CDF & D0 Higgs Search

Results from the Full Tevatron Data Set

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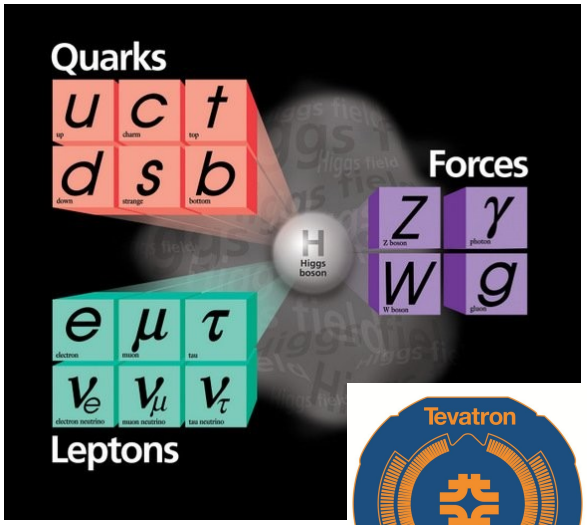
On Behalf of the CDF and DØ Collaborations

Tevatron Higgs Seminar
2 July 2012, Fermilab

The 2nd Half of Today's Presentation

DØ Higgs boson searches in a nutshell

- Discussion of updates since winter 2012
- Short review on what's to come
- DØ Higgs search results

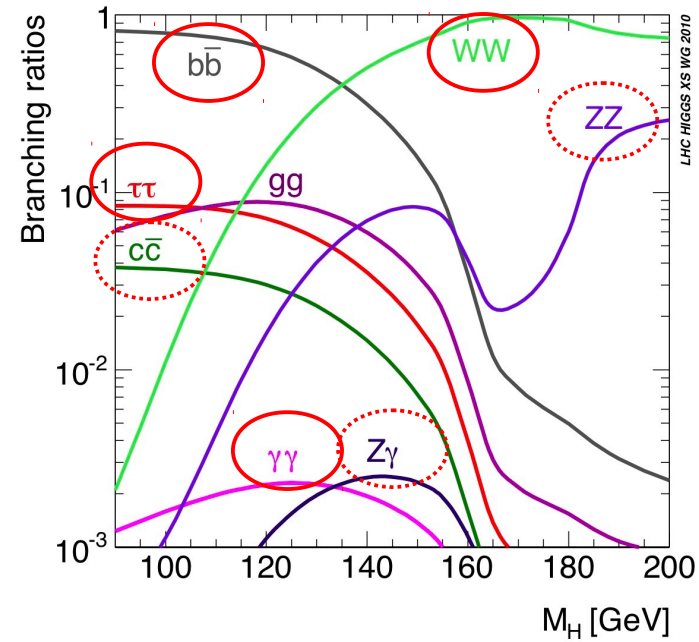


New Tevatron Higgs search results

- Details of combination procedures
- Updated CDF + DØ Higgs combination
- Discussion of results

The DØ Higgs Search

- A broad search program
  - Search for Higgs decays in H→bb/WW/γγ/ττ
  - Allow acceptance from H→ZZ/cc/Zγ
  - Production is dominated by gluon fusion and associated production

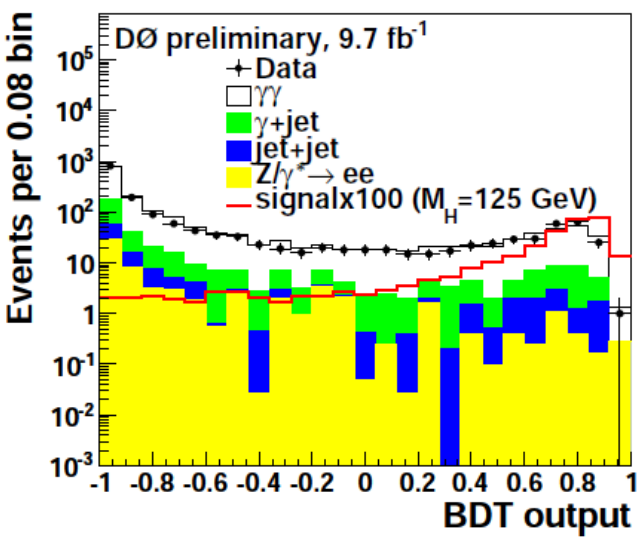


Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)
$H+(X) \to \ell\nu + \geq jj$ (0,1,≥2b-tags)×(2,3,4+ jet)	9.7	100-200
$ZH \to \nu\bar{\nu}b\bar{b}$ (MS,TS)	9.5	100-150
$ZH \to \ell^+\ell^- b\bar{b}$ (TST,TLDT)×(ee,$\mu\mu$,ee_{ICR},$\mu\mu_{trk}$)	9.7	100-150
$VH \to e^\pm\mu^\pm + X$	9.7	115-200
$H \to W^+W^- \to \ell^\pm\nu\ell^\mp\nu$ (0,1,2+ jet)	9.7	115-200
$H \to W^+W^- \to \mu\nu\tau_{\rm had}\nu$	7.3	115-200
$H \to W^+W^- \to \ell\bar{\nu}jj$	5.4	130-200
$VH \to \ell\ell\ell + X$	9.7	100-200
$VH \to \tau\tau\mu + X$	7.0	115-200
$H \to \gamma\gamma$	9.7	100-150

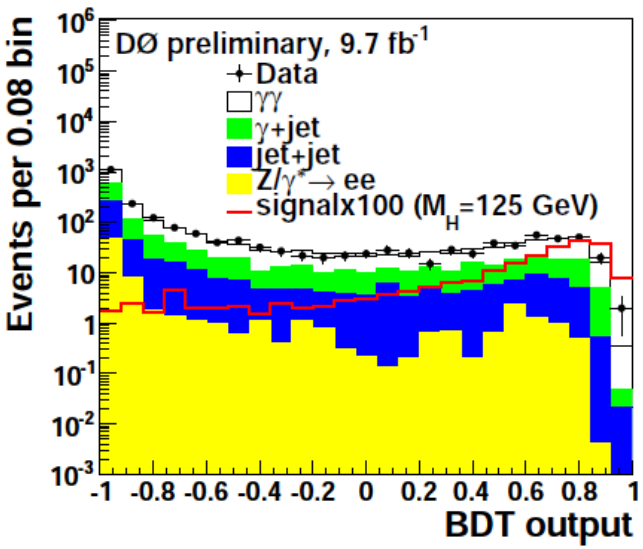
The DØ H→diphoton Analysis

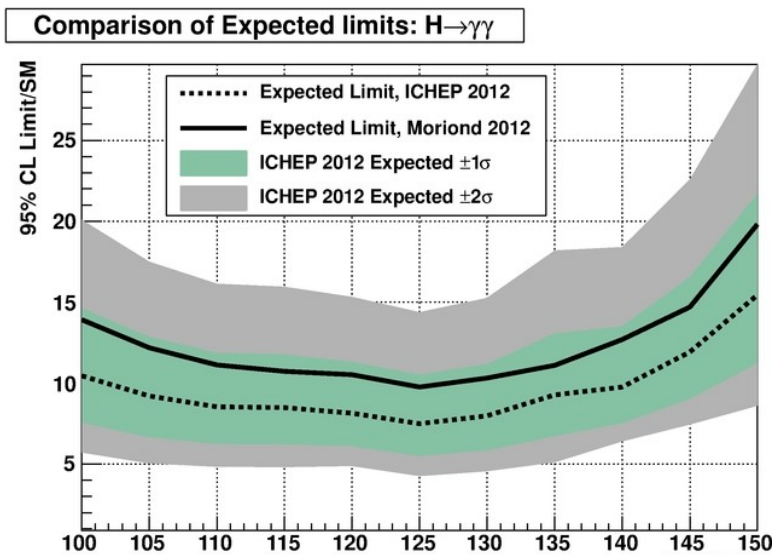
- Update recovers improvements unrealized for winter 2012 conferences
  - Improvement in MC/data statistics for background modeling
  - To combat systematic uncertainties, analysis is now split into **jet-dominated** vs **photon-dominated** fake rate regions
  - Bottom line: **20-30%** improvement in expected limits

Photon-Dominated



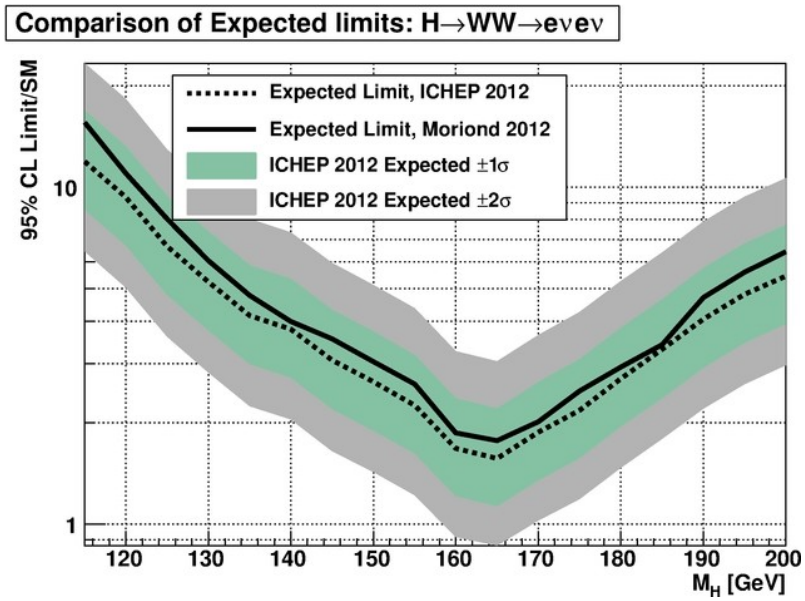
Jet-Dominated



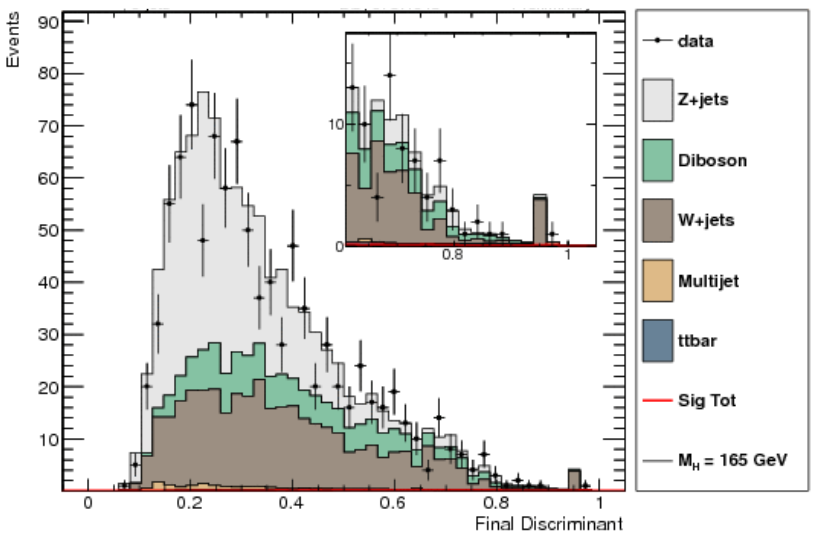


The DØ H→WW→lνlν Analysis

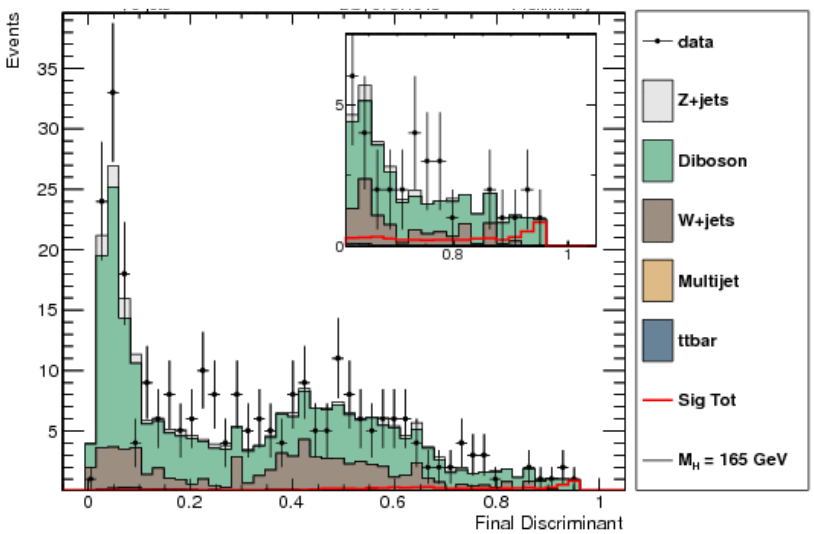
- More data & refined analysis technique
  - Di-electron channel adds 12% more data & improves electron identificiation efficiency
  - Di-muon and di-electron channels now split search sample into regions dominated by **Diboson** and **W/Z+jet** backgrounds
  - Technique improves expected limits by **5-10%**



W/Z+jet Dominated

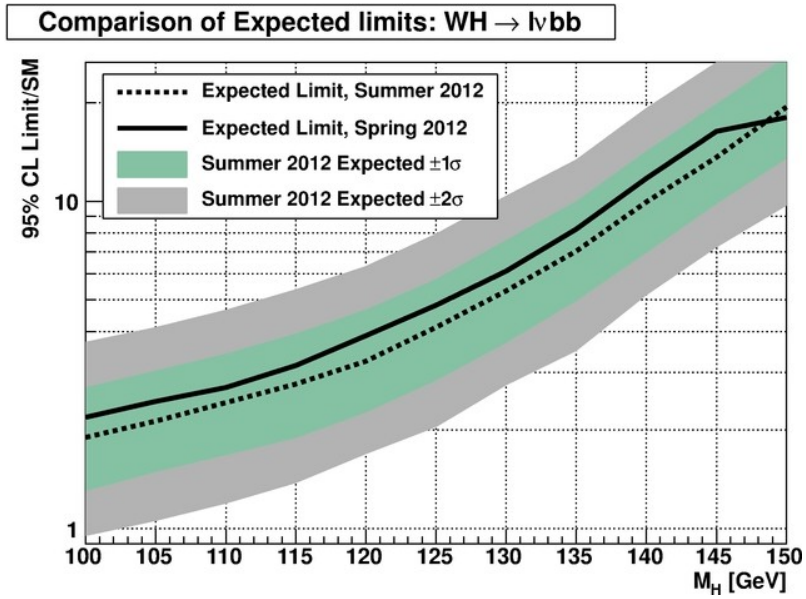


Diboson-Dominated

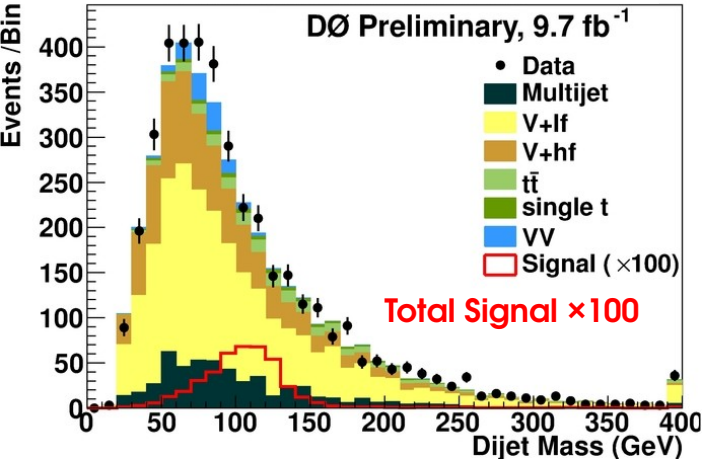


The DØ WH→lνbb Analysis

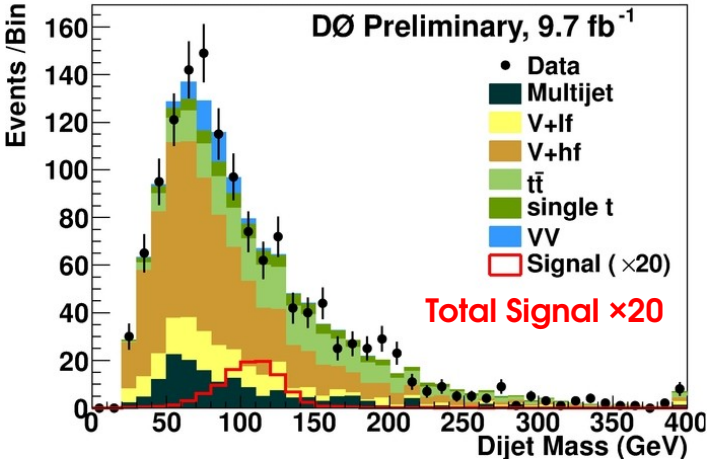
- Updates to the WH→lνbb Higgs search
  - Additional muon triggers
  - Improved multijet modeling & rejection
  - Improved signal isolation via separation into 3 double b-tagged final states (vs 2 previously)
  - Bottom line: **10-17%** improvements in expected limits



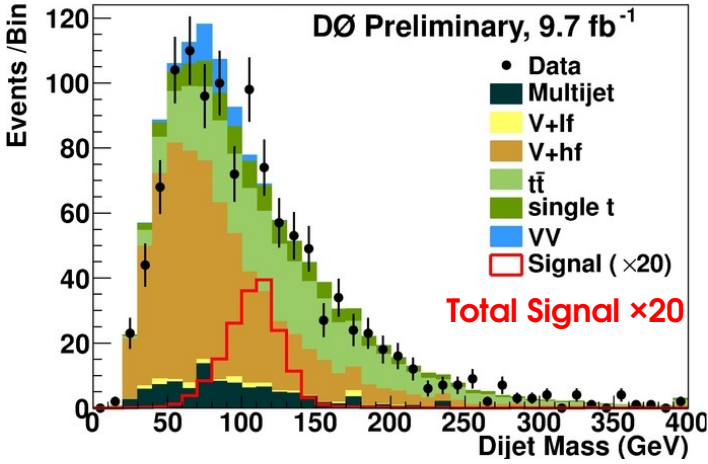
2 Loose b-tags



2 Medium b-tags

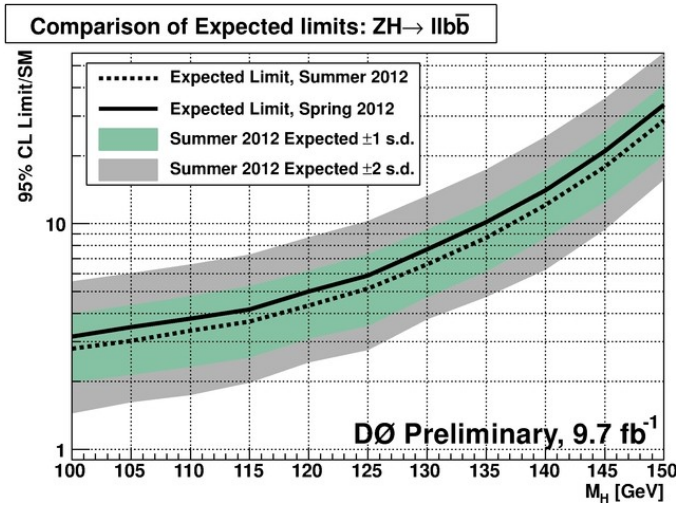


2 Tight b-tags

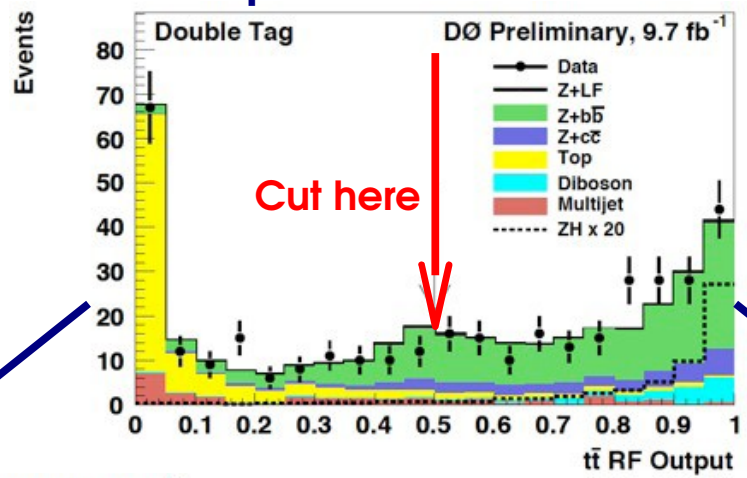


The DØ ZH→llbb Analysis

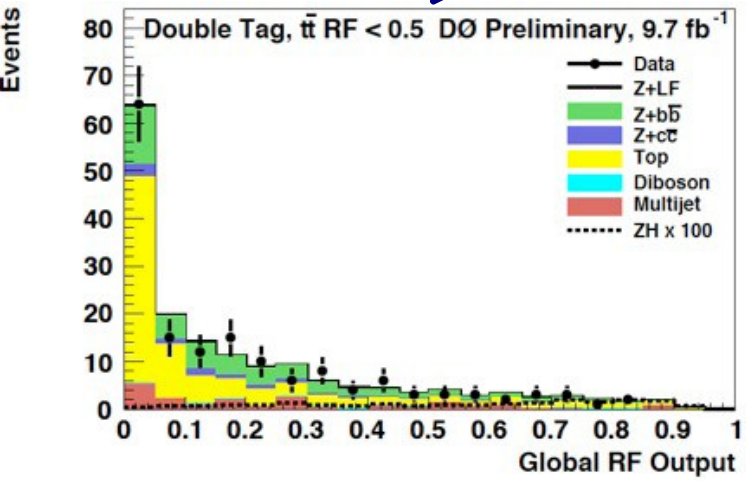
- Updates to the ZH→llbb Higgs search
  - Selection requirements relaxed
  - Isolation of top quark backgrounds represents largest change



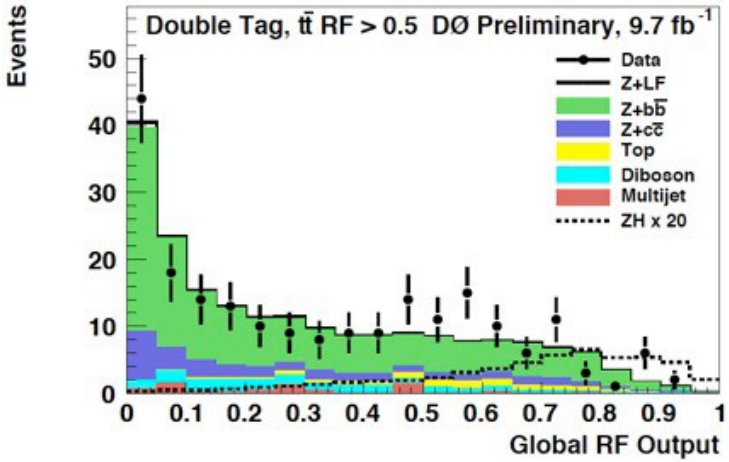
Top Quark Classifier



Region dominated by top quark backgrounds



Region dominated by Z+heavy flavor quark backgrounds

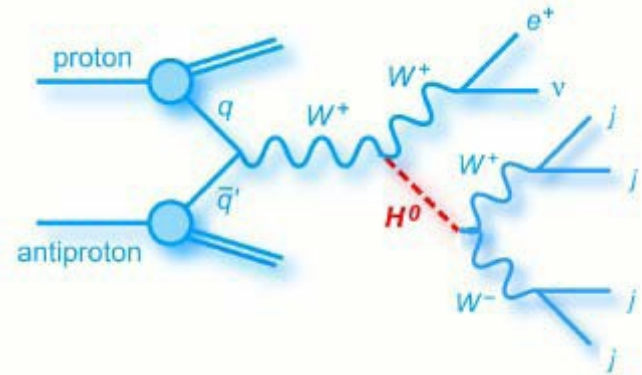


<u>Bottom line:</u>
10-15% improvement in expected limits

Updates to other DØ Analyses

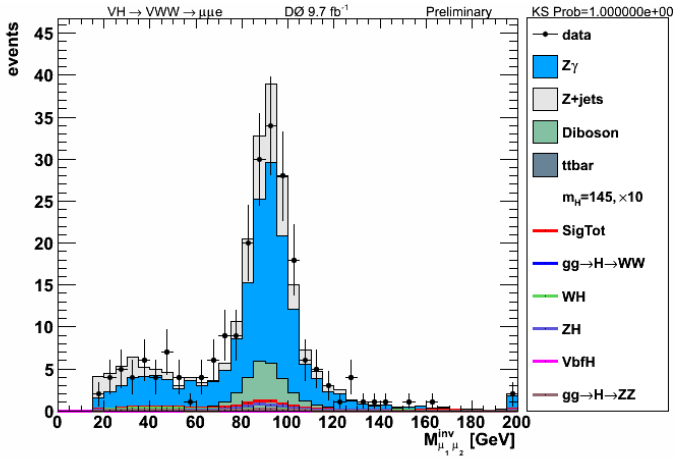
Added new e/μ+MET+4Jets analysis

- Primarily sensitive to VH→VWW processes
- Contributes mostly for m_H ~165 GeV



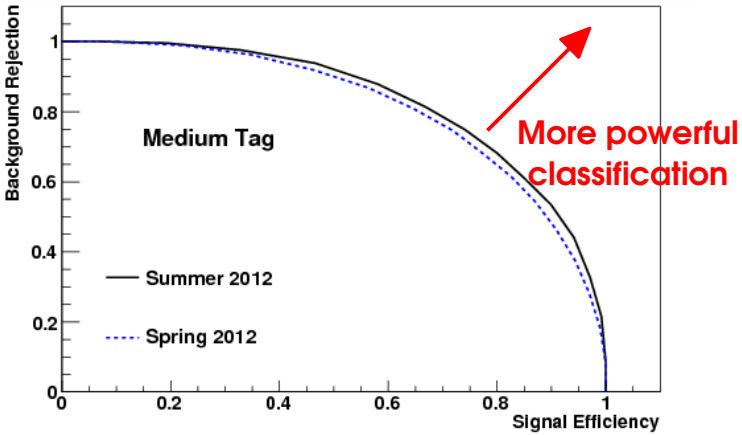
Update to VH→VVV→trileptons+X (μμe) search

- Additional data (~12%), improved Zγ background model, further reject backgrounds



ZH→ννbb search significantly refines MVA training

- Boost training performance via large increase in MC statistics (true for other analyses too)



Planned analysis updates

- Winter→Summer time window was short: some updates didn't make it
  - H→WW→lνjj: will add 80% in data with significant search improvements
  - VH→VVV→eeμ, μττ: add ~12% in data, MVA analysis improvements
  - VH→SS eμ: many new studies in multijet modeling & MVA treatment
  - H→WW→eνμν: adopt splitting in WW vs W+jets enriched regions (5-10% gain)
  - ZH→ννbb (3jets): challenging final state for trigger modeling
  - VH→e/μτ+jj: Will update to full luminosity, with modeling improvements

Bottom line: 5-10% overall improvement still possible for DØ

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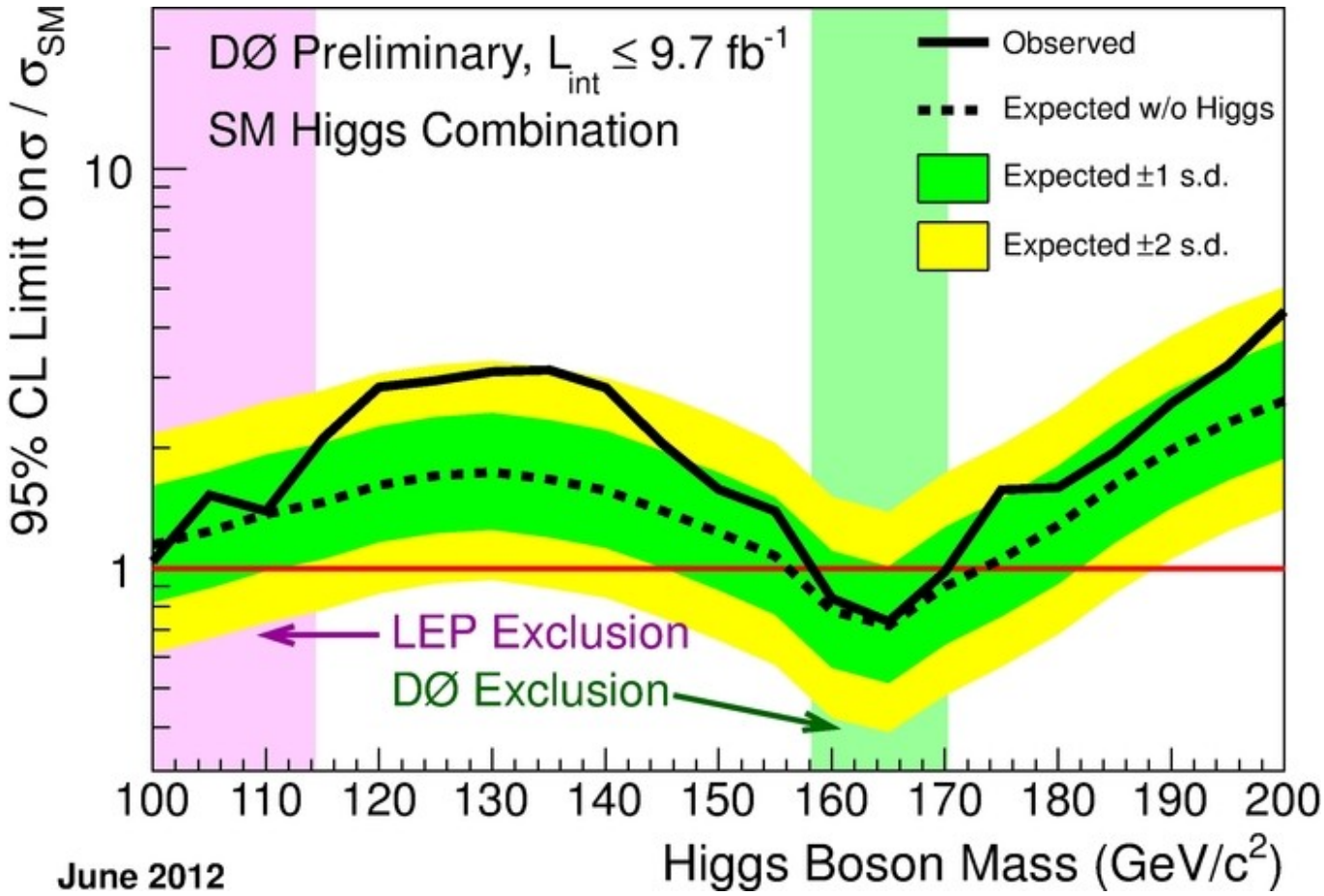
The Updated DØ Higgs Search



- 95% C.L. upper limits on SM Higgs boson production at the Tevatron
  - Expected exclusion: **$156 < M_H < 173$ GeV**
  - Observed exclusion: **$159 < M_H < 170$ GeV**

The Look Elsewhere Effect

– Could a significant result happen "by chance"?
Two main considerations: **p-values** & **the look elsewhere effect (LEE)**

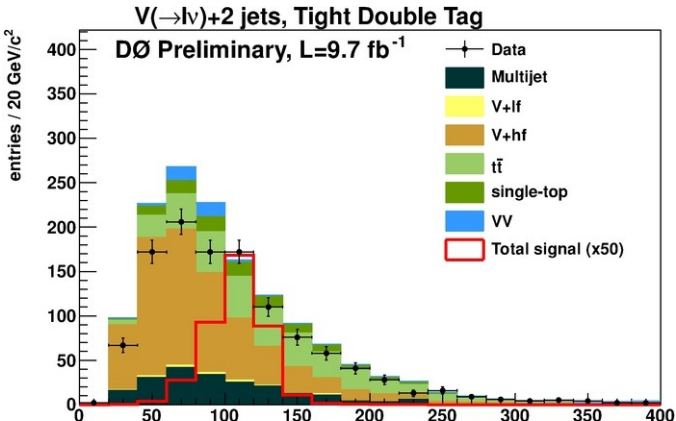
p-value:

– The probability of obtaining a result as extreme as the one observed, assuming the NULL hypothesis is true. (*NULL hypothesis = "there is no Higgs boson"*)
– In other words, "The probability that the background fluctuated up by chance."
– p-values of 0.15866 / 0.02275 / 0.00135 correspond to 1/2/3 standard deviations

The Look Elsewhere Effect (LEE)

– The probability of obtaining a result as extreme as the one observed in **all of the places that you looked.**
– We test Higgs masses from 100-200 GeV (100-150 GeV for H→bb), so we must account for the number of independent search regions in that range.

– Ultimately it's driven by mass resolution.
Eg, dijet invariant mass for H→bb.
– We use a LEE factor of 4 (2) for our global (H→bb) search.



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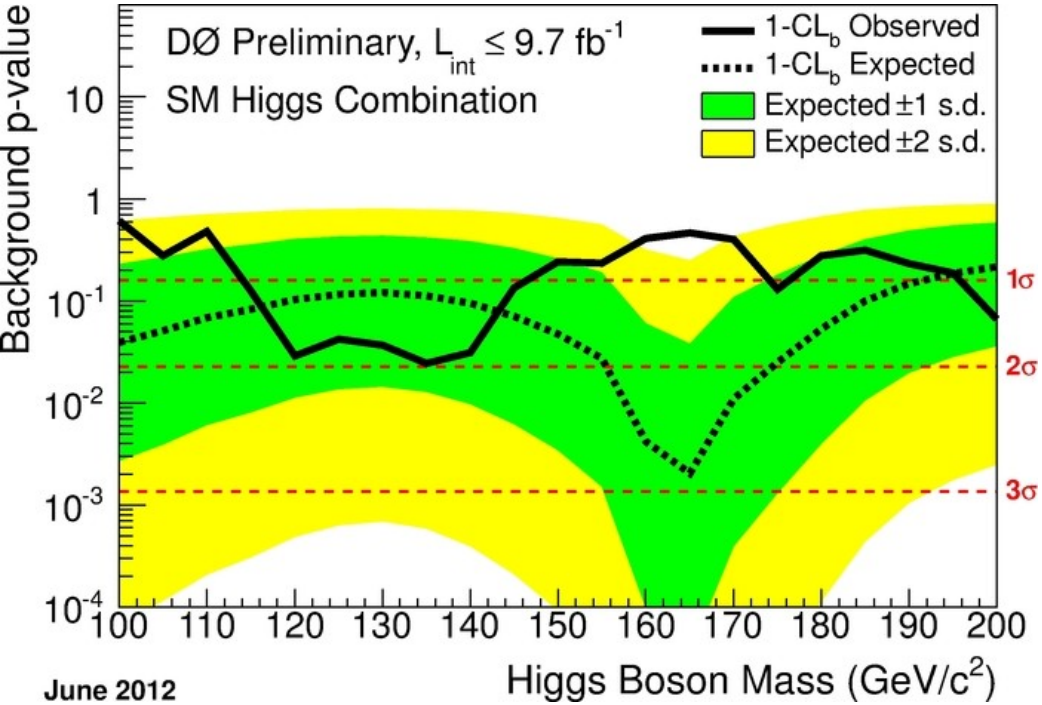
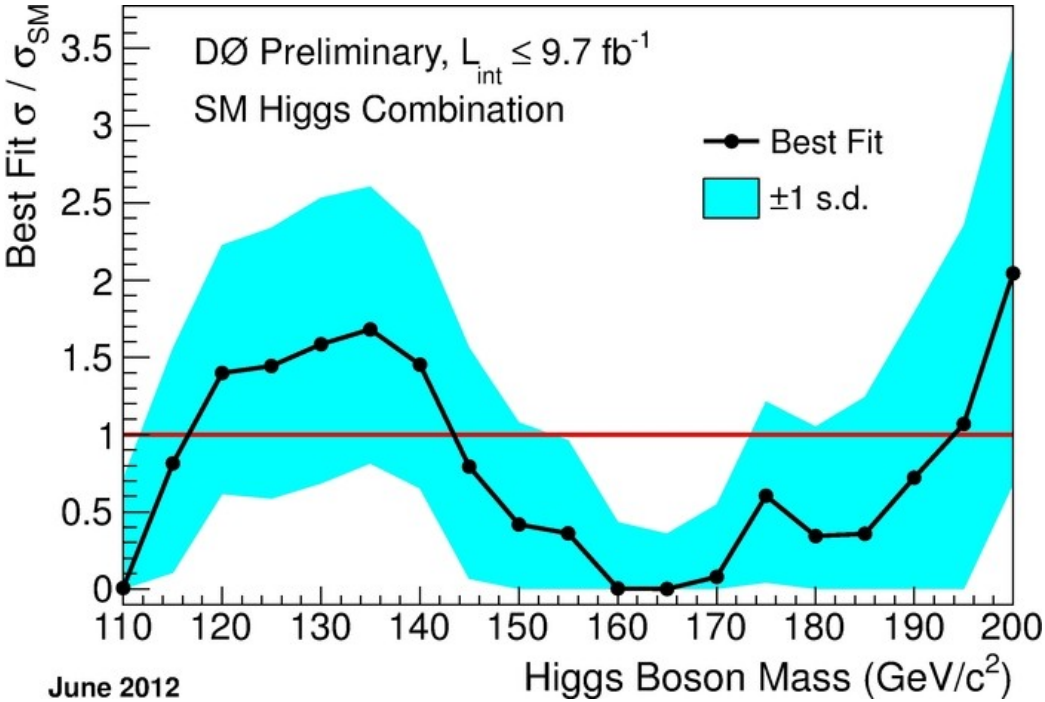
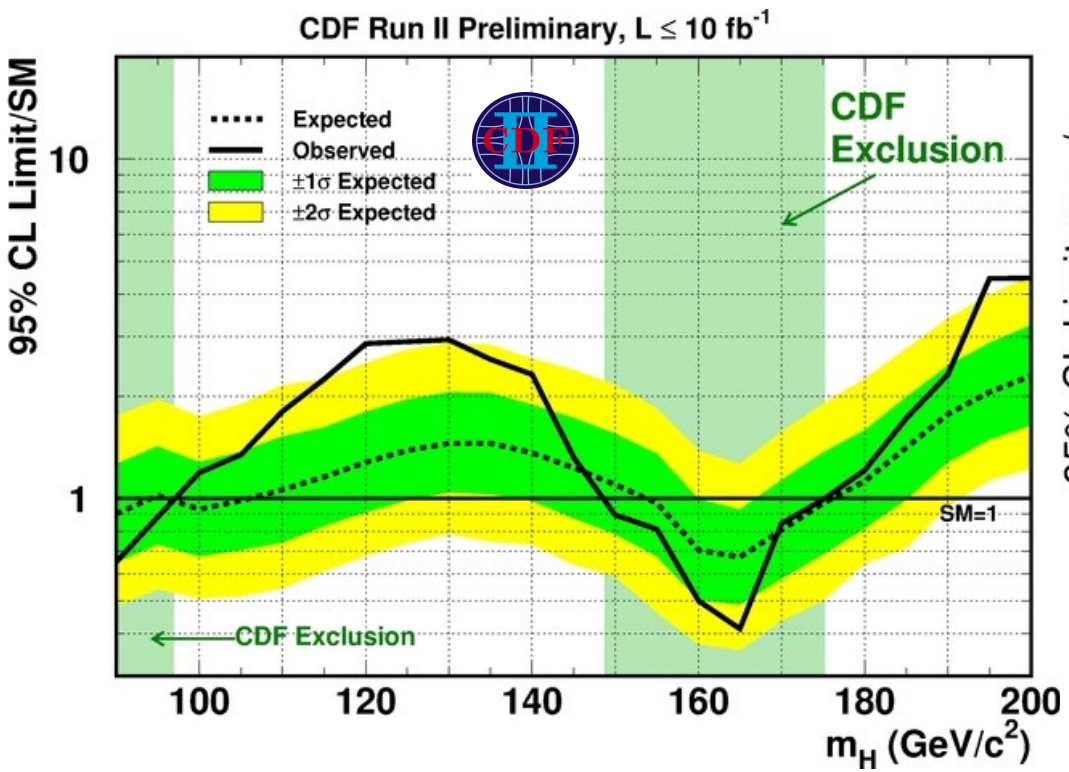


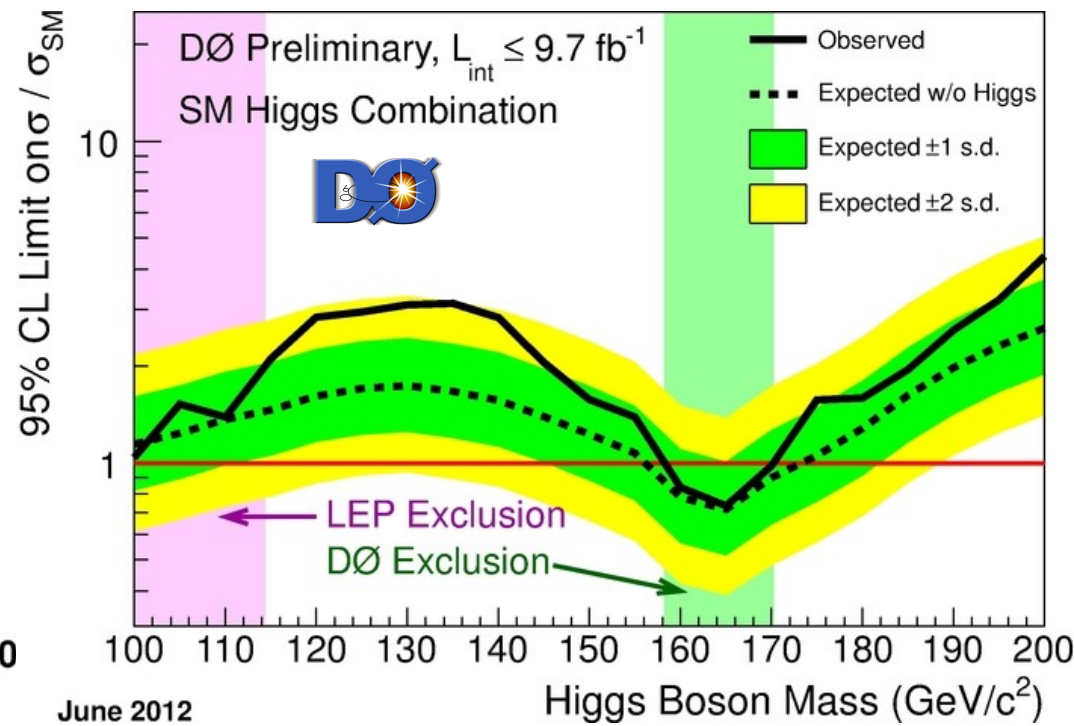


- **Two different test of the data**
  - **Left:** Local p-value distribution for background-only expectation.
    - Minimum local p-value: 2.0 standard deviations
    - Global p-value with LEE factor of 4: **1.3 standard deviations**
  - **Right:** Maximum likelihood fit to data with Higgs boson production rate as free parameter.

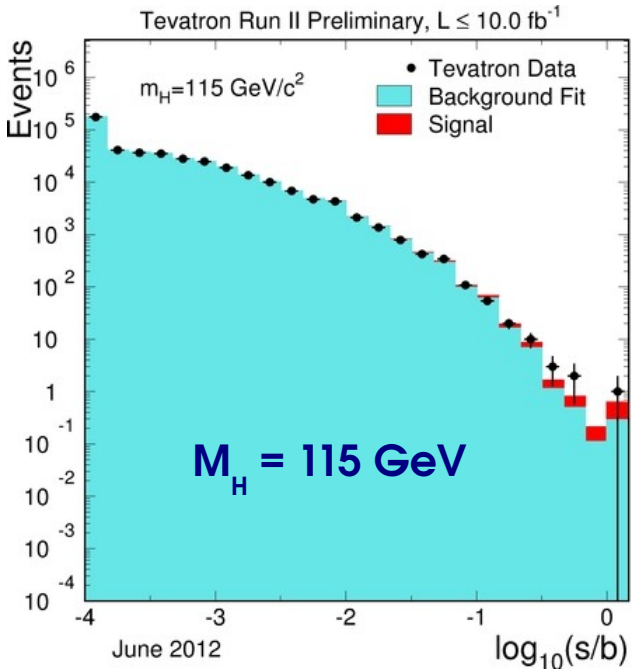
CDF & DØ Individual Results

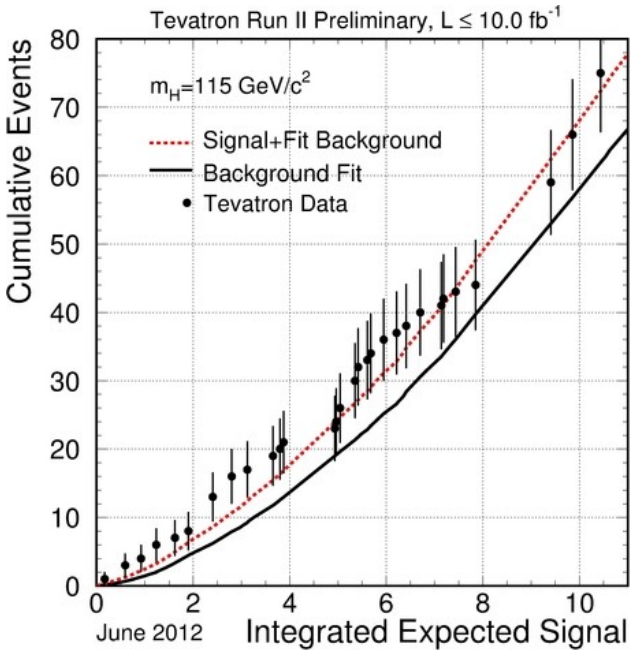
- Results from Tevatron experiments
  - Similar search sensitivity over entire probed mass region
    - DØ: Exclude $159 < M_H < 170$ GeV
    - CDF: Exclude $90 < M_H < 97$ & $147 < M_H < 175$ GeV



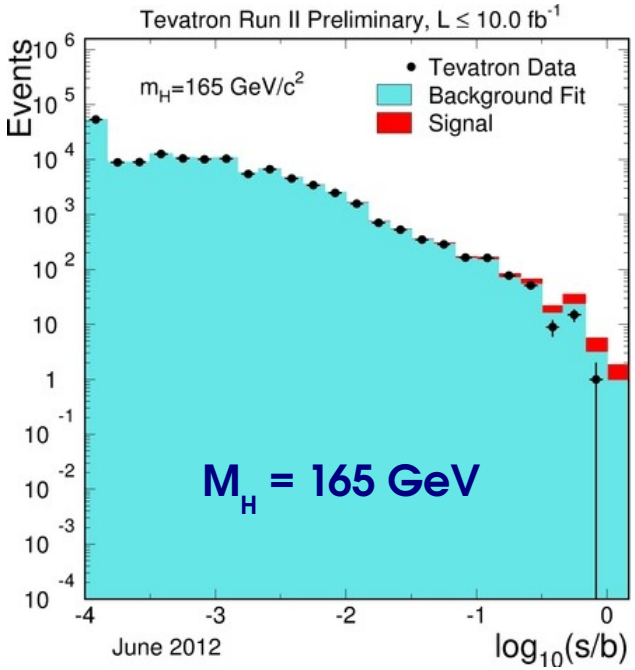


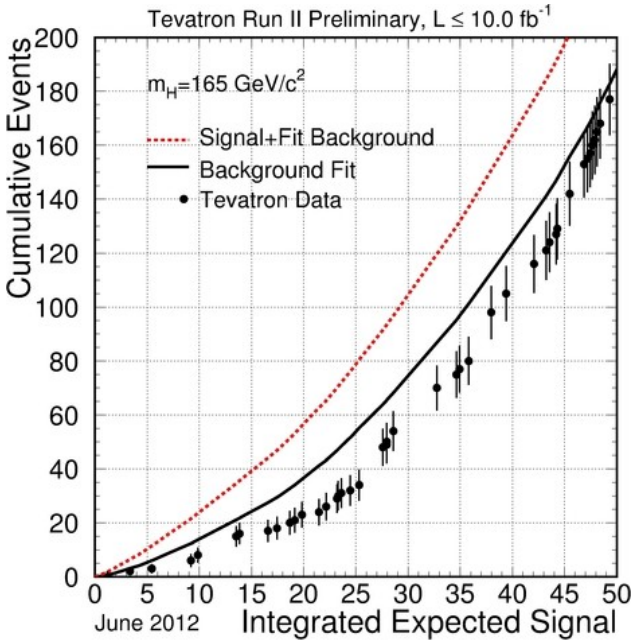
CDF & DØ Combined Distributions





Right-to-left integral yields a means to compare data with signal and background predictions





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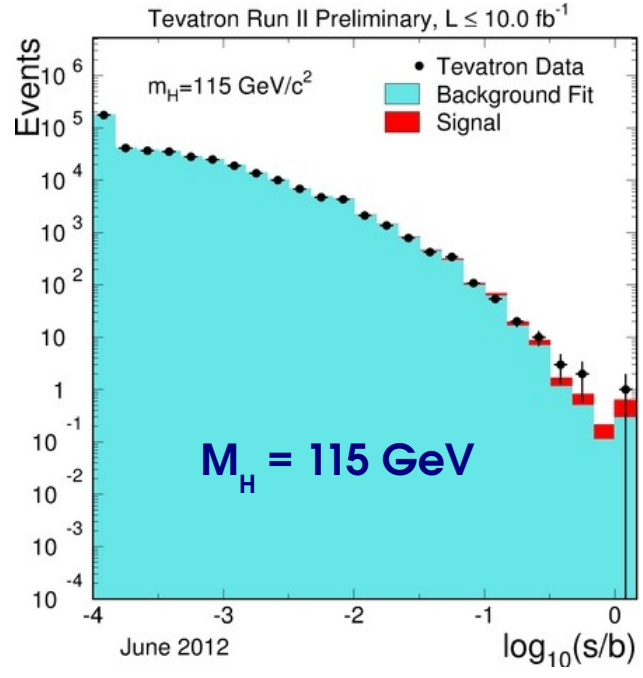
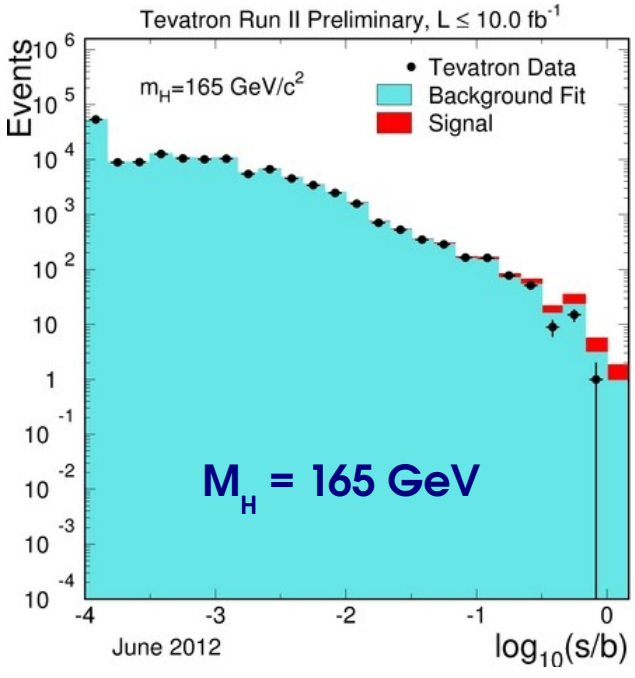
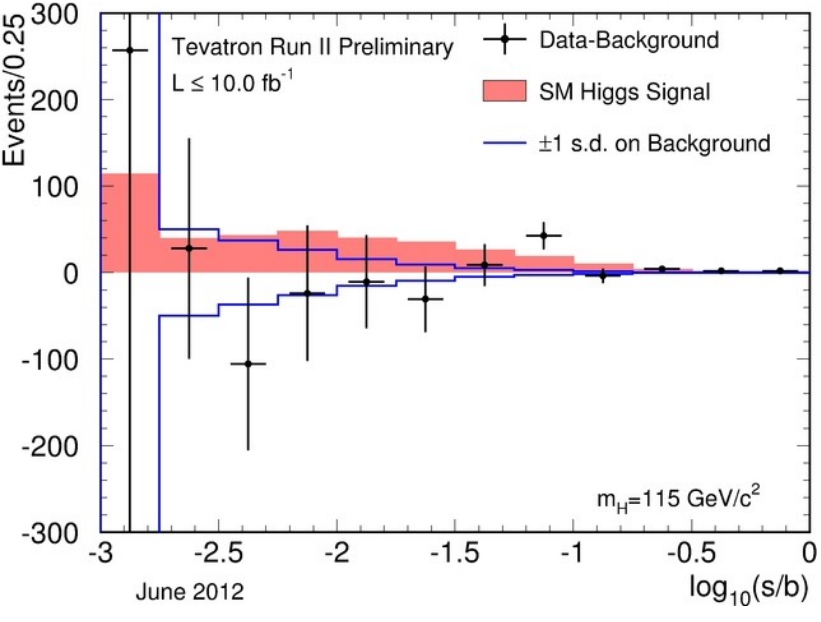
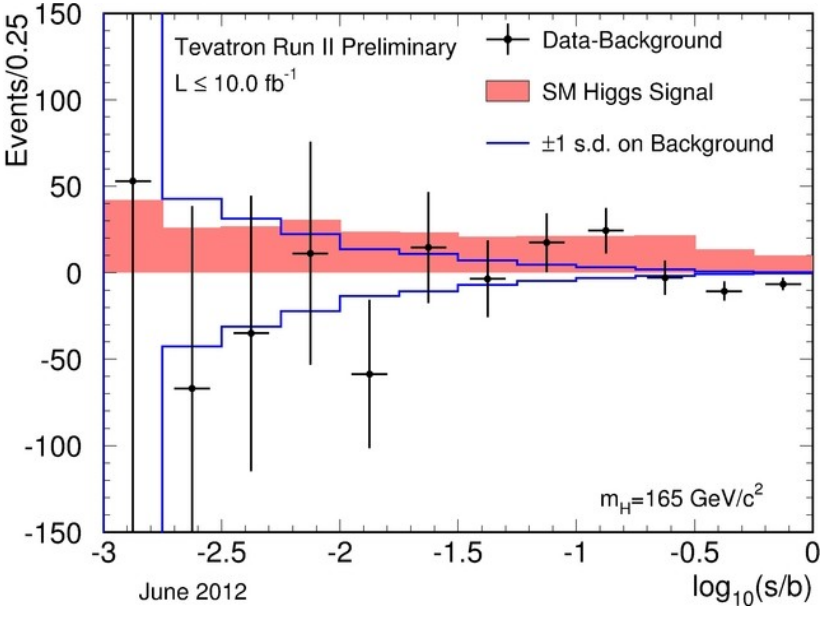


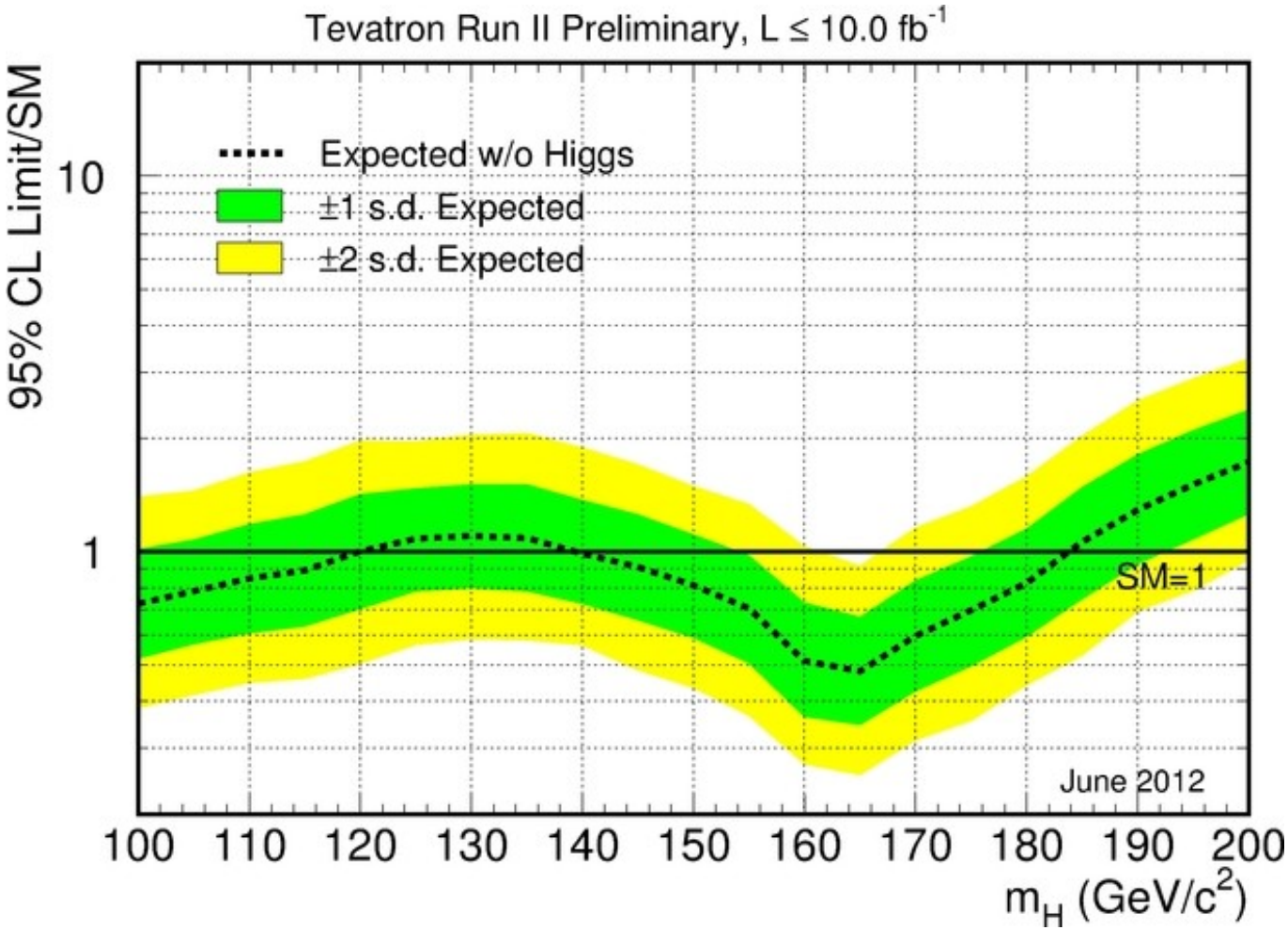
Fit to data, with background subtraction can reveal potential excesses







Upper Limits on Higgs Boson Production



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  - Expected exclusion: $100 < M_H < 120$ GeV $139 < M_H < 184$ GeV

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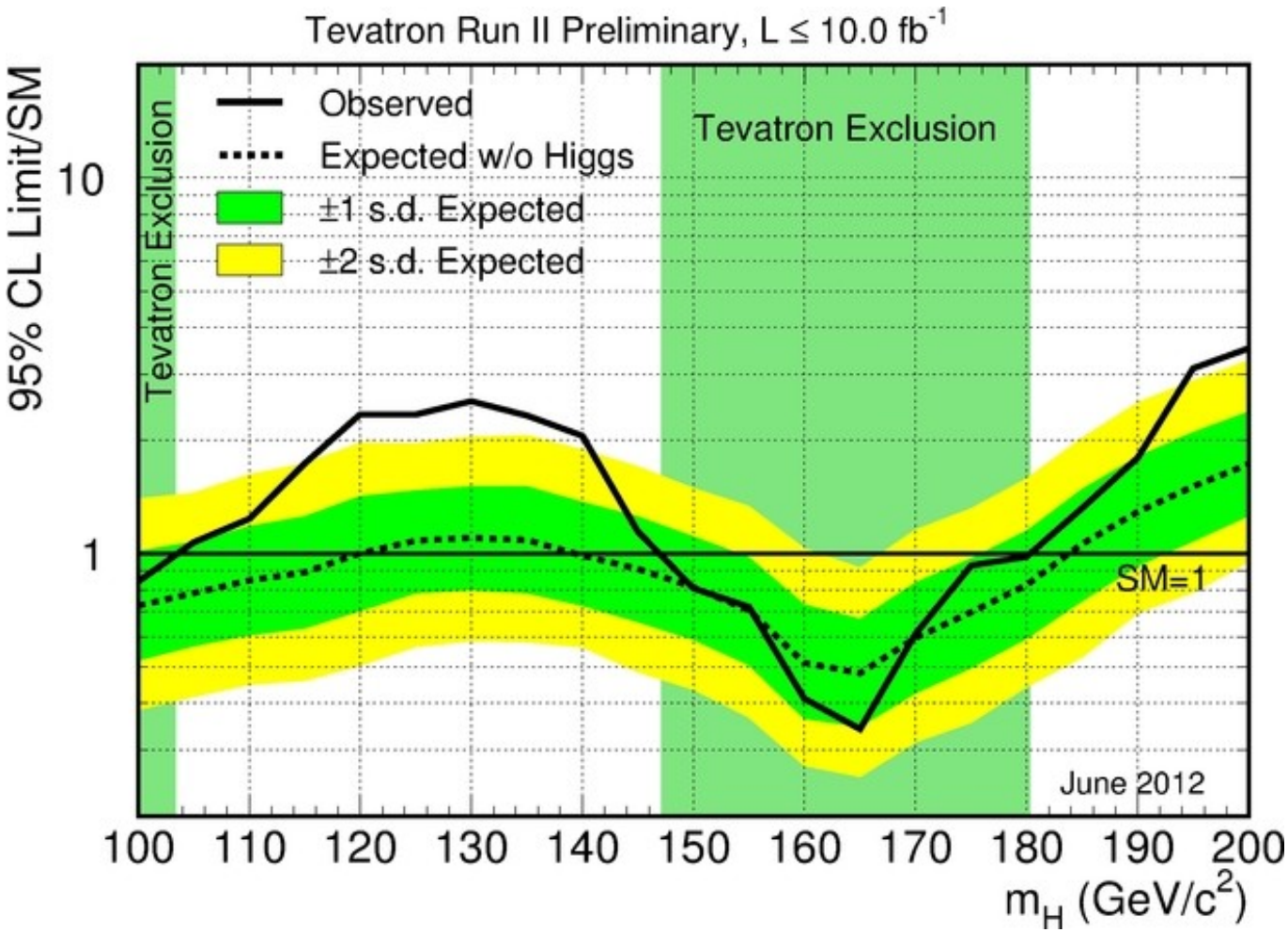

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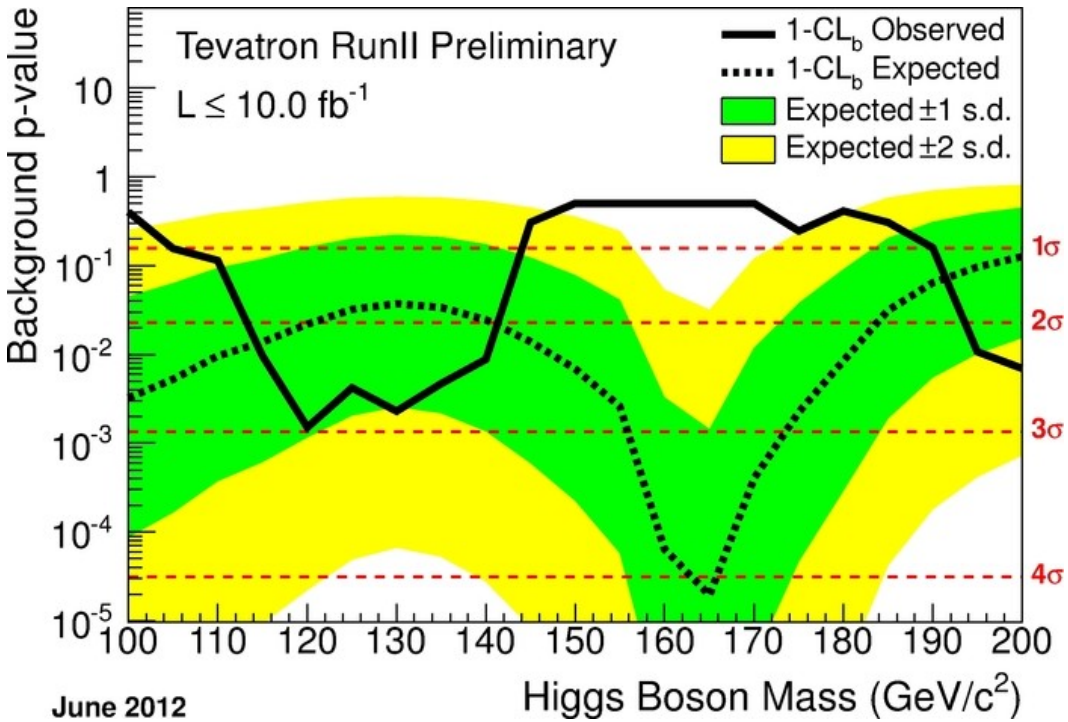
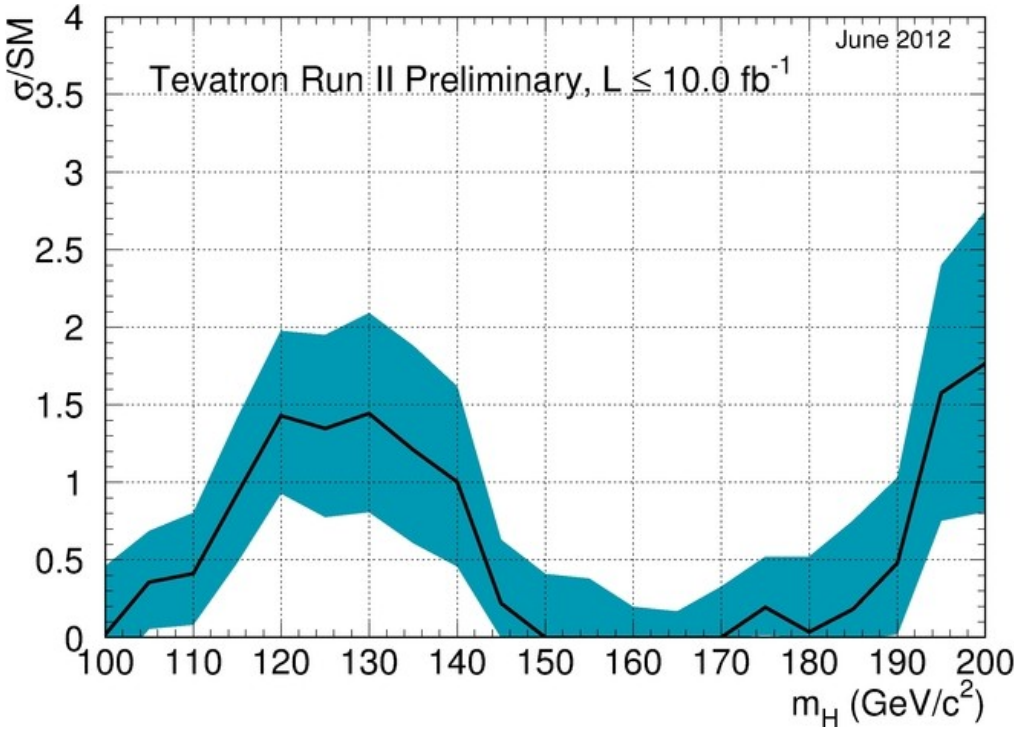
Quantifying the Excess





- **Two different tests of the data, comparing to S+B and B-only predictions**
  - **Left:** Local p-value distribution for background-only expectation.
    - Minimum local p-value: 3.0 standard deviations
    - Global p-value with LEE factor of 4: **2.5 standard deviations**
  - **Right:** Maximum likelihood fit to data with Higgs rate as free parameter.

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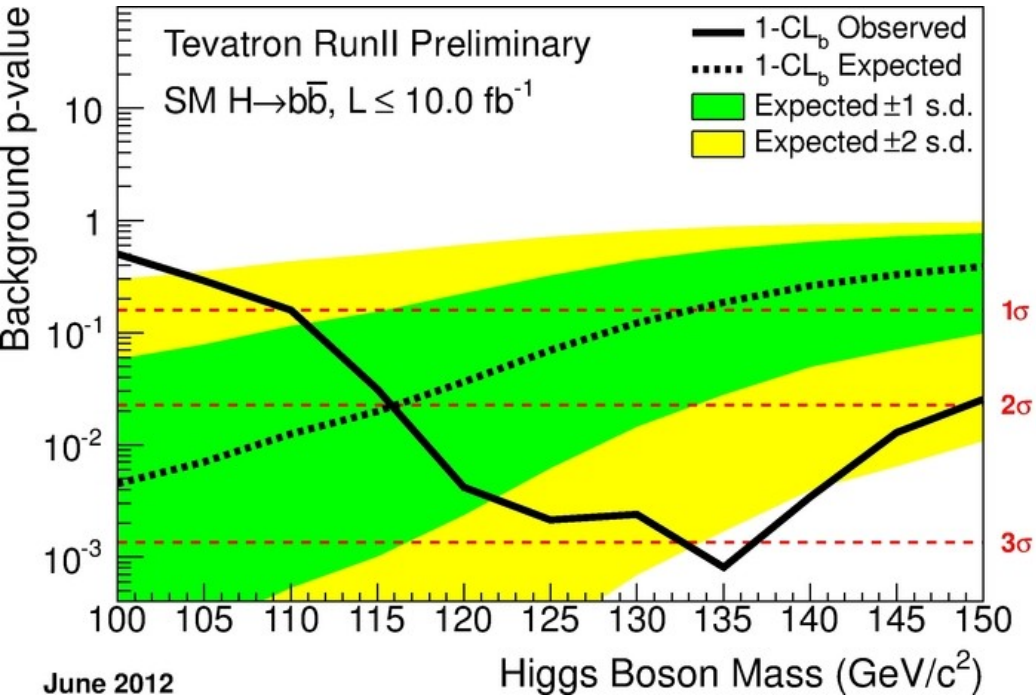
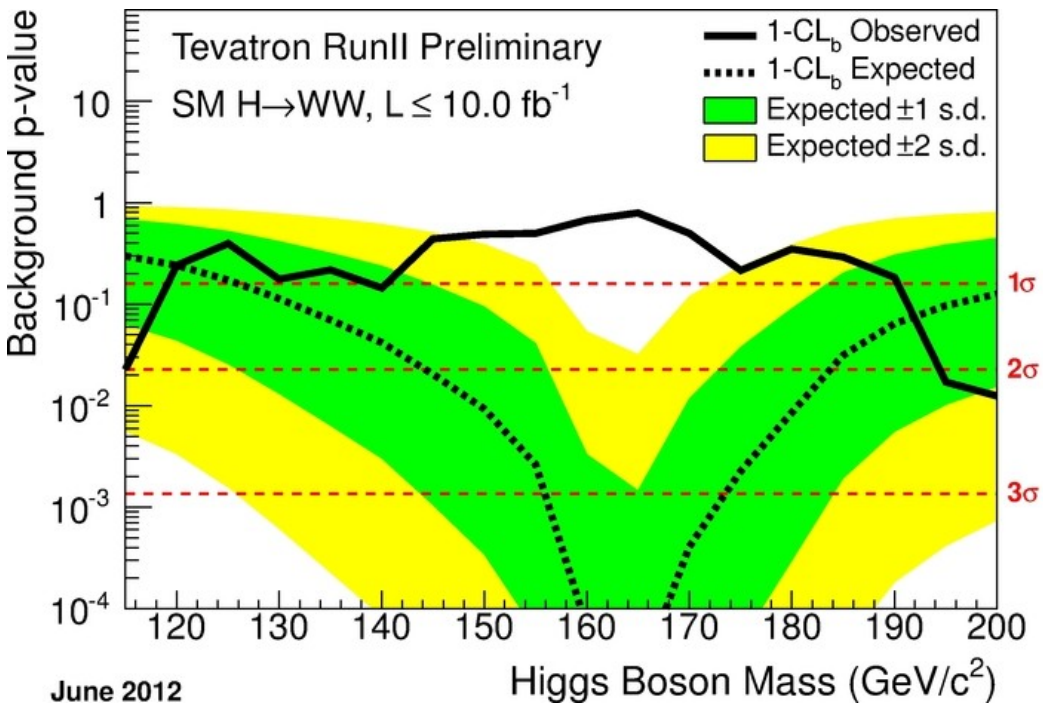
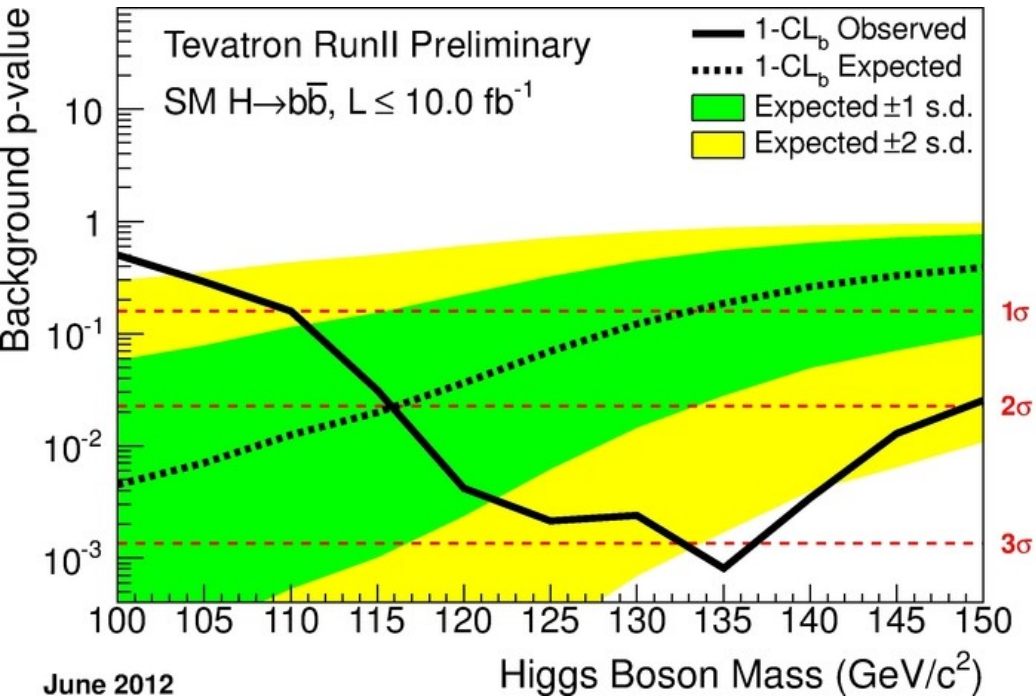
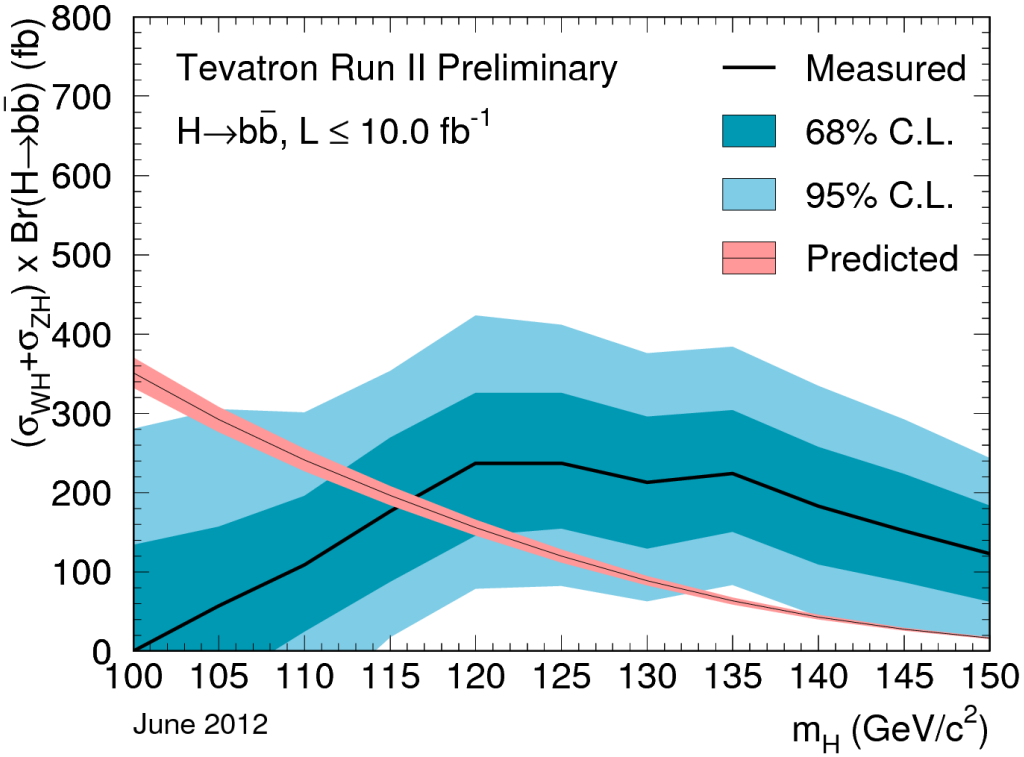




- **Considering separately the H→bb and H→WW channels**
  - Local p-value distribution for background-only expectation.
    - Minimum H→bb local p-value: 3.2 standard deviations
    - Global H→bb p-value with LEE factor of 2: **2.9 standard deviations**

Quantifying the Excess





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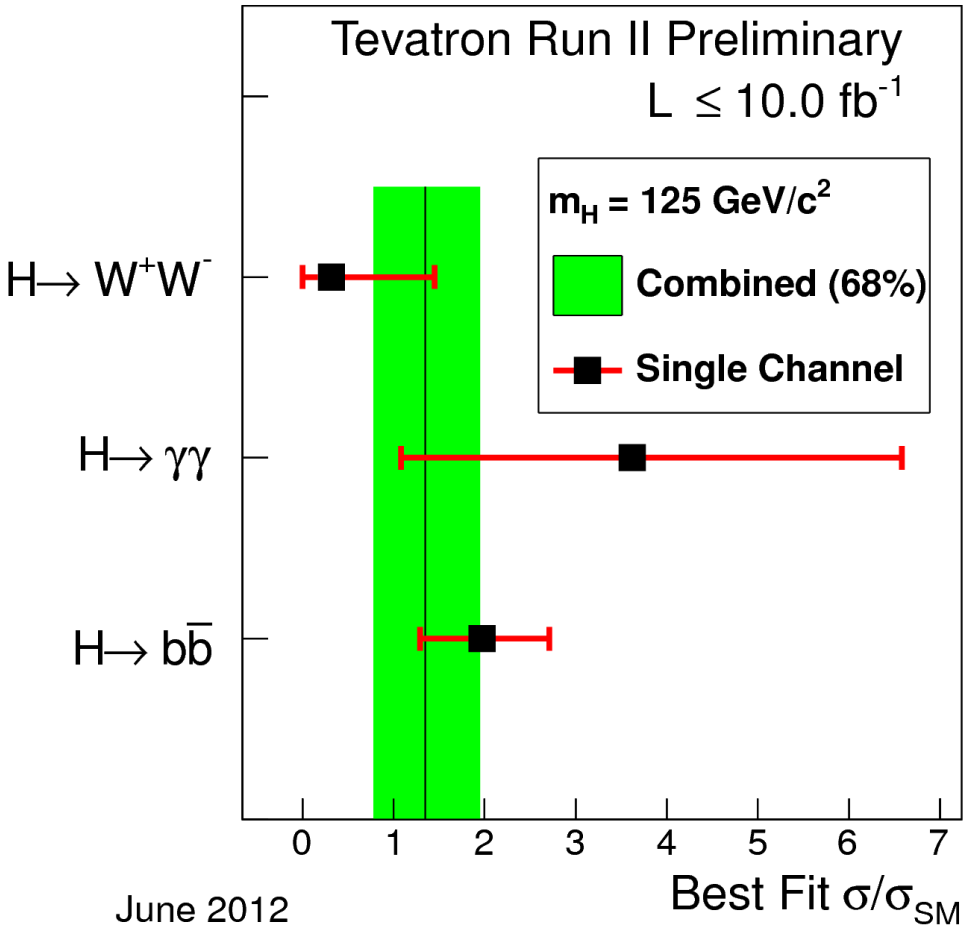
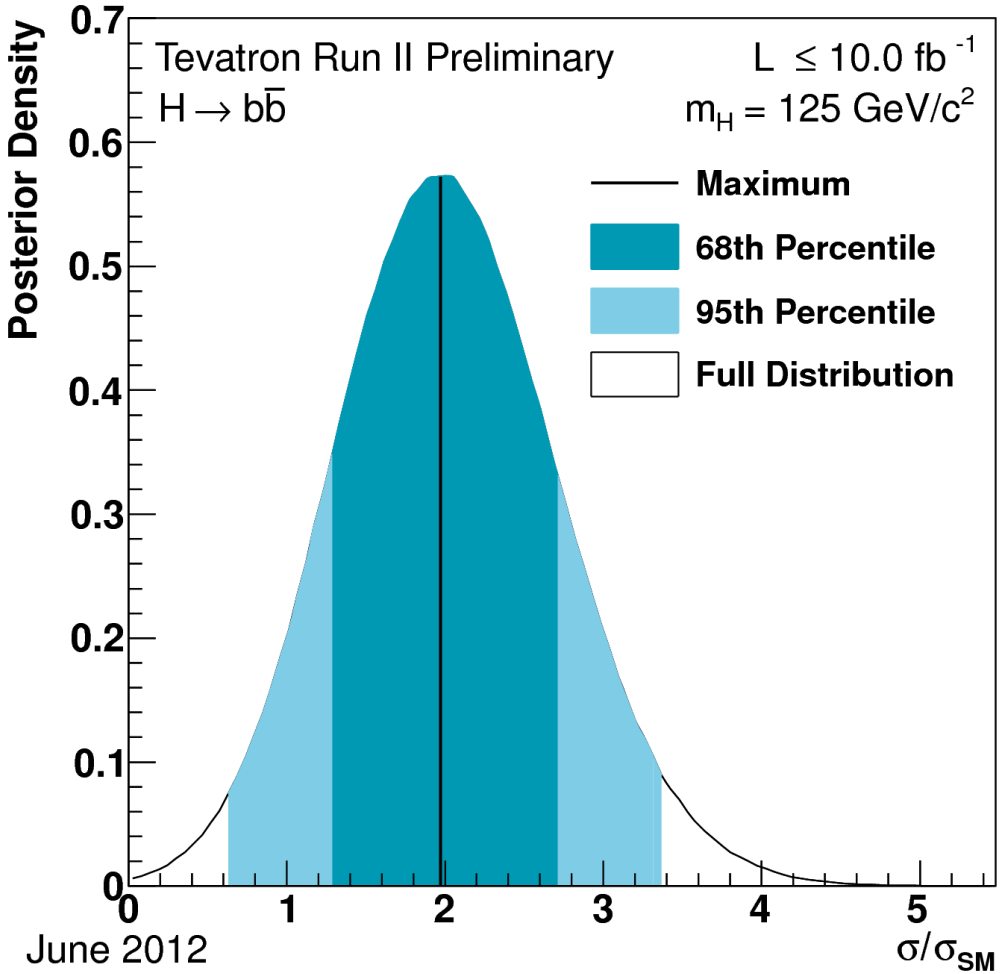
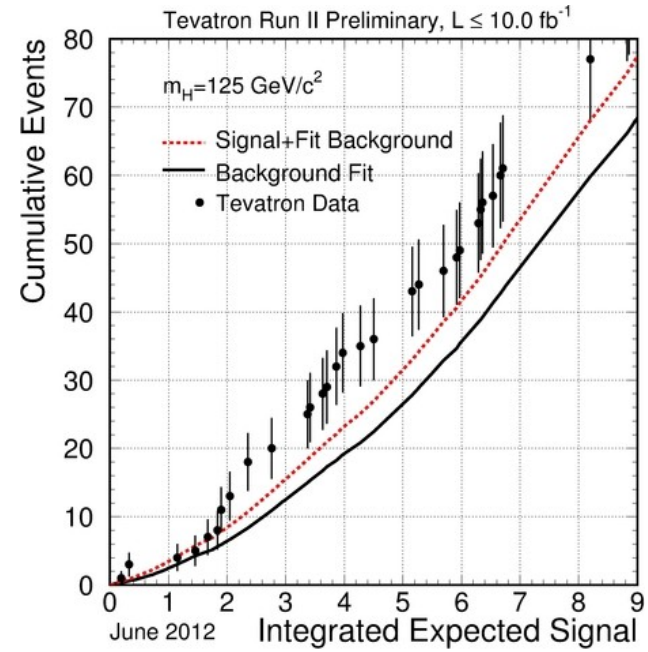
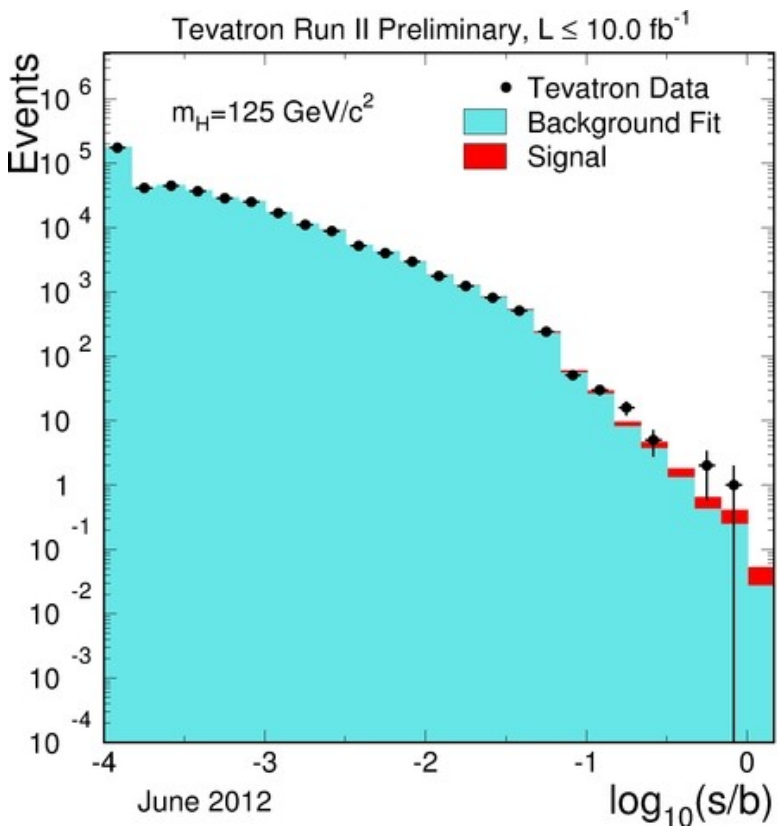


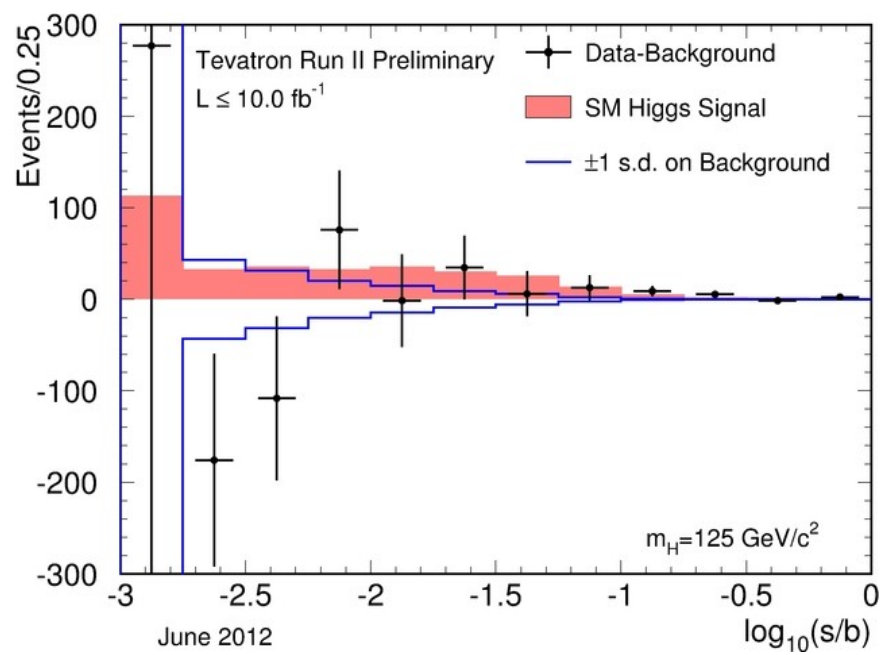


Quantifying the Excess

- Revisit s/b rebinned distribution plot for M_H=125 GeV
  - Cumulative distribution seems to prefer S+B model
  - Background-subtracted plot illustrates several interesting candidate events

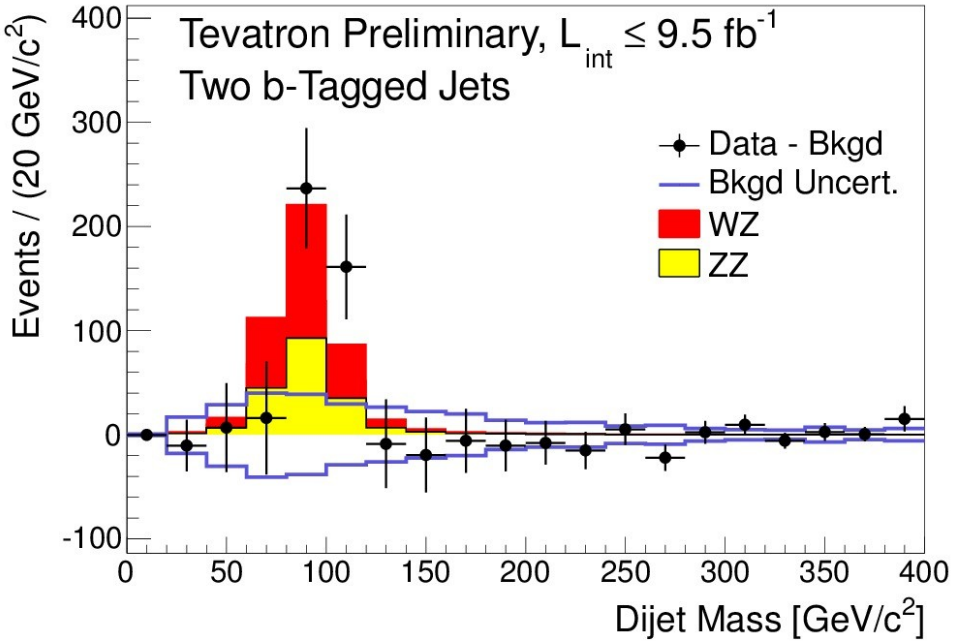


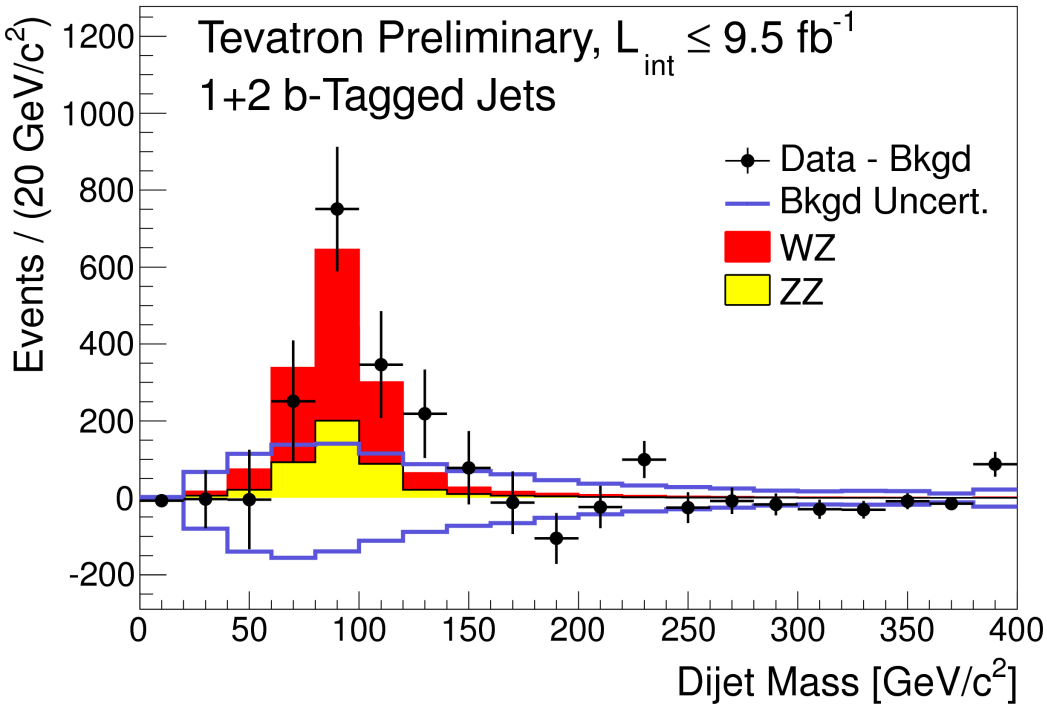


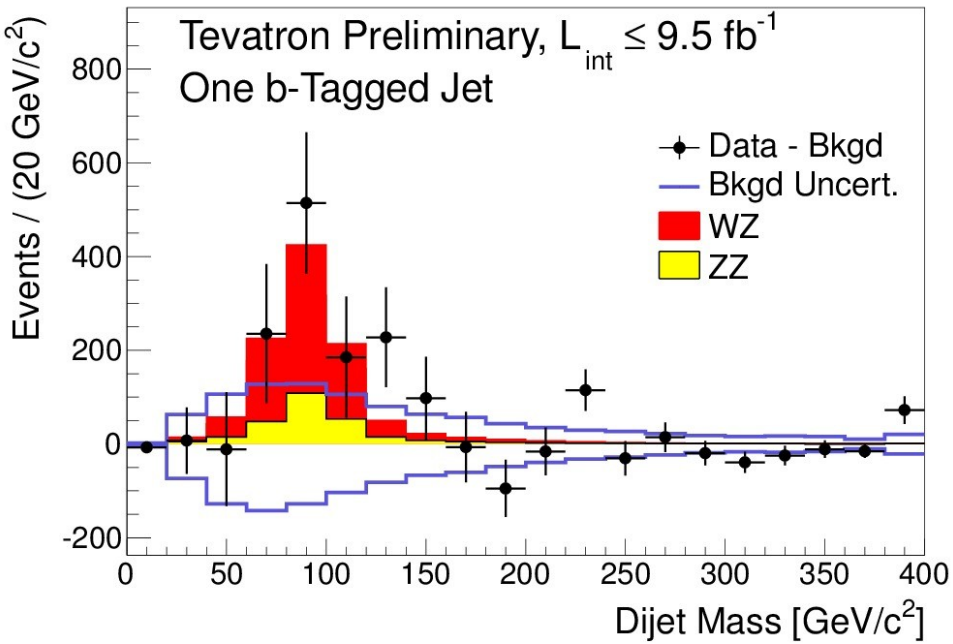


Overlaying a Higgs Signal

- Diboson measurement in dijet final states
  - Data and diboson prediction come from Tevatron low mass WZ/ZZ measurement

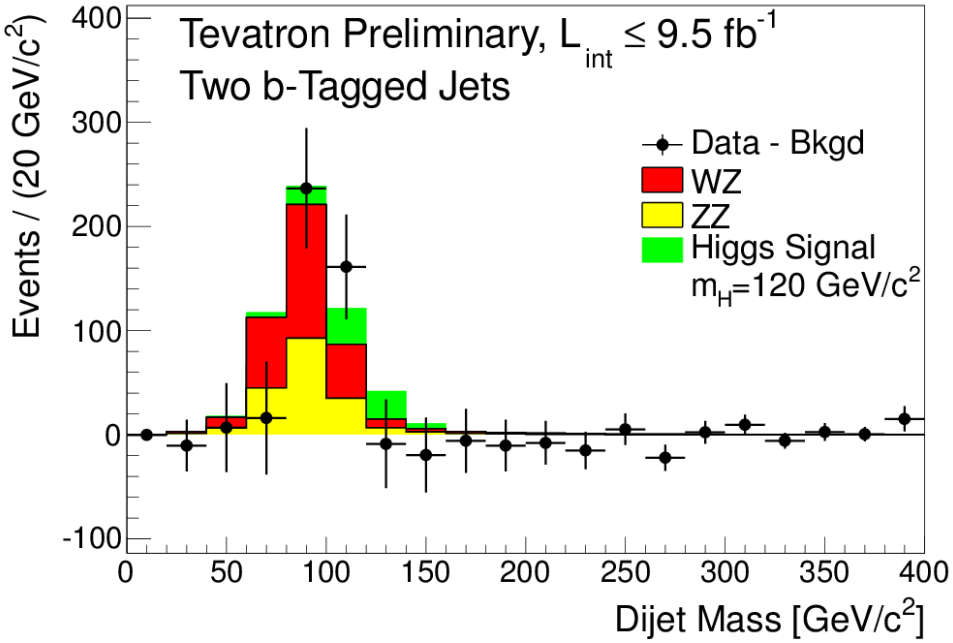


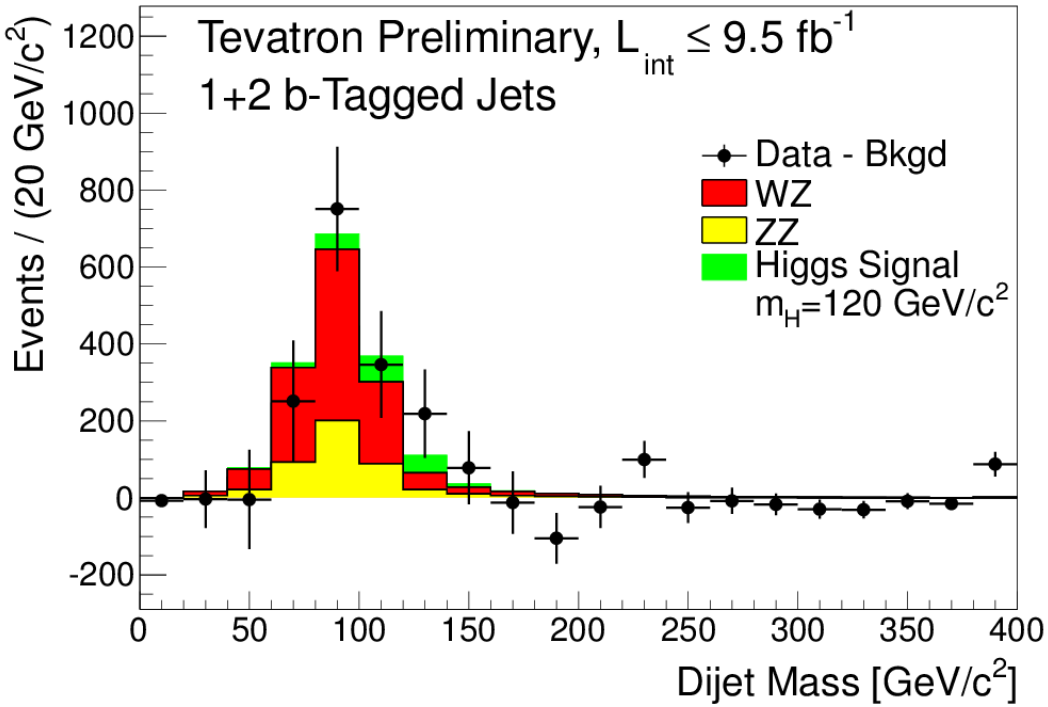


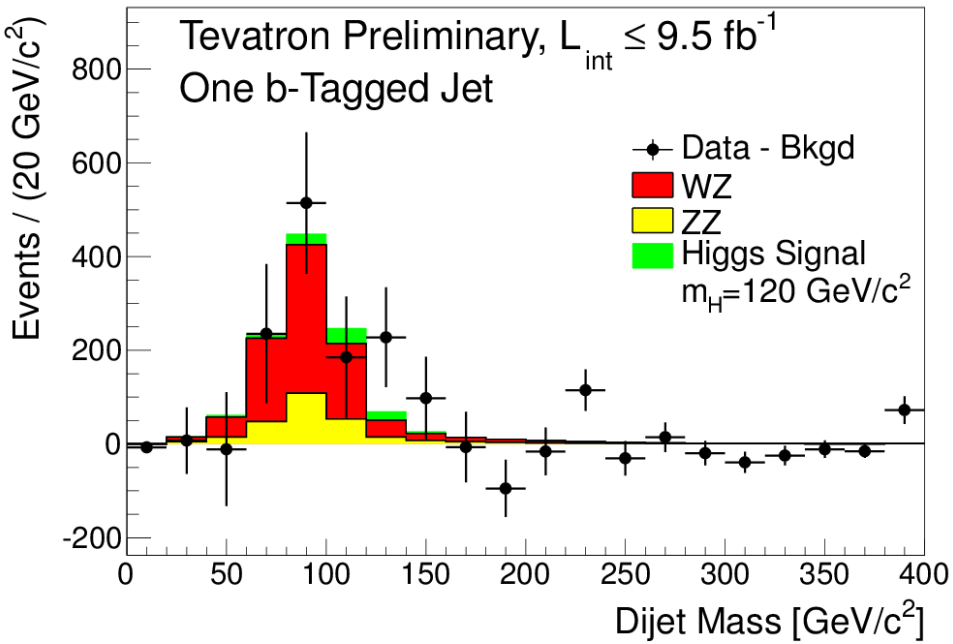


Overlaying a Higgs Signal

- Diboson measurement in dijet final states
  - Data and diboson prediction come from Tevatron low mass WZ/ZZ measurement
  - Simple overlay of H → bb signal prediction for the dijet invariant mass (MH=120 GeV)
  - Additional signal is not incompatible with data







Log-Likelihood Distributions

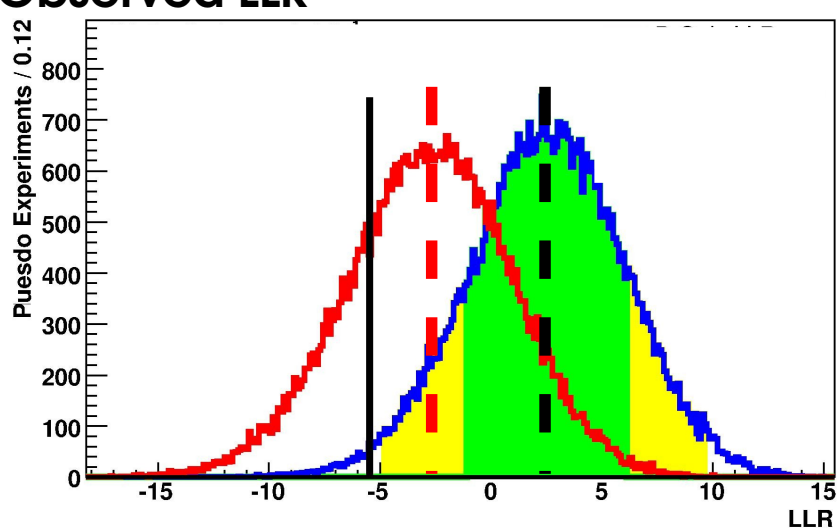
- The log-likelihood ratio helps to gauge the relative agreement of the data with the background or signal+background models

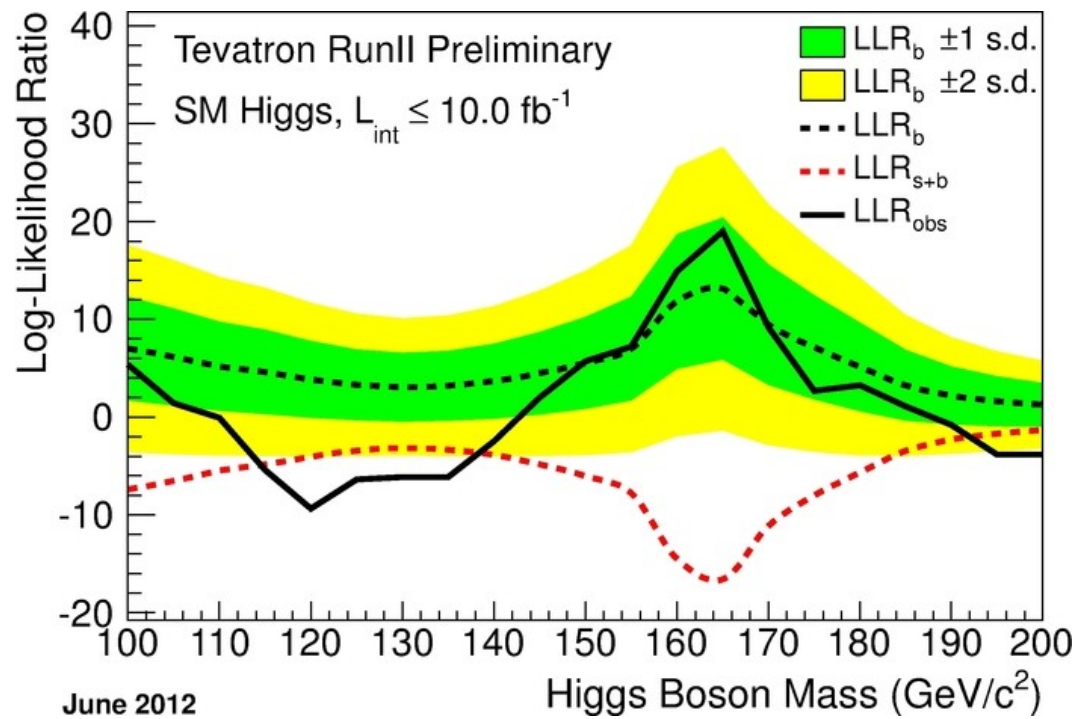
- Distributions are populated with pseudo-experiments to get an estimate of significance.

Background-Only Pseudo-Experiments

Signal+Bkgd Pseudo-Experimentss

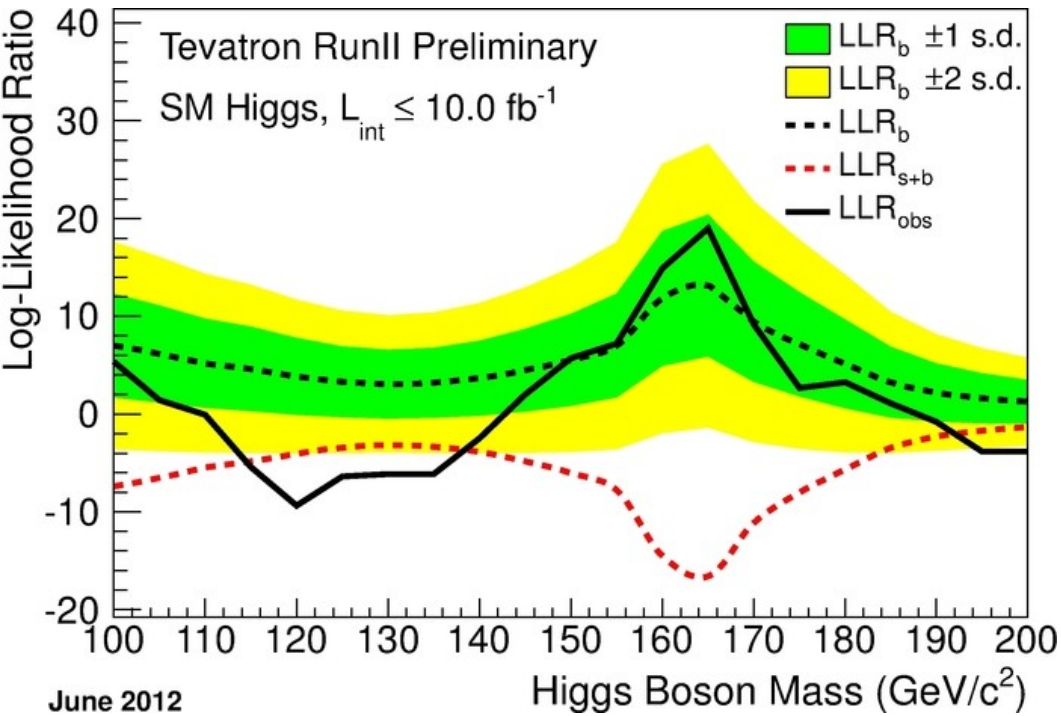
Observed LLR



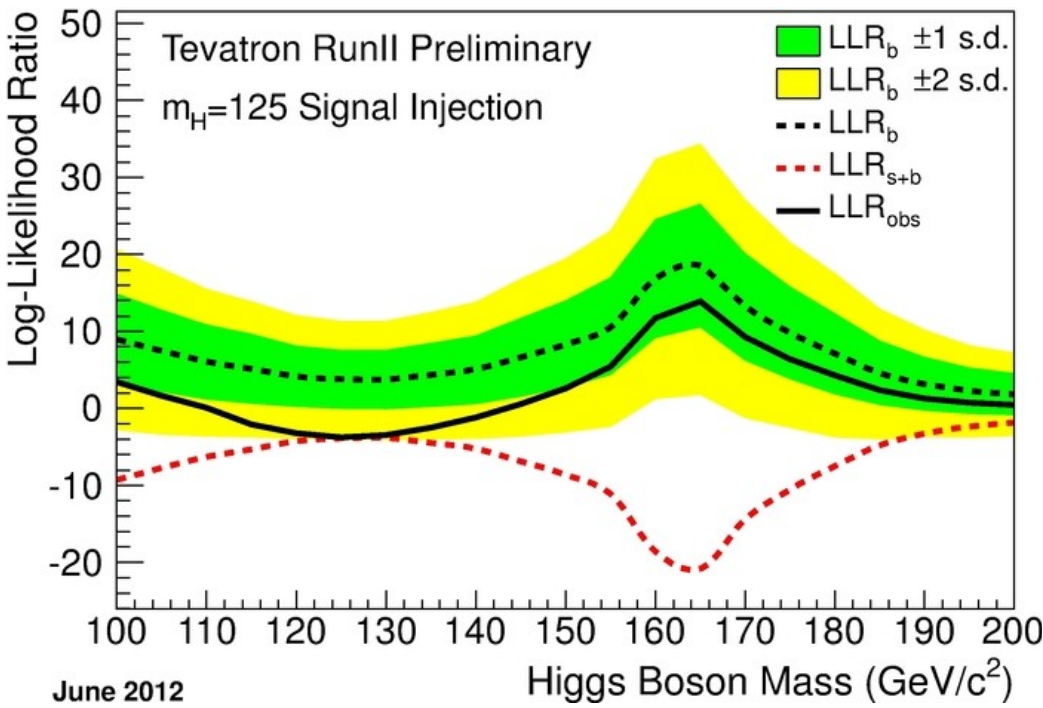


Quantifying the Excess

Tevatron Data

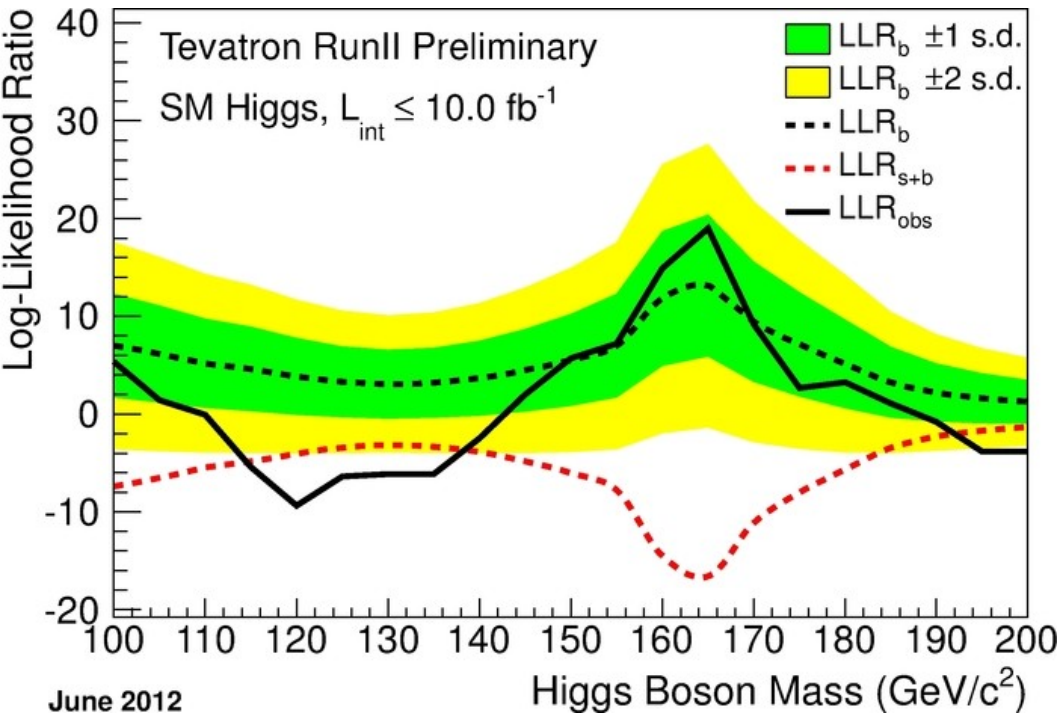


Signal Injection Study

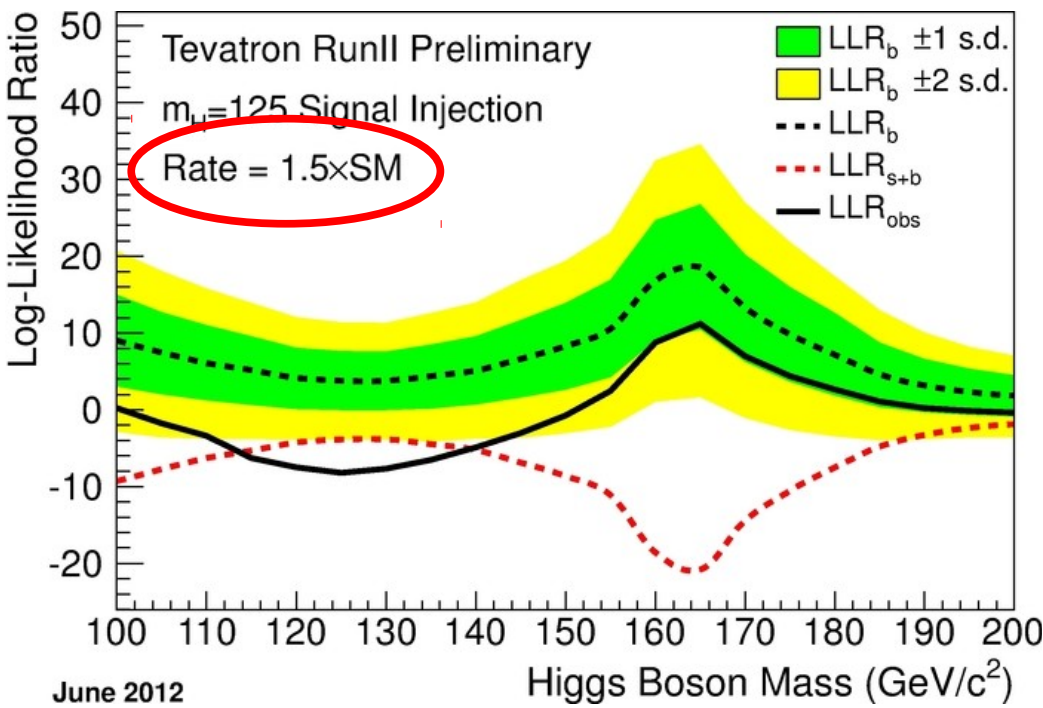


Quantifying the Excess

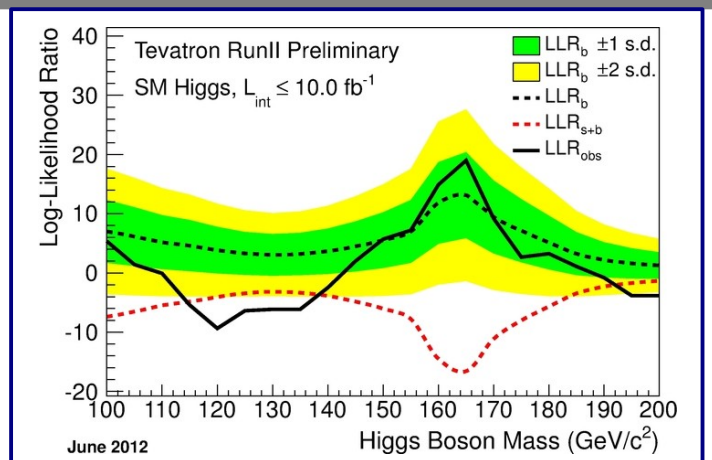
Tevatron Data



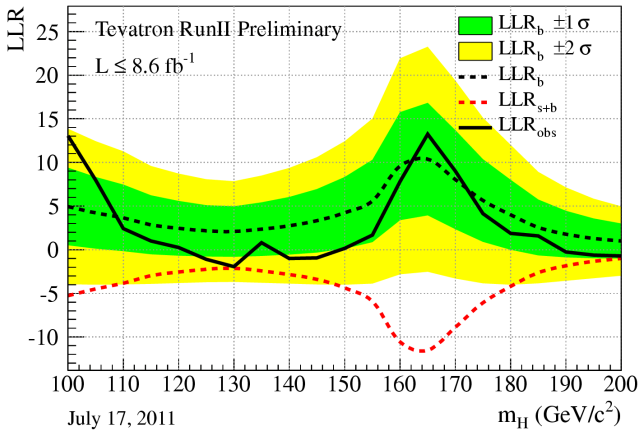
Signal Injection Study



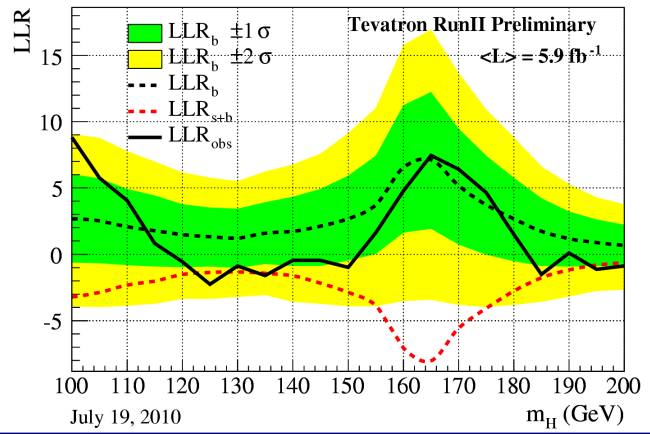
Log-Likelihood Distributions



2012

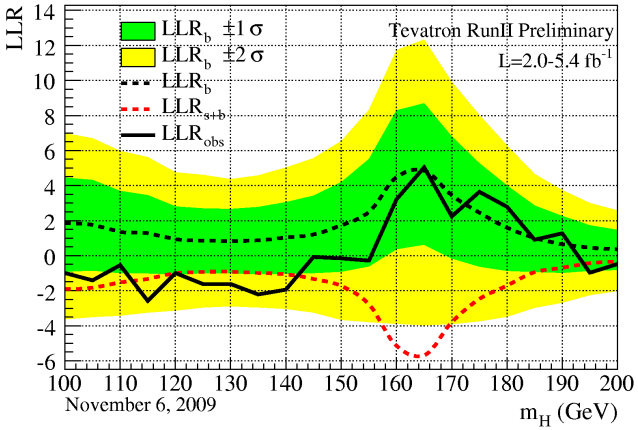


2011

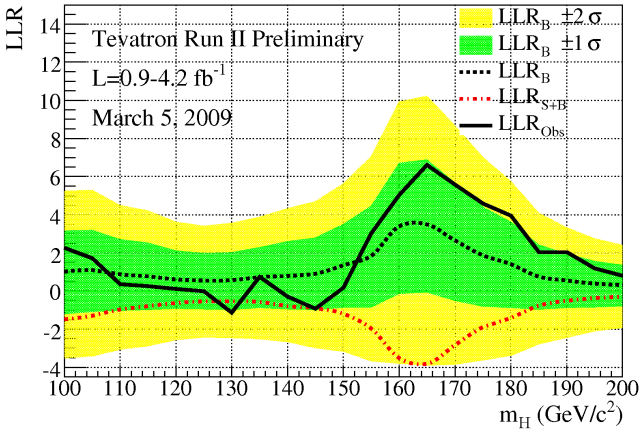


2010

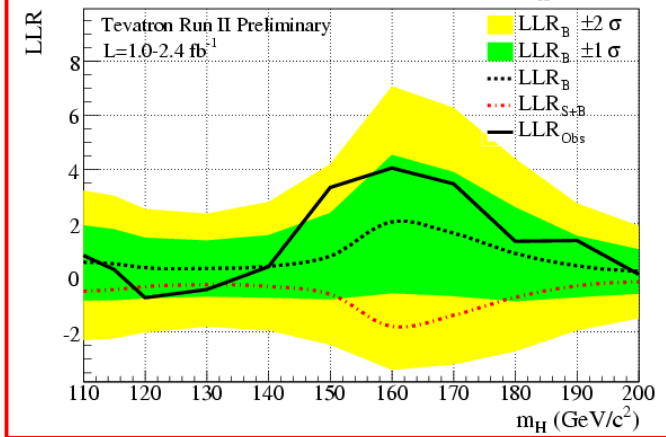
2009



2008



2007



Conclusions

– Tevatron program analyzing full data set

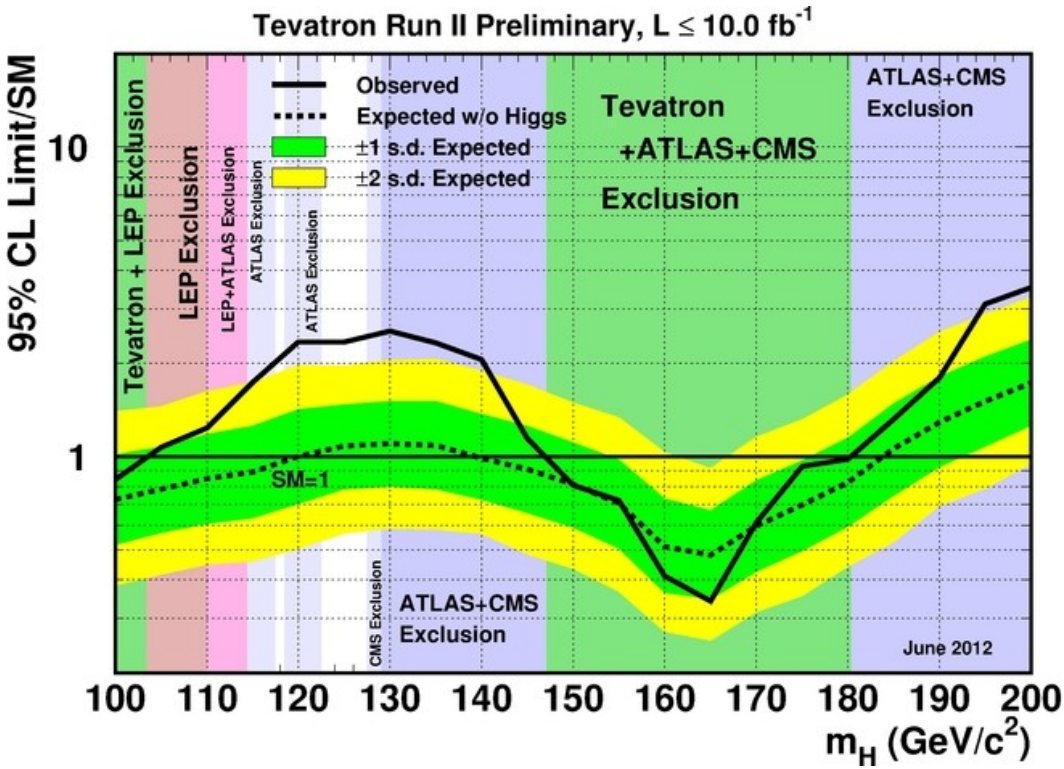
– The data appear to be incompatible with the background, with a global p-value of:

2.5 s.d. (3.0 local **)**

H→bb only: 2.9 s.d. (3.2 local **)**

– Tevatron data are compatible with SM Higgs boson production for 115 < M_H < 140

– Tevatron data will play a large role in any potential measurements of **σ(WH+ZH)×BR(H→bb)** for years to come



For additional details see

- Tevatron: http://tevnphwg.fnal.gov/results/SM_Higgs_Summer_12/index.html
- CDF: http://www-cdf.fnal.gov/physics/new/hdg/Results.html
- DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.html

Thank you, Fermilab

Special thanks to every single person & group at Fermilab who made this possible

It really is a huge team effort!!