Implications (Perspectives) from Tevatron Higgs

Ben Kilminister (Fermilab)
Workshop on Implications of LHC results for TeV-scale physics
August 29, 2011
• Prospects
  – What are the most interesting Higgs results we can expect from Tevatron with full dataset of 10 fb-1?

• Perspectives
  – What can Tevatron teach us given the recent CMS & ATLAS Higgs results?
- Exclusion 156 GeV – 177 GeV, 100 – 109 GeV
- Below 115 GeV
  - Expected = observed
  - Almost at SM 95% CL exclusion
- Expected sensitivity less than 1.35*SM across interesting range (114 – 185 GeV)
  - Most difficult at 130 GeV
TEV, CMS, ATLAS
Consistencies TeV, CMS, ATLAS

- Sensitivities to $< \sim 2 \times \text{SM}$ for 125 to 200 GeV
- Exclusion above 155 GeV
- Excesses overlap 130 to 155 GeV
  - But, CMS/ATLAS nearly exclude this range

- Sensitivity at 130 GeV
  - CMS : 0.9*SM
  - ATLAS : 1.1*SM
  - Tevatron : 1.35*SM
Differences TeV, CMS, ATLAS

• LHC is ~ 1.5 - 2 Sigma high ~155 to 175 GeV
  • No excess at Tevatron
Differences TeV, CMS, ATLAS

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  - No excess at Tevatron

- Tevatron sensitivity improves for less than 130 GeV as you go down in mass
  - Opposite at CMS, ATLAS
Differences TeV, CMS, ATLAS

- LHC is ~ 1.5 - 2 Sigma high ~155 to 175 GeV
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- Tevatron sensitivity improves for less than 130 GeV as you go down in mass
  - Opposite at CMS, ATLAS

- CMS & ATLAS fluctuate high mH < 120 GeV
  - Tevatron sees no excess

- Sensitivity at 115 GeV
  - Tevatron : 1.15*SM
  - CMS : 1.95*SM
  - ATLAS : 2.8*SM
Interesting regions for study

• ~115 GeV
  – CMS, ATLAS see some excess
• ~130 GeV
  – Tevatron, ATLAS see some excess
• ~140 GeV
  – Tevatron, CMS, ATLAS see some excess
    • Though CMS, ATLAS prefer very small signal
      – Ie, CMS best fit is 0.6*SM
• Interesting regions for Tevatron to study

Tevatron Run II Preliminary, $L \leq 8.6$ fb$^{-1}$

95% CL Limit/SM

LEP Exclusion

Expected

Observed

$\pm 1\sigma$ Expected

$\pm 2\sigma$ Expected

SM=1

Tevatron Exclusion

July 17, 2011

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Primary Higgs interactions at Tevatron

Production: For 2 TeV $p+p\bar{p}$ collider

Decay: Same at LHC 😊
Tevatron vs. LHC

- LHC has higher cross-sections for signal processes

  - Gluon fusion
    - 40x more at LHC

  - Associated Production
    - 10x more at LHC

  - Vector boson fusion
    - 50x more at LHC

- But ...
  - Tevatron currently better at lowest allowed masses
    - Anti-quarks from pbars yield WH and ZH
    - Much less W+jets, Z+jets than LHC
  - Tevatron has different background compositions
Higgs at the Tevatron

**WH → l⁺l⁻b⁺b⁻**

**ZH → l⁺l⁻b⁺b⁻**

**ZH → ννb⁺b⁻**

**H → WW → l⁺l⁻νν**

---

**Events produced at CDF in 1 fb⁻¹**

Events vs. Higgs mass (GeV)

- Total
- H → WW → l⁺l⁻νν
- WH → l⁺l⁻b⁺b⁻
- ZH → ννb⁺b⁻
- ZH → l⁺l⁻b⁺b⁻

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Higgs at the Tevatron

$WH \rightarrow l\nu bb$

$ZH \rightarrow llbb$

$ZH \rightarrow \nu\nu bb$

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

*Events produced at CDF in 1 fb$^{-1}$*

*~6 months Double including D0*

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115 (expected) :
WH→lvbb
WH/ZH→MET+bb
ZH→llbb
H→WW
115 (expected) :
WH → lvbb
WH/ZH → MET+bb
ZH → llbb
H → WW

130 (expected) :
H → WW
WH → lvbb
WH/ZH → MET+bb
WH/ZH → WWW/ZWW
ZH → llbb
115 (expected) :
WH→lvbb
WH/ZH→MET+bb
ZH→llbb
H→WW

130 (expected) :
H→WW
WH→lvbb
WH/ZH→MET+bb
WH/ZH→WWW/ZWW
ZH→llbb

140 (expected) :
H→WW
WH/ZH→WWW/ZWW
Tevatron perspective at 115 GeV

Dominated by WH/ZH → leptons+bb

Expected sensitivity : 1.2*SM
**Tevatron H → bb**

- **At 115-120 GeV**
  - Almost at 1*SM sensitivity
  - No excess seen
  - Inconsistent with CMS & ATLAS

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Tevatron $H \rightarrow bb$

- At 115-120 GeV
  - Almost at 1*SM sensitivity
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Basics of WH/ZH $\rightarrow$ leptons + bb

Before b-tagging, rich control sample
B-tags enhance signal

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Basics of WH/ZH $\rightarrow$ leptons + bb

Before $b$-tagging, rich control sample

B-tags enhance signal

Multivariate output reduces background
Other channels at 115 GeV

• At Tevatron, small gain in sensitivity from including other channels besides WH/ZH→leptons+bb

• Currently analyzed:
  - H→γγ
  - H→ττ
  - ttH→l+ν+bb+jets
  - ttH→met+bb+jets
  - ttH→jets+bb
  - WH/ZH→qqbb
  - WH/ZH→leptons+ττ
  - H→ZZ

• Expected sensitivity = 5.4*SM combined for all above channels
  – Similar to single experiment primary WH/ZH→lep+bb channel
  – However, techniques are quite advanced
    • Can be useful at the LHC
D0 analysis models di-photon background
(Rather than data sideband fit of $M_{\gamma\gamma}$ of CMS, ATLAS)
Multivariate analysis correlates $M_{\gamma\gamma}$ with
$P_{T_{\gamma\gamma}}, d\Phi_{\gamma\gamma}, P_{T_{\gamma1}}, P_{T_{\gamma2}}$
$\rightarrow$ signal fit of MVA output
D0 analysis models di-photon background (Rather than data sideband fit of $M_{\gamma\gamma}$ of CMS, ATLAS)
Multivariate analysis correlates $M_{\gamma\gamma}$ with $P_T^{\gamma\gamma}$, $d\Phi^{\gamma\gamma}$, $P_T^{\gamma_1}$, $P_T^{\gamma_2}$
→ signal fit of MVA output

CDF+D0 expected 8*SM at 115 GeV
ttH

- Many final states tested
  - Simultaneous fits over 2 or 3+ b-tags, in bins of jet multiplicity
    - 8 signal regions
  - Multivariate tools to remove top-pair and multijet backgrounds

Combined expected $10^{*}$SM limit at 120 GeV (just CDF)
Background modeling at 115 GeV

- **BKG modeling impressive over 7 orders of magnitude**
  - Dominated by b-tagged W+jets, Z+jets

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Tevatron perspective at 130 GeV

Most difficult mass at Tevatron
Equal sensitivity between WH/ZH→bb and H→WW

Expected sensitivity : 1.35*SM
Most signal-like value

• Most signal-like excess at 130 GeV (only ~1.5 σ)

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Signal injected at 115 GeV

Signal injected at 125 GeV

Signal injected at 135 GeV
Signal injected at 115 GeV  Signal injected at 125 GeV  Signal injected at 135 GeV

Not consistent with 130 GeV injection at either end

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Excess at 130 GeV mainly $H \rightarrow WW$

Mostly from D0
Exp: 3*SM, Obs: 4.5*SM

CDF contributes at 0.5 $\sigma$ level
Exp: 2.5*SM, Obs: 3.2*SM
Excess at 130 GeV mainly $H \rightarrow WW$

Mostly from D0
Exp: 3*SM, Obs: 4.5*SM

CDF contributes at 0.5 $\sigma$ level
Exp: 2.5*SM, Obs: 3.2*SM

$H \rightarrow bb$ sees nothing :
Exp: 2*SM, Obs: 2*SM
Tevatron perspective at 140 GeV

$gg \rightarrow H \rightarrow WW$ dominates

Expected sensitivity : $1.2\times SM$
WW excesses at CMS & ATLAS

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WW excesses at CMS & ATLAS

Tevatron has different background composition
Tevatron can provide independent crosscheck

ATLAS (and CMS) have small Z+jets (green), larger ttbar (yellow) contribution at low $M_T$ where excess is

CDF has large Z+jets (yellow), smaller ttbar (purple) at low $M_T$ in same region
• And much smaller ttbar

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**Tevatron cross-checks of excesses**

- Excesses at LHC or Tevatron could be due to different backgrounds
  - Consistent excesses between Tevatron and LHC
    - Constrain interpretation of possible background fluctuation

- Tevatron also more sensitive to WH/ZH production in high mass analysis, whereas LHC has more from VBF
  - Consistent excesses between Tevatron and LHC could indicate SM Higgs boson relationship (ggH, WH/ZH, VBF)
    - Constrain interpretation as a Higgs signal

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Background modeling at 140 GeV

- BKG modeling over 7 orders of magnitude
  - Dominated by WW, Drell-Yan

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Tevatron perspectives

• 115 GeV
  – Tevatron can crosscheck excesses seen in CMS, ATLAS data from $H \rightarrow WW, H \rightarrow \gamma\gamma, H \rightarrow ZZ$ using different Higgs signal mode
    • Tevatron $WH/ZH \rightarrow bb$ provides best sensitivity

• 130 GeV
  – Most consistent excesses between CMS, ATLAS, Tevatron
    • Tevatron $H \rightarrow WW$ & $WH/ZH \rightarrow bb$ provide equal sensitivity
      – But no excess in $H \rightarrow bb$

• 140 GeV
  – Largest excesses seen at CMS, ATLAS
    • Tevatron $H \rightarrow WW$ provides best sensitivity
  – Even when LHC has more data ...
    • Tevatron $H \rightarrow WW$ has different background composition
    • Tevatron $H \rightarrow WW$ has different signal composition (More WH, less VBF)
Future
Tevatron expectations

- Only 1 month left!
- Tevatron will have delivered over 12 fb\(^{-1}\) by Sept. 30, 2011
  - 10 fb\(^{-1}\) acquired data by CDF and D0
    - Effectively means \(\sim 9\) fb\(^{-1}\) for use with all detector systems good (necessary WH, ZH b-tagged analyses)
Tevatron projections 10 fb$^{-1}$ analyzed

2xCDF Preliminary Projection

- $3 \sigma$: 115 GeV with 9 fb$^{-1}$
- $2.4 \sigma$: 130 - 140 GeV with 10 fb$^{-1}$

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Are there potential improvements left?

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<th>Improvements (e.g. DØ)</th>
<th>Type</th>
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- Yellow cells are existing improvements to be propagated to final analysis.
- White cells with numbers are the areas the experiment is actively working on.

Estimates of remaining:
- 35% WH
- 65% ZHllbb
- 12% ZHvvbb

Some of these improvements were made this summer.

from P5 report Oct. 2010

15 Oct 2011

Denisov/Punzi/Roser/Söldner-Rembold
More importantly, can Tevatron achieve all projected improvements on time-scale of Moriond 2012?

• Are improvements slowing down due to reduced personnel?
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• Are improvements slowing down due to reduced personnel?
Still incorporating new channels to improve sensitivity at 120 GeV and 130 GeV

- New additions for summer 2011 Tevatron combination
  - $ttH \rightarrow met+jets$
  - $ttH \rightarrow leptons+jets$
  - $ttH \rightarrow all-jets$
  - $WH \rightarrow l\nu\tau\tau$
  - $ZH \rightarrow ll\tau\tau$

  – Good review at Higgs Hunting Workshop talk from E. Pianori on “Challenging channels at Tevatron”
What else can Tevatron say about the SM Higgs boson mass?
Indirect Higgs mass constraints

- $\Delta m_W \propto m_t^2$
- $\Delta m_W \propto \ln m_H$

Tevatron: $m_t = 173.2 \pm 0.9 \text{ GeV} \ (0.5\%)$
Indirect Higgs mass constraints

- $\Delta m_W \propto m_t^2$
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Tevatron: $m_t = 173.2 \pm 0.9$ GeV (0.5%)

$m_H = 92^{+34}_{-26}$ GeV

With all indirect measurements
Indirect Higgs mass constraints

- $\Delta m_W \propto m_t^2$
- $\Delta m_W \propto \ln m_H$

Tevatron: $m_t = 173.2 \pm 0.9$ GeV (0.5%)

CDF alone $\delta m_W$: 48 $\rightarrow$ $\sim$25 MeV 2 fb-1 $\sim$6 months
$\sim$15 MeV 10 fb-1

$m_H = 92 ^{+34} _{-26}$ GeV
With all indirect measurements
Can Tevatron be even more precise about mass determination?
How well could we measure Higgs mass given a 3 Sigma excess?

- Higgs boson mass is more sensitive to cross-section than kinematic resolution

Assuming Cross Section x Branching Fraction Measurement Uncertainty is 2x Larger at the same Luminosity for low-mass than it is for high-mass searches

Using resolution from LLR, median outcomes

Resolution at 115 GeV: ±5 GeV
Resolution at 135 GeV: ~±10 GeV

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And if there is no SM Higgs boson?

- Mechanism for electroweak symmetry breaking and fermion mass may reveal itself in strange ways
  - Tevatron provides $> 10 \text{ fb}^{-1}$ of 2 TeV proton-antiproton data
    - May prove useful in the future to disentangle a more complex theory
Conclusions

• Tevatron important at low mass 115-120 GeV
  – World’s best limits at 115 GeV
  – Unique window to Higgs of $H \rightarrow \text{bb}$
  – Sensitivity continues to improve
• Tevatron important in 130-140 GeV region
  – $H \rightarrow \text{WW}$ analyses sensitive to different signals and backgrounds than LHC
• Tevatron will have 10 fb$^{-1}$ analyzed by spring/summer 2012
  – Even more to say about 115 - 140 GeV

• To claim a Higgs boson discovery
  – Requires consistent picture of SM Higgs boson across multiple signal topologies with different background compositions
  – Tevatron contributes to this picture even after sensitivity is eclipsed by LHC