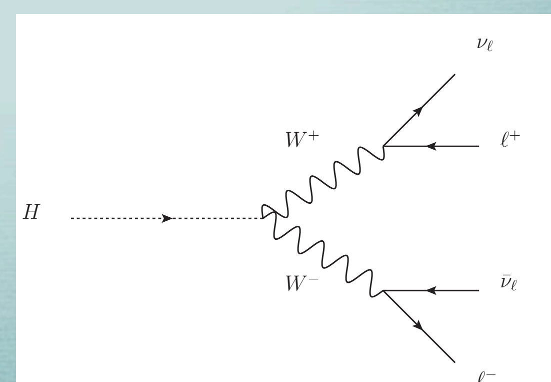


- New LHC plan is to run at 7 TeV to accumulate roughly 1 fb^{-1} of data

- In this scenario:
  - Can the LHC be expected to probe the EWSB sector of the SM?
  - What might the Tevatron say after 10 fb^{-1} of accumulated data?

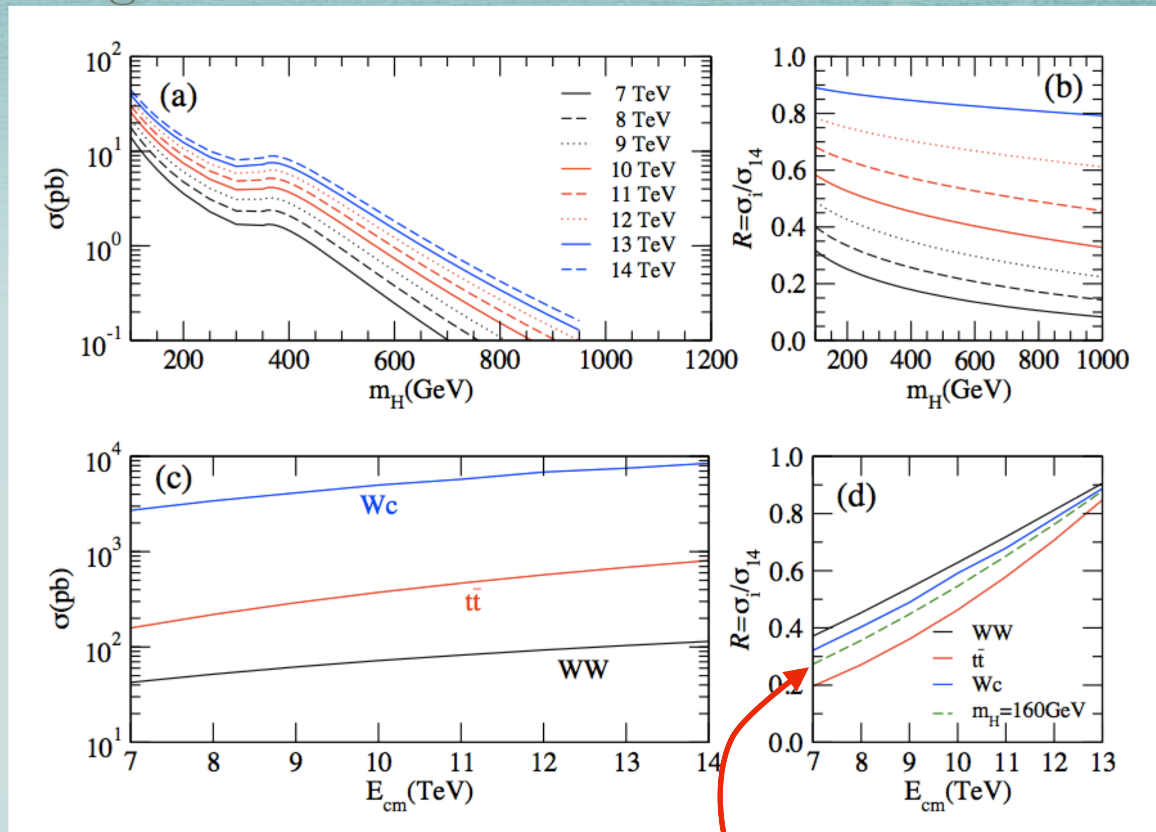
- We focus on $H \to W^+W^-$ channel alone

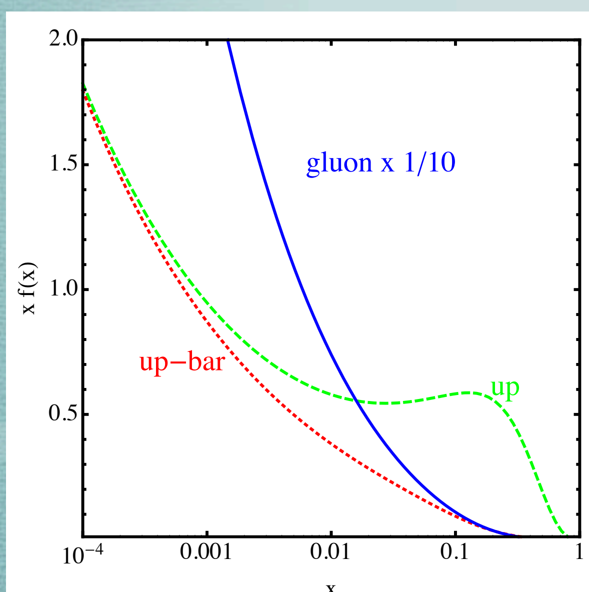
Barger, Han, Bhattacharya, Kniehl ('91)



Scaling of cross sections

- Decreased E_{cm} probes different region of Bjorken-x
- Gluon-induced channels more suppressed than valence-quark induced channels





$$\langle x_1 x_2 \rangle \simeq \frac{m_H^2}{S}$$

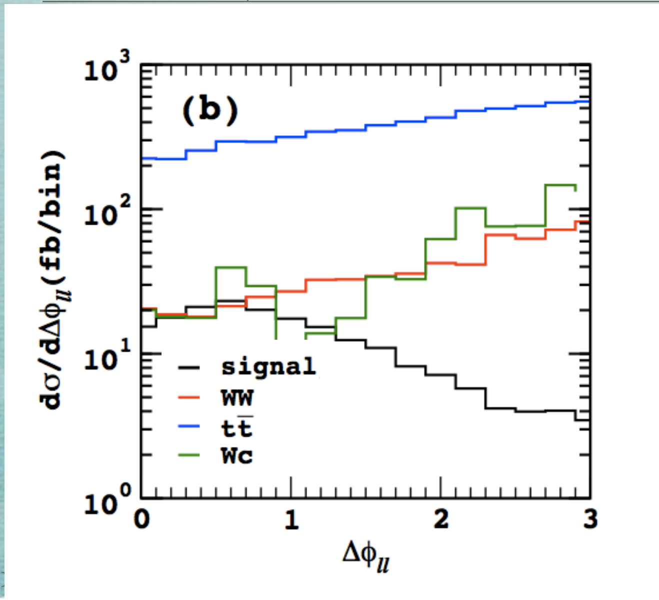
Lower rates and lower S/B

ATLAS and CMS cuts

ATLAS Technical Design Report arXiv:0901.0512.

CMS Technical Design Report Volume II

	ATLAS	CMS
BKGDs	$t\bar{t}$ WW W+jets Single t $Z \to ll$	$qq/gg \to WW \to ll$ $t\bar{t} \to WWbb \to ll$ $tWb \to WWb(b) \to ll$ $ZW \to lll$ $ZZ \to ll$
Preselection	Two leptons with opposite charge with $p_T > 15$ GeV and $\|\eta\| < 2.5$ (crack region $1.37 < \|\eta\| < 1.52$)	Two tagged leptons with opposite charge with $p_T > 20$ GeV and $\|\eta\| < 2$
Physics Cuts	$12\,\text{GeV} < m_{ll} < 300\,\text{GeV}$ $\not{E}_T > 30$ GeV $Z \to \tau\tau$ veto with $\|m_{\tau\tau} - m_Z\| < 25\,\text{GeV}$ No jets with $p_T > 20\,\text{GeV}$ and $\|\eta\| < 4.8$, No b-jets with $p_T > 15\,\text{GeV}$ $\Delta\phi_{ll} < \pi/2$ and $M_T^C < 600\,\text{GeV}$	$\not{E}_T > 50$ GeV $\Delta\phi_{ll} < \pi/4$ $12\,\text{GeV} < m_{ll} < 40\,\text{GeV}$ No jets with $p_T > 15\,\text{GeV}$ and $\|\eta\| < 2.5$ $30\,\text{GeV} < \max\{p_T^{l1}, p_T^{l2}\} < 55\,\text{GeV}$ $25\,\text{GeV} < \min\{p_T^{l1}, p_T^{l2}\}$



- CMS is more sensitive to near the $H \to W^+W^-$ threshold ($\Delta\phi_{\ell\ell}$ cut)
- CMS uses all lepton combinations: $e^+e^-, \mu^+e^-, e^+\mu^-, \mu^+\mu^-$
- DY rejected by strong $m_{\ell\ell}$ cut
- ATLAS uses $\mu^+e^-, e^+\mu^-$

Simulation Details

- Parton level analysis of signal and background
  - Signal: $pp \to H + nj \to W^+W^- + nj \to \ell^+\nu\ell^-\bar{\nu} + nj, \quad n \le 2$
  - Dominant backgrounds:

irreducible $pp \to W^+W^- + nj \to \ell^+\nu\ell^-\bar{\nu} + nj, \quad n \le 2$

reducible
$$pp \to Wc + nj \to \ell\nu c + nj\,, \quad n \le 4$$
$$pp \to t\bar{t} + nj \to W^+W^-b\bar{b} + nj \to \ell^+\nu\ell^-\bar{\nu}b\bar{b} + nj, \quad n \le 2$$

- Additional jets included to model ISR and hard jet recoils
- Take CMS and ATLAS preselection cuts with jet veto of

$$\text{ATLAS: } p_T(j) > 20 \text{ GeV}, \ |\eta_j| < 4.8$$
$$\text{CMS: } p_T(j) > 15 \text{ GeV}, \ |\eta_j| < 2.5$$

- Energy resolution: $\dfrac{\delta E}{E} = \dfrac{a}{\sqrt{E/\text{GeV}}} \oplus b$

where $a = 10\%$ (50%) and $b = 0.7\%$ (3%) for leptons (jets).

Comparison with ATLAS

Table 1: Cut acceptance for $m_H = 170\,\text{GeV}$ for Higgs boson production via gluon fusion, with $H \to WW \to e\nu\mu\nu$, at 14 TeV. The kinematic cuts listed in each row are applied sequentially.

	$H + (0,1,2)j$		$t\bar{t} + (0,1,2)j$		$WW + (0,1,2)j$		$Wc + (0-4)j$	
	Our	ATLAS	Our	ATLAS	Our	ATLAS	Our	ATLAS
i.d. + $m_{\ell\ell}$	100%	100%	100%	100%	100%	100%	100%	100%
$\not{E}_T$	89%	89%	88%	86%	71%	70%	57%	87%
$Z \to \tau\tau$	89%	88%	88%	80%	71%	68%	57%	72%
Jet veto	37%	37%	0.31%	0.23%	31%	33%	28%	36%
b veto	37%	37%	0.31%	0.11%	31%	33%	28%	36%
$\Delta\phi_{\ell\ell}$ and M_T^C	30%	30%	0.07%	(0.04 ± 0.03)%	12%	(12 ± 0.4)%	8%	(18 ± 18)%

- ATLAS comparisons quite good for $m_H = 170$ GeV at 14 TeV
- Similar comparison for other masses at 14 TeV
- Largest uncertainty from $W^{\pm}c$ background
  - Our uncertainty ±10%

Comparison with CMS

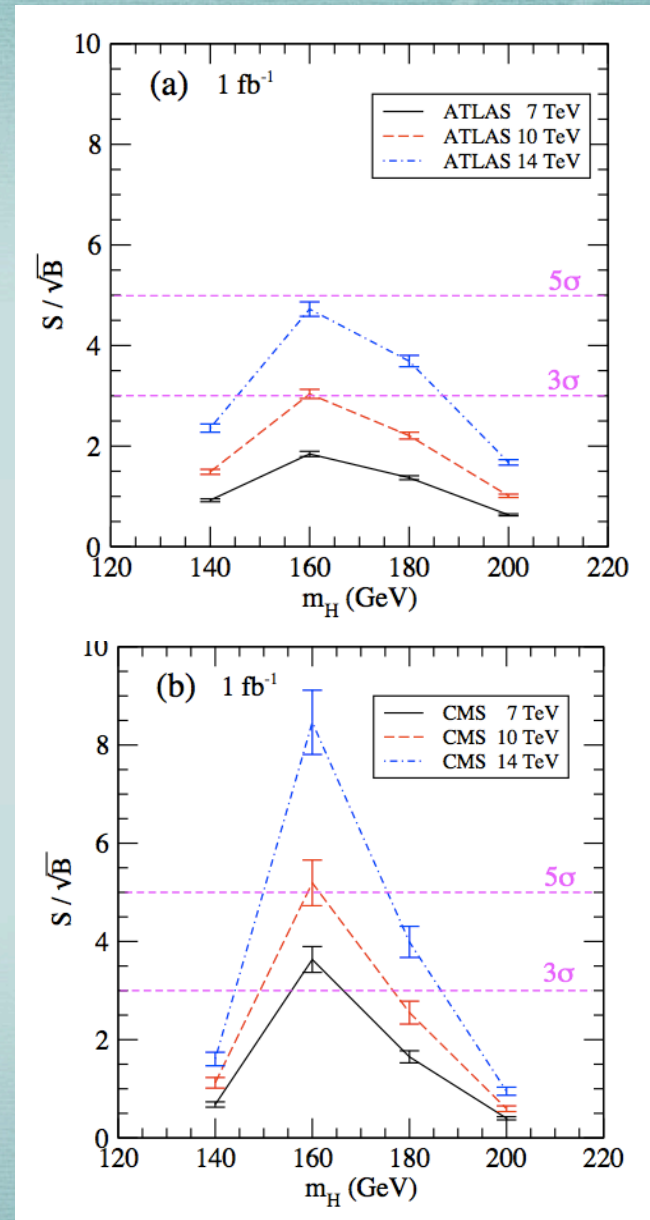
Table 1: Acceptance comparison to the CMS study for $m_H = 170\,\mathrm{GeV}$ at 14 TeV.

	$H + (0,1,2)j$		$t\bar{t} + (0,1,2)j$		$WW + (0,1,2)j$	
	Our	CMS	Our	CMS	Our	CMS
lepton selection	100%	100%	100%	100%	100%	100%
All cuts	9.6%	8.8%	0.016%	0.062%	1.16%	1.07%

- CMS signal and continuum background acceptance comparison quite good
- The $t\bar{t}$ background acceptance different than in CMS report
  - Smaller jet p_T threshold cut may be responsible
  - Lower p_T region may require parton showering
  - In our results, we provide both our $t\bar{t}$ and the CMS $t\bar{t}$ numbers to compare
  - Due to good rejection of $t\bar{t}$ conclusions not altered

LHC signal significance

- Four test masses m_H = 140, 160, 180 and 200 GeV at $\sqrt{s}$ = 7, 10 and 14 TeV
- Signal significances with 1 fb^{-1} of integrated luminosity
- Cut preference for $H \to W^+W^-$ threshold apparent in the CMS case
- 3σ evidence possible for m_H = 160GeV
- Error bars based on Poisson statistics



LHC Luminosity required for 5σ

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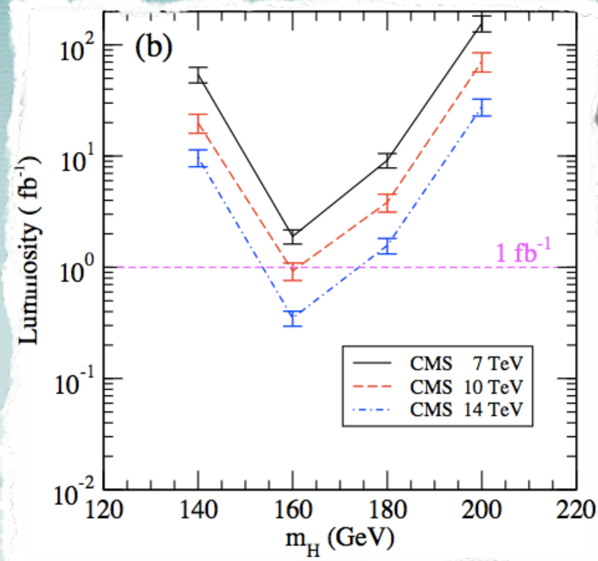
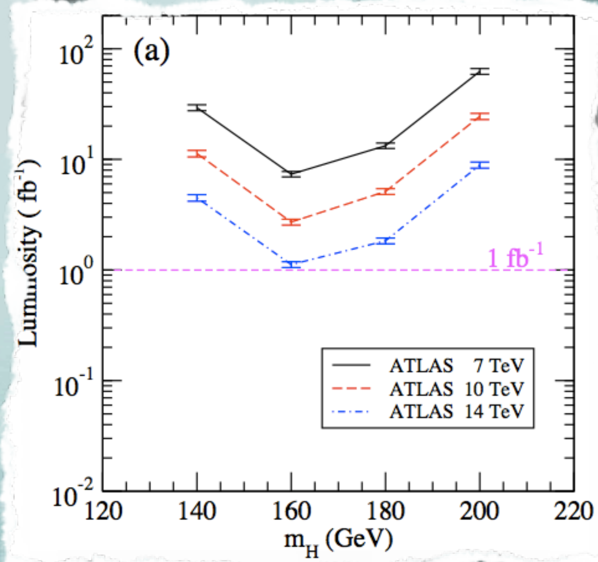
- Target luminosity required for significance given by

$$\frac{S}{\sqrt{B}} = \frac{\sigma_S}{\sqrt{\sigma_B}} \times \sqrt{\mathcal{L}}$$

- Higgs boson discovery though the $H \to W^+W^-$ channel may require at least 2 fb^{-1} at 7 TeV using CMS cuts
    - Increased to ~ 8 fb^{-1} with ATLAS cuts





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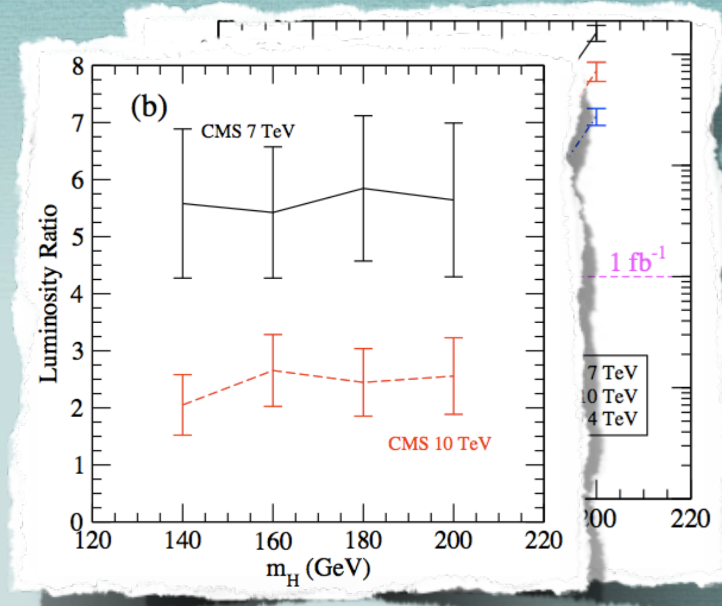
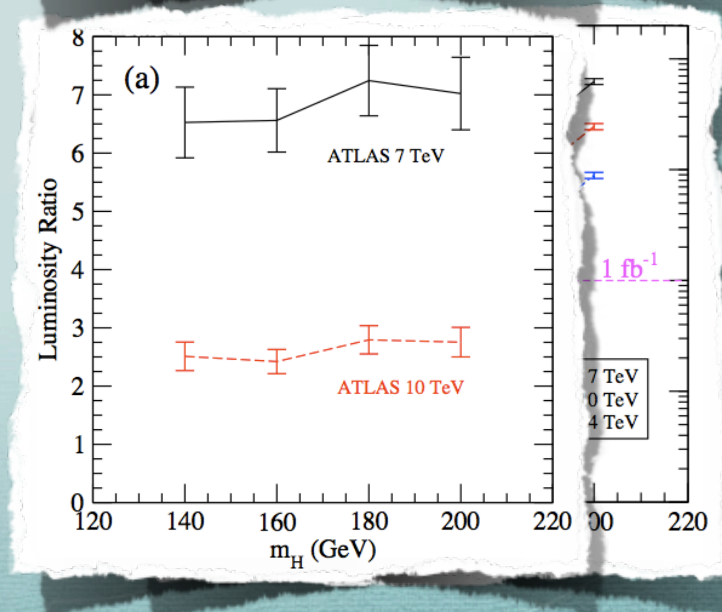
- Luminosity factor w.r.t 14 TeV machine

$$\frac{\mathcal{L}_i}{\mathcal{L}_{14}} = \left[\left(\frac{\sigma_S}{\sqrt{\sigma_B}}\right)_{14} \Big/ \left(\frac{\sigma_S}{\sqrt{\sigma_B}}\right)_i\right]^2$$

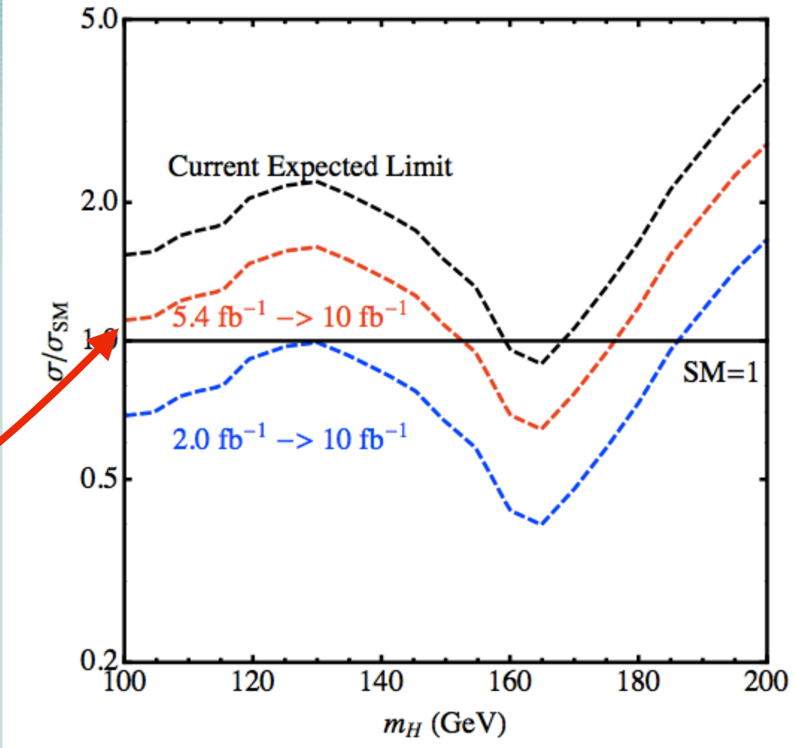
- Larger error-bars for CMS due to lower overall rate from tighter cuts





Tevatron Sensitivity

- Current combined Tevatron SM Higgs limits naively scaled to give projected limit
  - Combination of modes from CDF and DO with range of $2.0\ \text{fb}^{-1}$ to $5.4\ \text{fb}^{-1}$ of data
- Scaling of combined limit by $\sqrt{\mathcal{L}_{current}/\mathcal{L}_{projected}}$
- $5.4\ \text{fb}^{-1}$ scaling excludes mass ranges from ~150 GeV - 180 GeV with $10\ \text{fb}^{-1}$
- More detailed analysis where scaling of individual modes, then combining done with earlier data set
  - Comparison with our $5.4\ \text{fb}^{-1} \rightarrow 10\ \text{fb}^{-1}$ scaling nearly identical

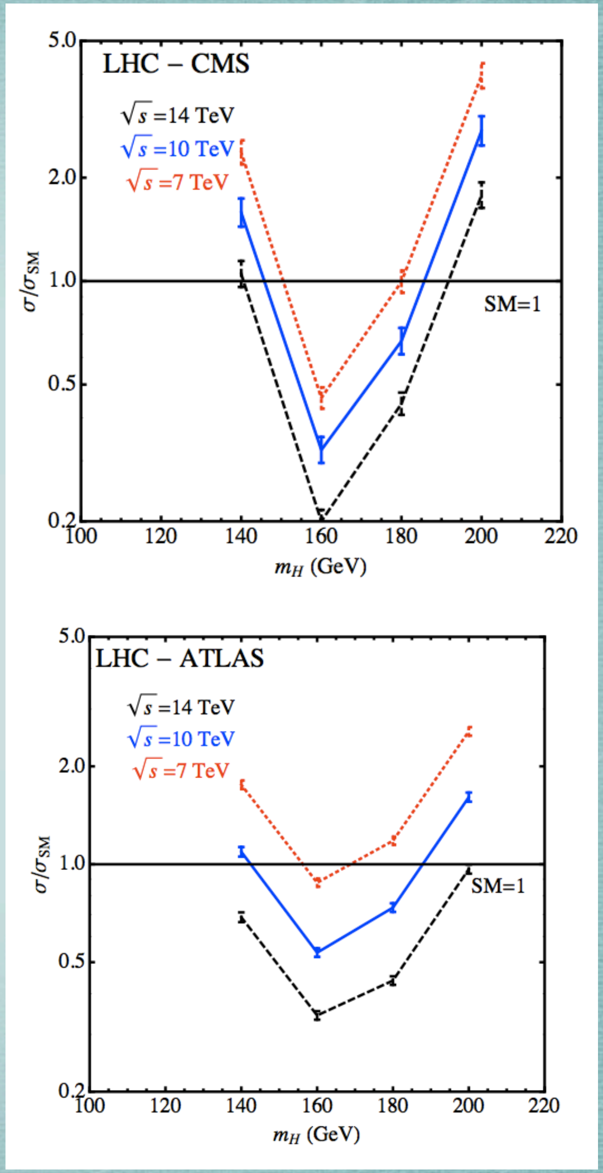


Current exclusion @ 95% C.L.:
$163\ \text{GeV} \le m_H \le 166\ \text{GeV}$

Draper, Liu, Wagner ('09)

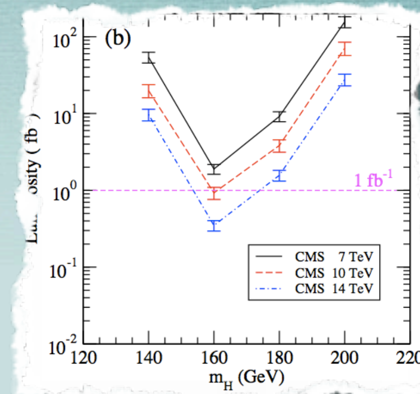
LHC exclusion reach at 7 and 10 TeV

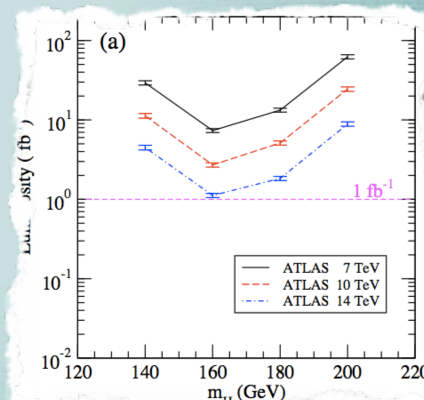
- Recast our results into signal exclusion assuming Poisson statistics
  - ATLAS cuts at 7 TeV with 1 fb^{-1} comparable to current Tevatron limits
  - With 1 fb^{-1}, CMS cuts may exclude 160 GeV and 180 GeV at 7 TeV
    - Linear interpolation*: 150 GeV - 180 GeV
- To compare with CMS/ATLAS analyses:
  - CMS Exclusion range from $150 \text{ GeV} \leq m_H \leq 185 \text{ GeV}$ at 95% C.L. https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResultsHIGSevenTeV
  - ATLAS claims similar exclusion
- Improvement possible by
  - Tuning cuts for trial Higgs masses
  - More advanced signal extraction: Matrix Element, Neural Net, Boosted Decision Tree



Conclusions

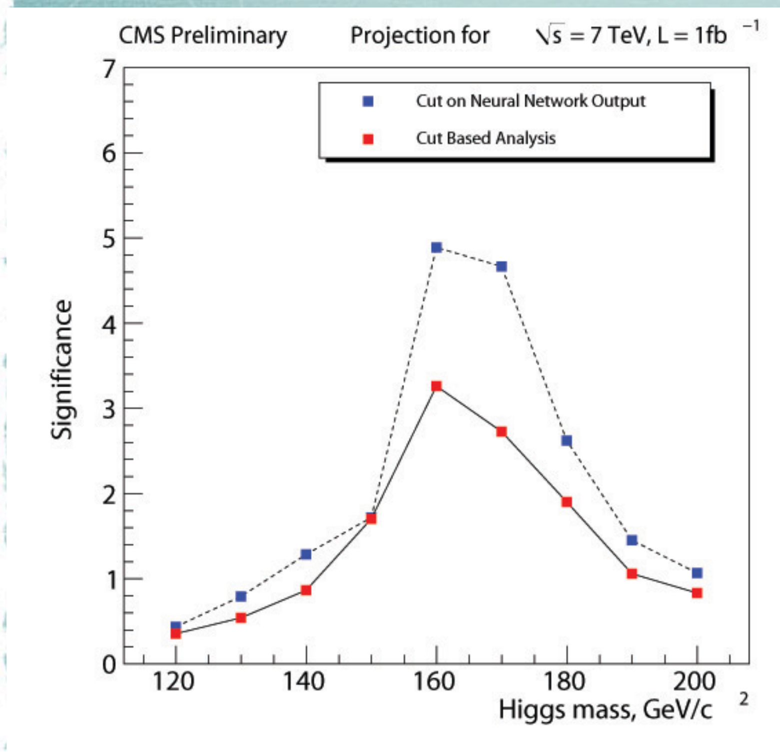
- Sensitivity of LHC at 7 and 10 TeV to the $H \to W^+W^-$ dilepton channel based on CMS and ATLAS-style cuts:
  - Verified ATLAS and CMS significances for 14 TeV
  - Luminosity increase for discovery w.r.t. 14 TeV by factors of 2.5 for 10 TeV and 6-7 for 7 TeV
  - Discovery may require at least 2(8) fb^{-1} at 7 TeV using CMS(ATLAS) cuts
  - With 1 fb^{-1}, CMS cuts may exclude 160 GeV and 180 GeV at 7 TeV
    - Linear interpolation* yields exclusion from 150 GeV - 180 GeV
    - Comparable to recent CMS/ATLAS studies of $150\ \text{GeV} \leq m_H \leq 185\ \text{GeV}$
  - Projected Tevatron exclusion limits with 10 fb^{-1} may be competitive with LHC reach after 1 fb^{-1}



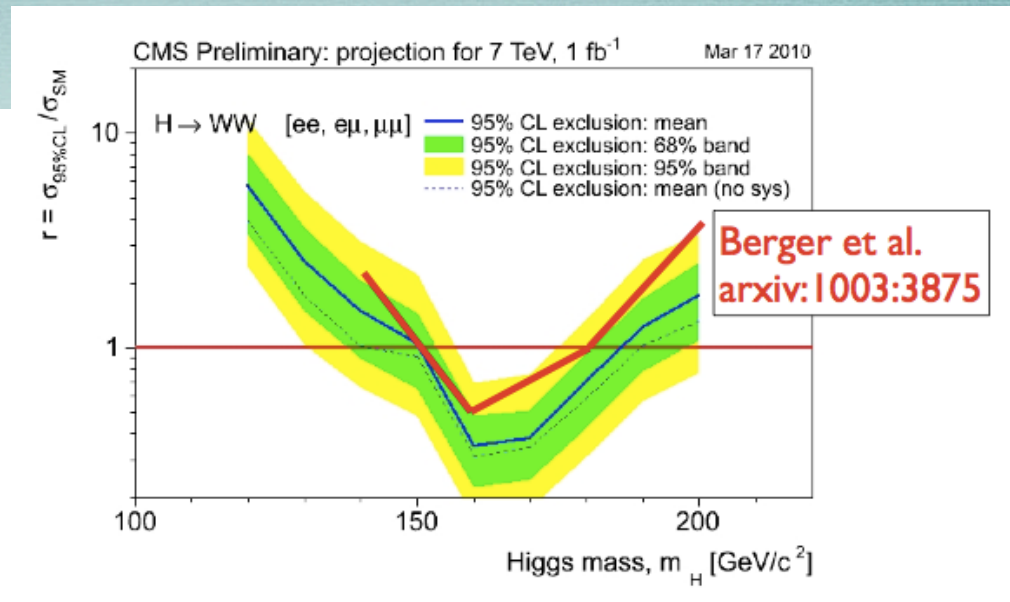


More sophisticated analyses can further push the reach for the Higgs boson

CMS Higgs Exclusion and Discovery

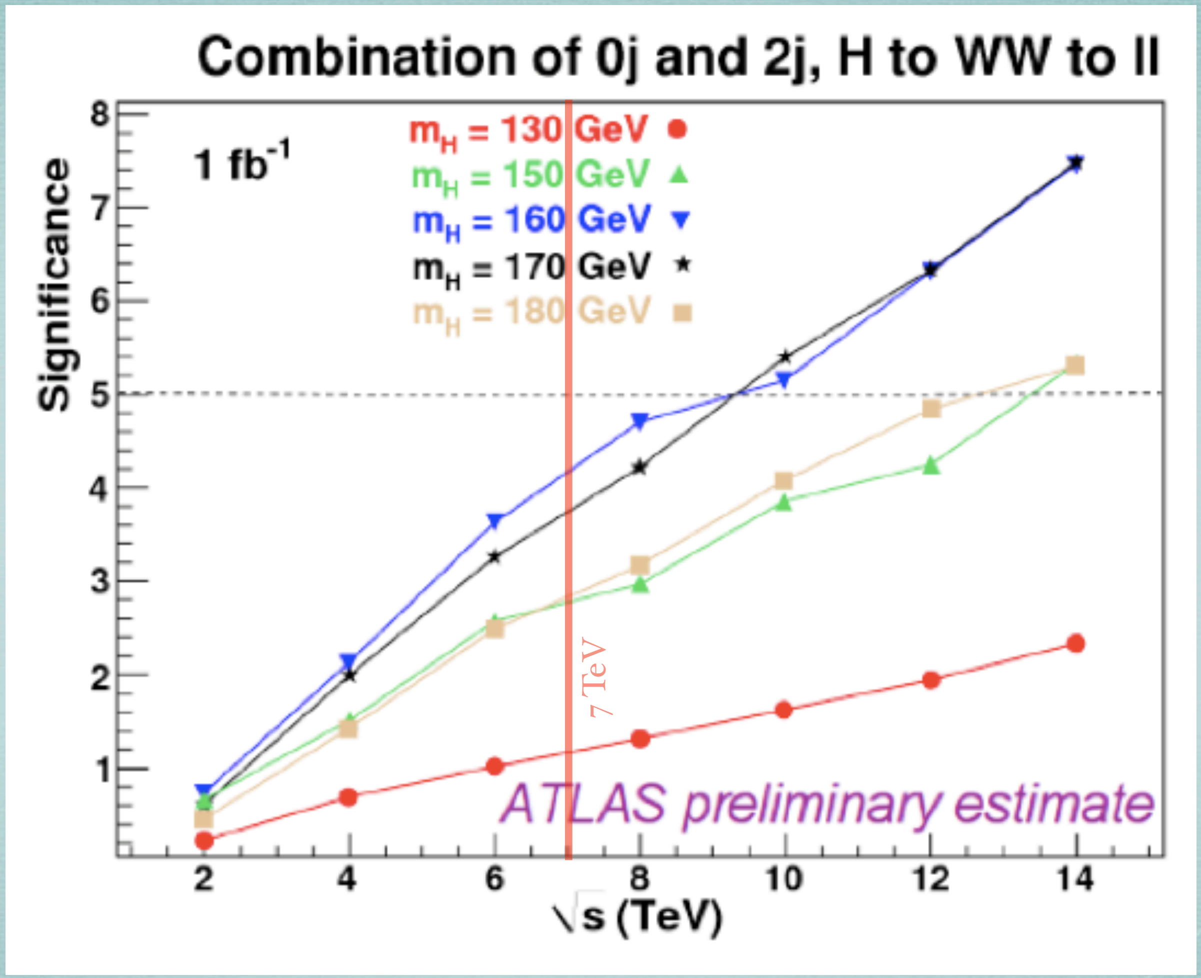


CMS PAS HIG-08-006 for cuts scaled to 7 TeV by cross section ratio



See John Conway's Monday CMS Talk

ATLAS Higgs Discovery



See Jianming Qian's Monday ATLAS Talk