Higgs Searches at the Tevatron

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on behalf of the CDF and D0 Collaborations

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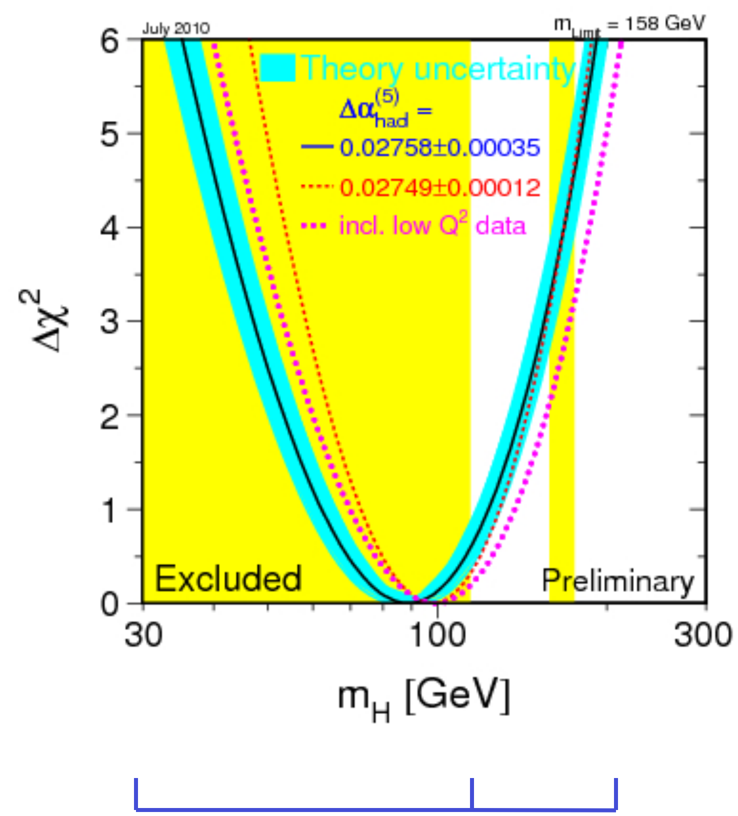
EPS - HEP 2011

Higgs Boson in SM

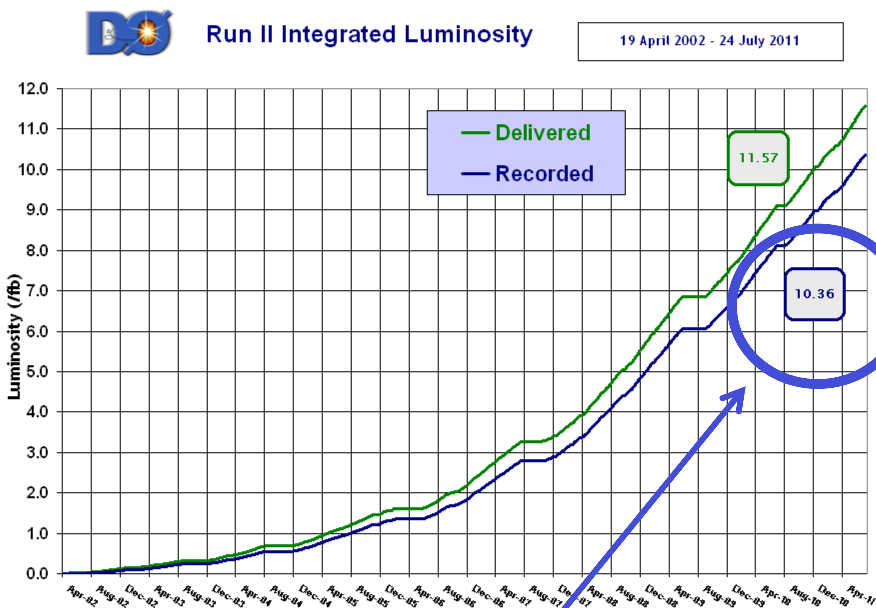
- Higgs field is the SM mechanism for electroweak symmetry breaking
- The mass of Higgs boson is not predicted (must be determined experimentally)
- Combination of direct constraints from LEP and indirect constraints from precision EWK data indicates m_H in range accessible to Tevatron



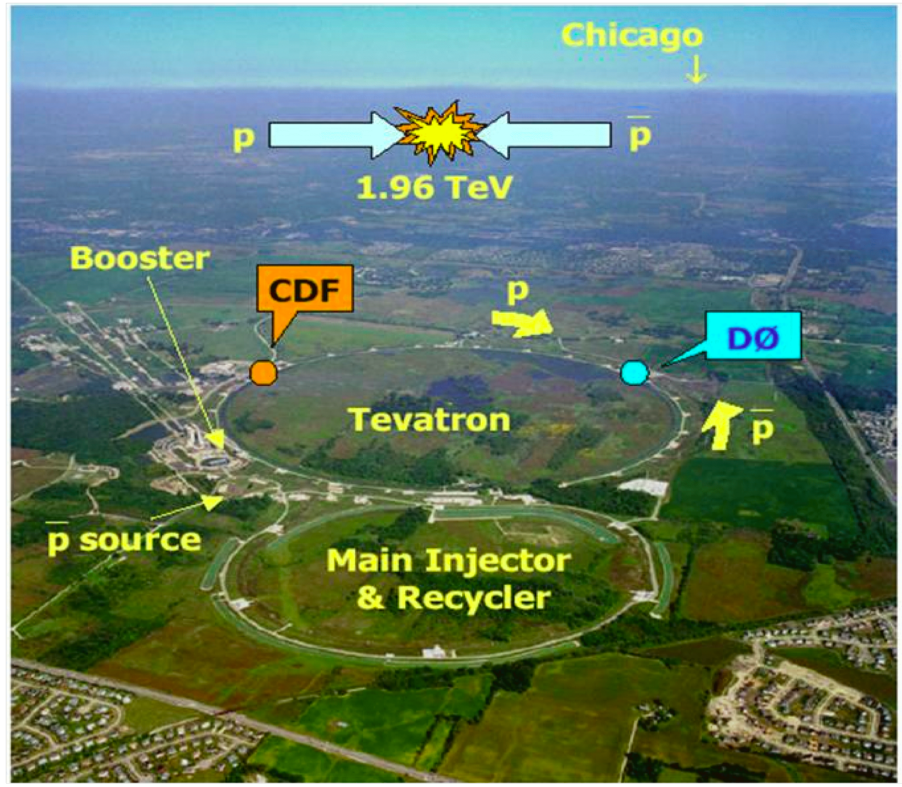
Excluded by direct searches at LEP

Potentially observable at Tevatron

Tevatron



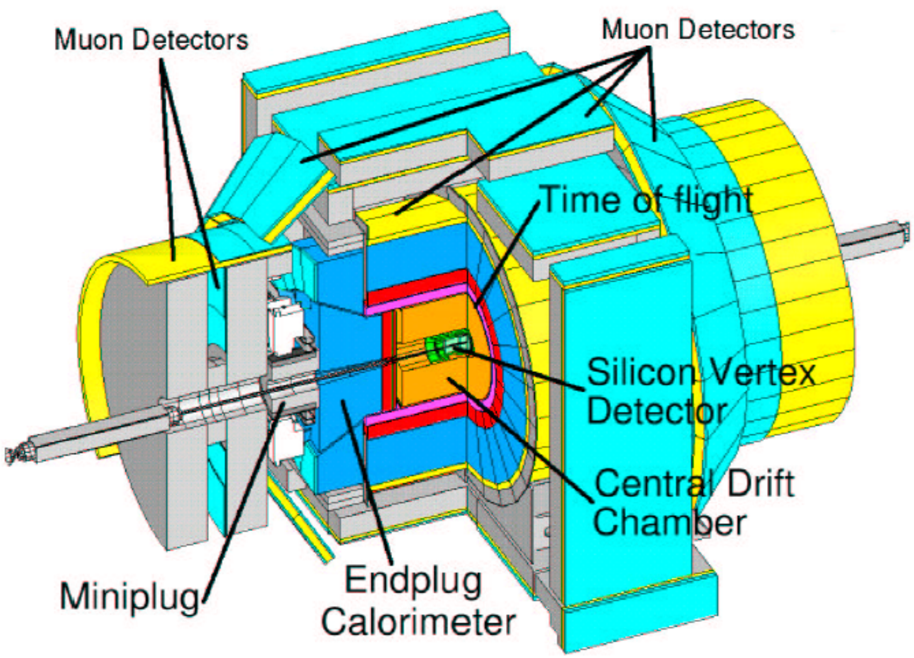
Over 10fb-1 on tape!



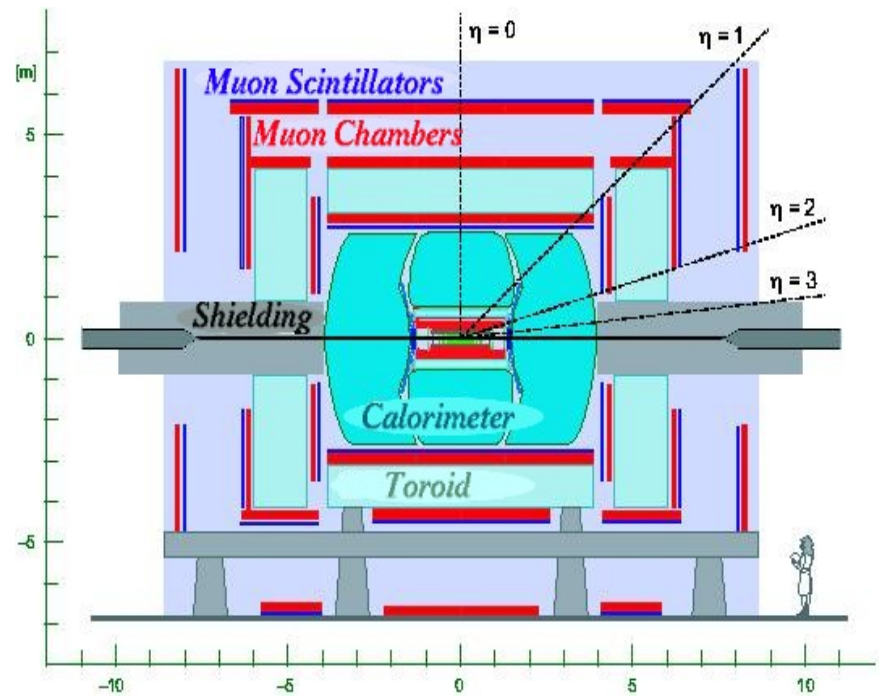
- Expect > 10 fb^{-1} analyzable data by end of September

Tevatron Detectors

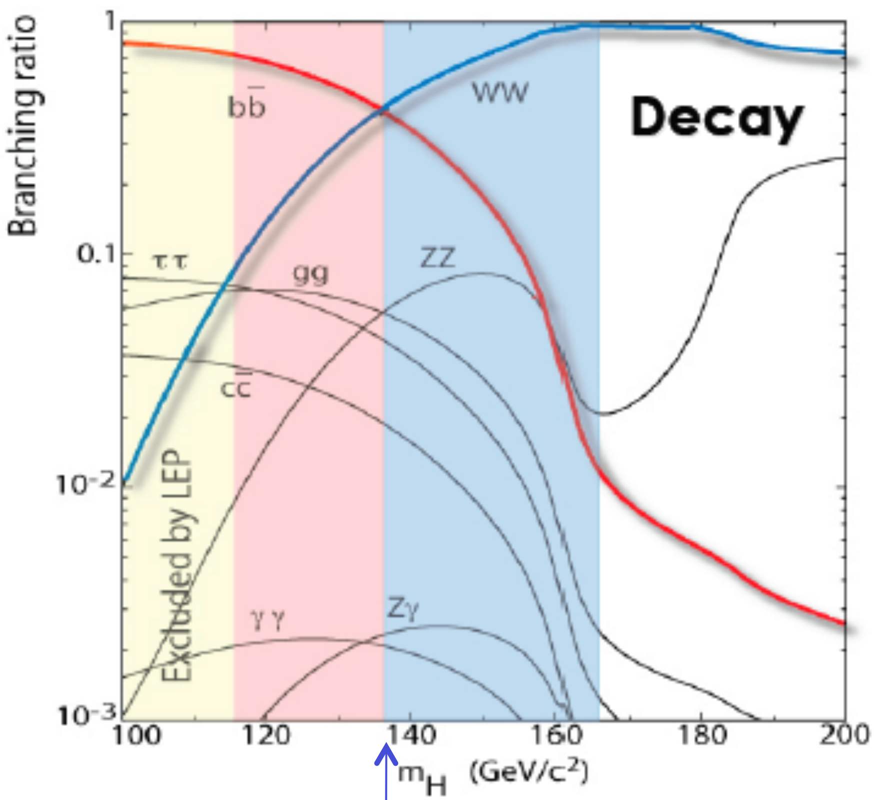
CDF II Detector



DØ Detector



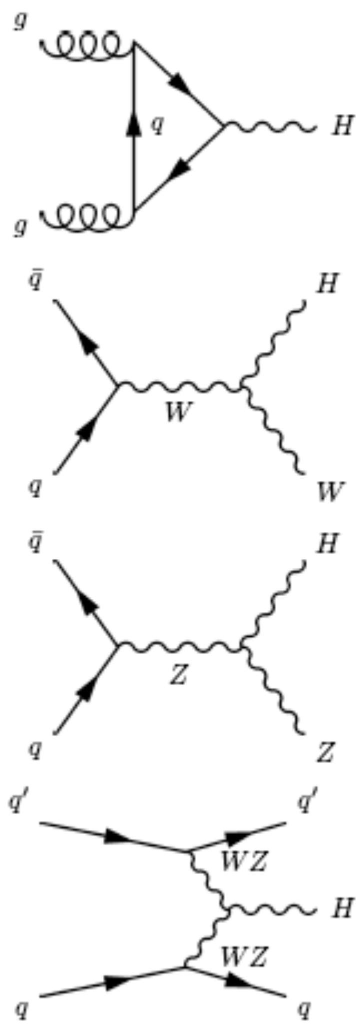
Higgs Decay

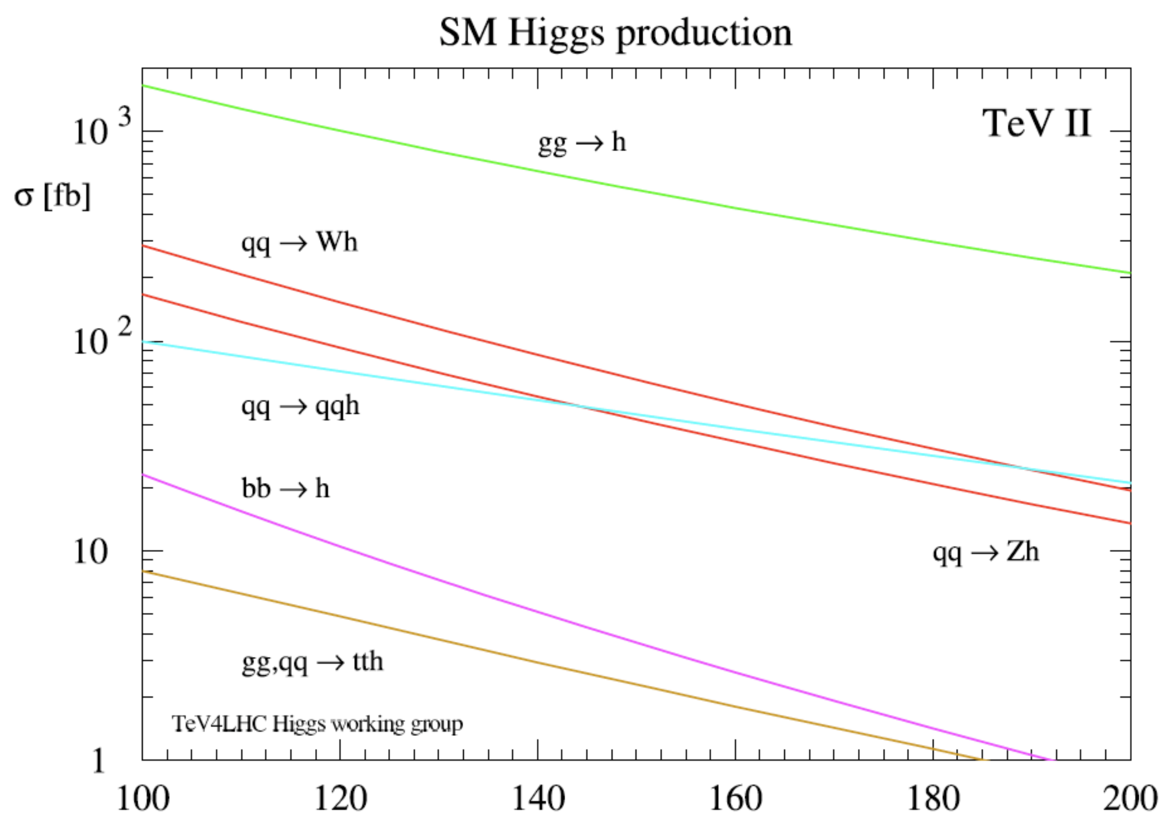


Cross-Over Point
($m_H \sim 135$ GeV)

- Low Mass
  - Focus on $H \rightarrow bb$
  - Also $H \rightarrow \tau\tau$ and $H \rightarrow \gamma\gamma$
- High Mass
  - Focus on $H \rightarrow WW$
  - Also $H \rightarrow ZZ$

Higgs Production at Tevatron





Higgs Search Challenge

Expected number of events per fb^{-1} per experiment

Higgs Mass (GeV/c^2)	WH→lνbb	ZH→ννbb	ZH→llbb	H→WW→lνlν
120	25	12	4	13
135	10	5	2	26
150	3	2	1	32

reconstruction/selection/tagging efficiencies ~ 10% in H→bb channels and ~25% in H→WW channels

Higgs Search Strategy

- Select inclusive candidate samples that preserve the maximum possible acceptance to a potential Higgs signal
- Separate these samples into multiple analysis channels to isolate potential signal events in high S/B regions
- Carefully model all backgrounds and cross check using control regions in data
- Use advanced multivariate analysis tools to separate signal from background based on the full event kinematics

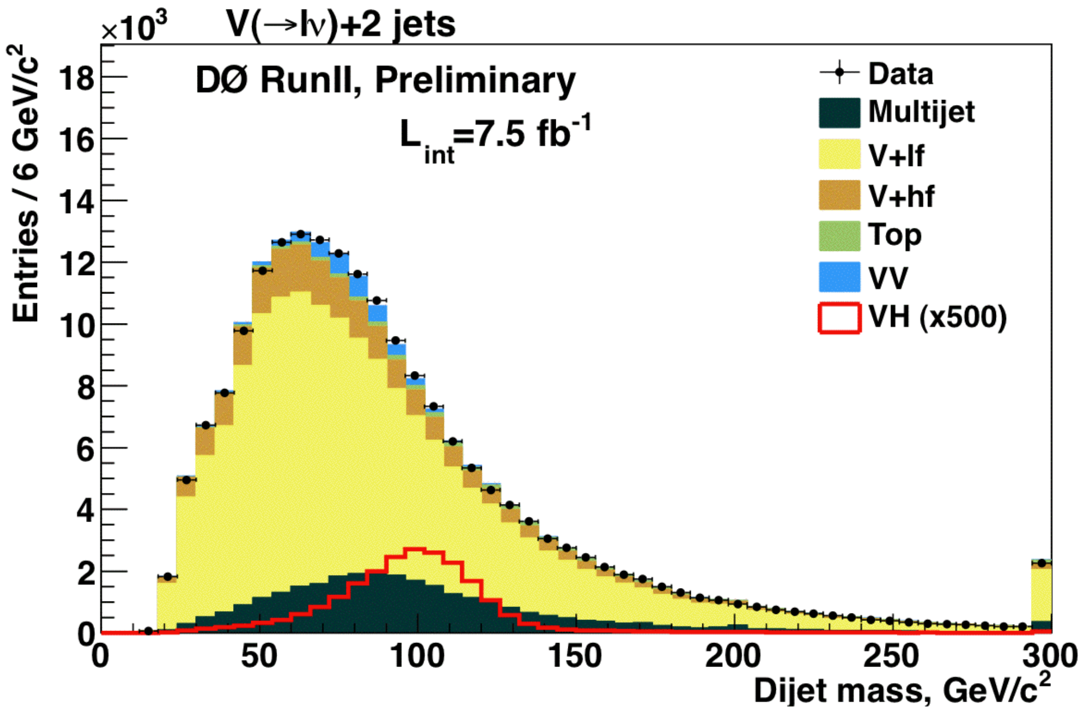
Event Selection

- Need to maximize signal acceptance
- Three main areas of focus :

  (1) Increasing lepton reconstruction and selection efficiencies

  (2) Improving the efficiency for tagging b-quark jets

  (3) Optimizing dijet mass resolution



Pre-tagged events

Event Selection

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- Three main areas of focus :

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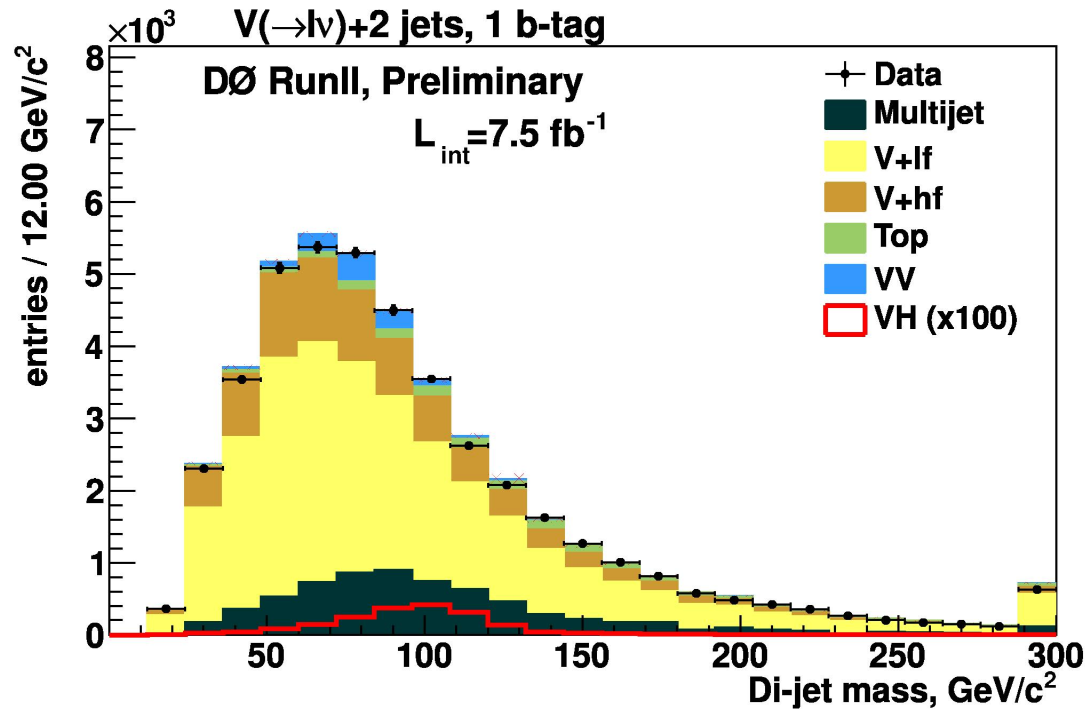
  (2) Improving the efficiency for tagging b-quark jets

  (3) Optimizing dijet mass resolution



Single b-tagged events

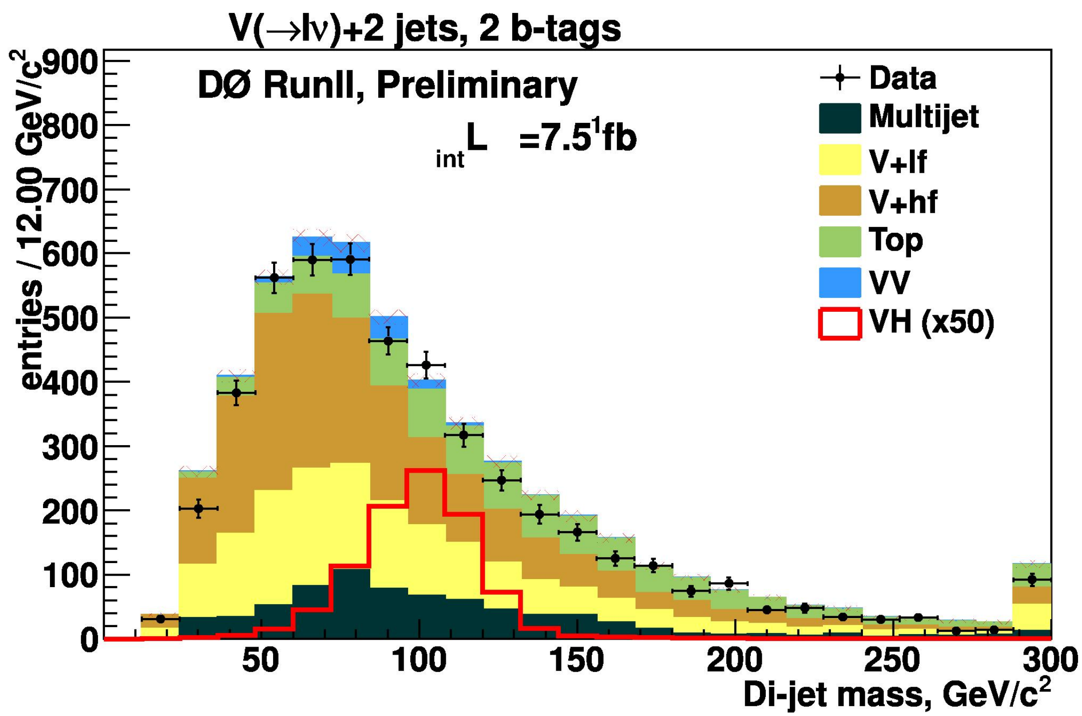
Event Selection

- Need to maximize signal acceptance
- Three main areas of focus :

  (1) Increasing lepton reconstruction and selection efficiencies

  (2) Improving the efficiency for tagging b-quark jets

  (3) Optimizing dijet mass resolution

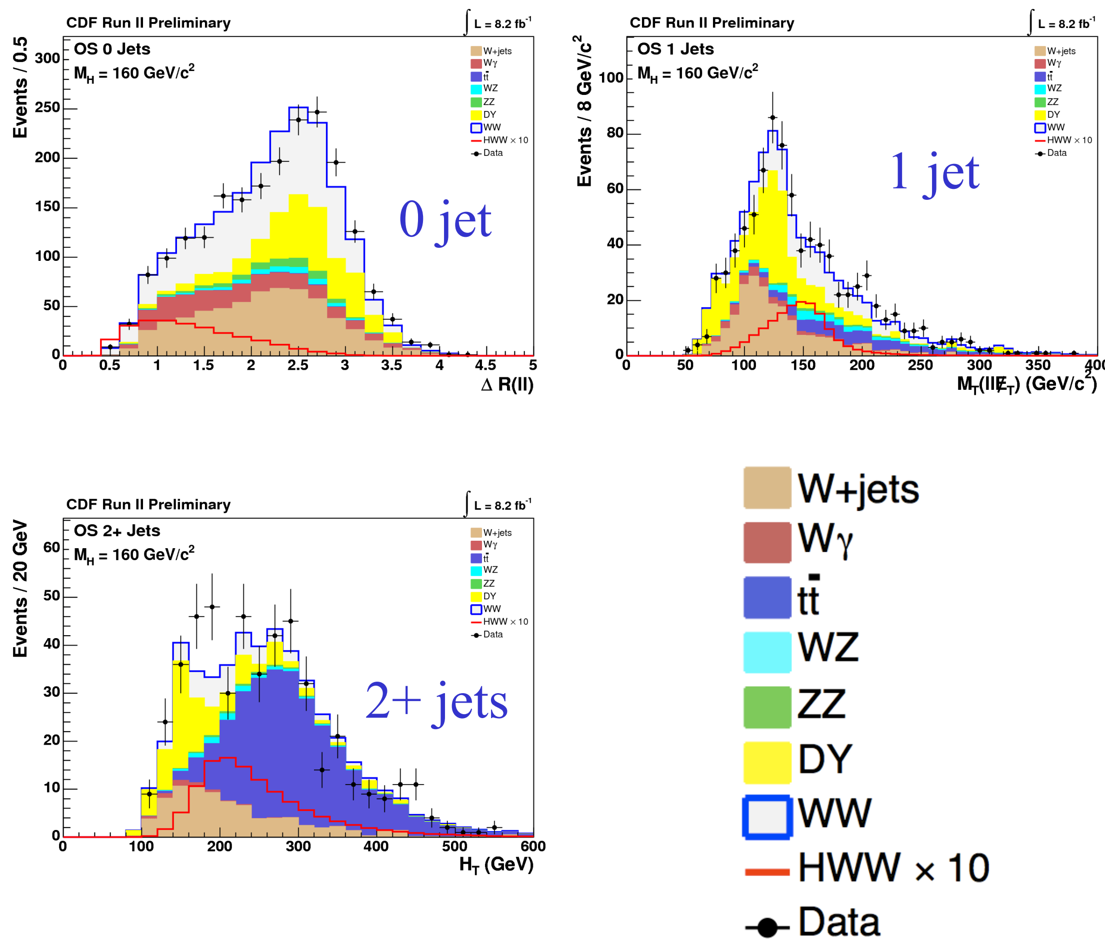


Double b-tagged events

Maximizing Sensitivity

- We optimize search sensitivity by dividing events into multiple analysis channels
- This allows us to use separate, optimized discriminants for each channel based on
  - specific signal contributions
  - specific background contributions
  - specific event kinematics

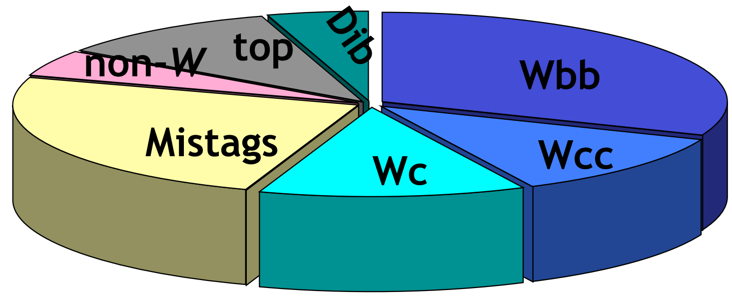
H→WW→lνlν



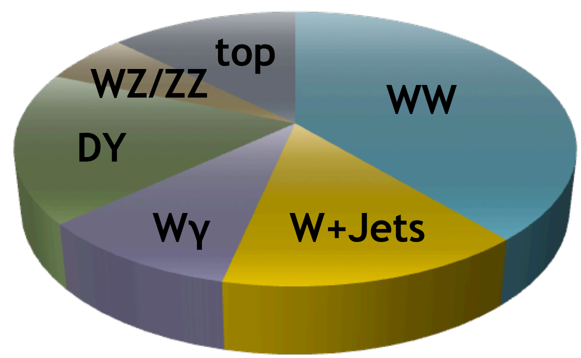
SM Backgrounds

- Need to separate small potential signal from large SM background contributions in our search channels
- For example, applying minimal selection criteria S/B ~ 0.015 in our most sensitive search channels
- Background modeling carefully checked in data control regions

WH→lνbb



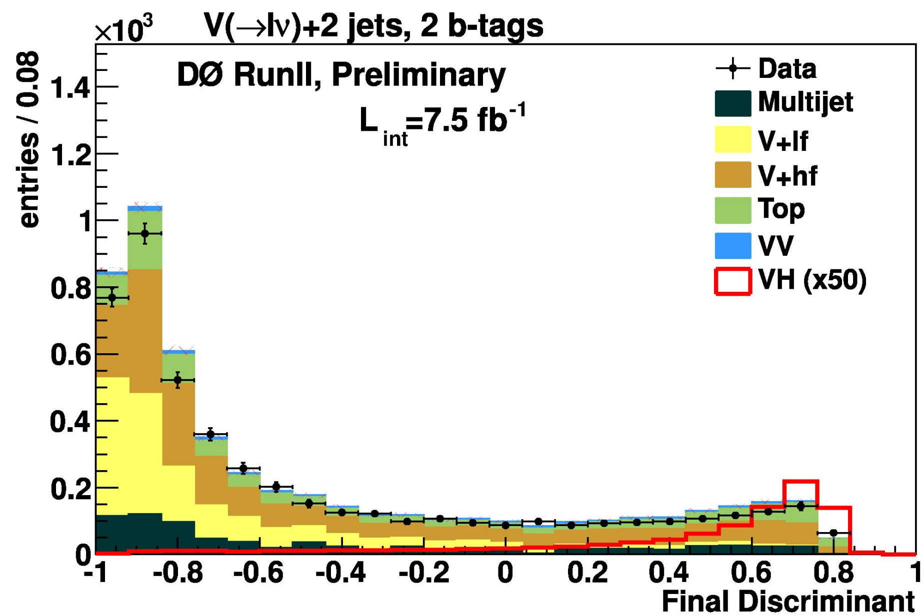
H→WW→lνlν



Improving S/B

- In order to improve S/B need to utilize full kinematic event information
- Multi-variant techniques are used to maximize search sensitivities
  - Neural Networks
  - Boosted Decision Trees
  - Matrix Element Calculations
- Typically these add 10-20% in sensitivity beyond that obtained from optimized, cut-based analysis

WH→lνbb



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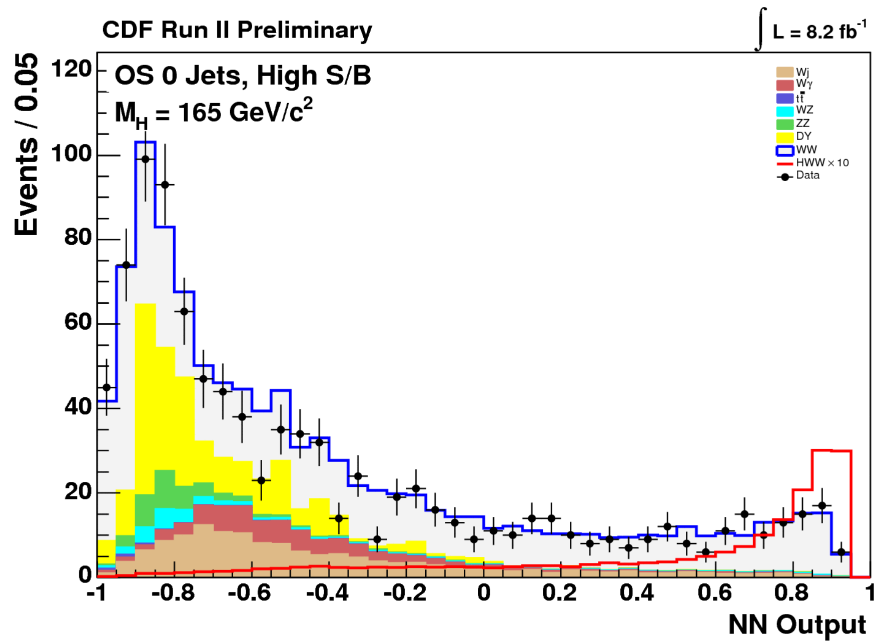
$H \rightarrow WW \rightarrow l\nu l\nu$



Combining Channels

- Our goal is to leave no Higgs events behind
- Best sensitivity is obtained through the combination of many independent search channels

WH→lνbb
ZH→ννbb
ZH→llbb
WH/ZH→jjbb
ttH→WbWbbb
H→γγ
H→ττ
WH→lνττ / ZH→llττ
H→WW→lνlν
H→WW→lνjj
WH→WWW / ZH→ZWW
H→ZZ

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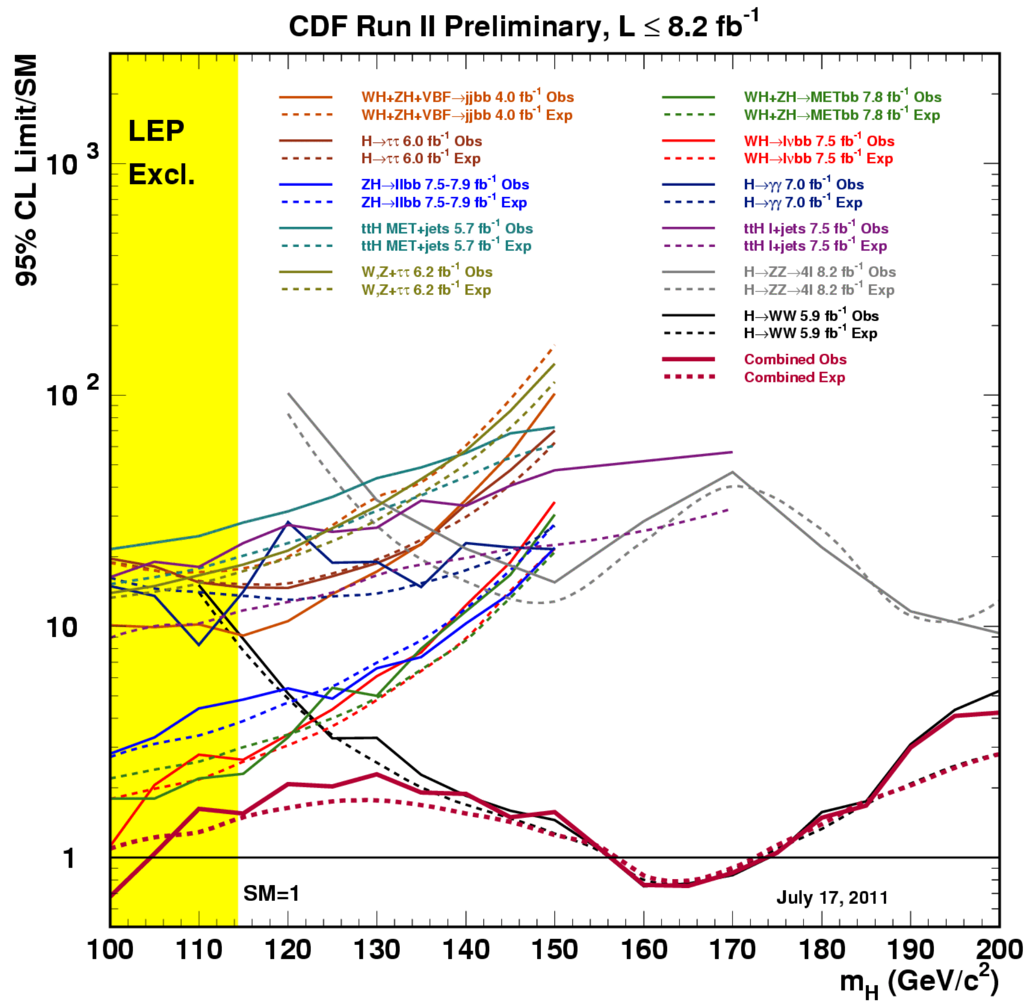
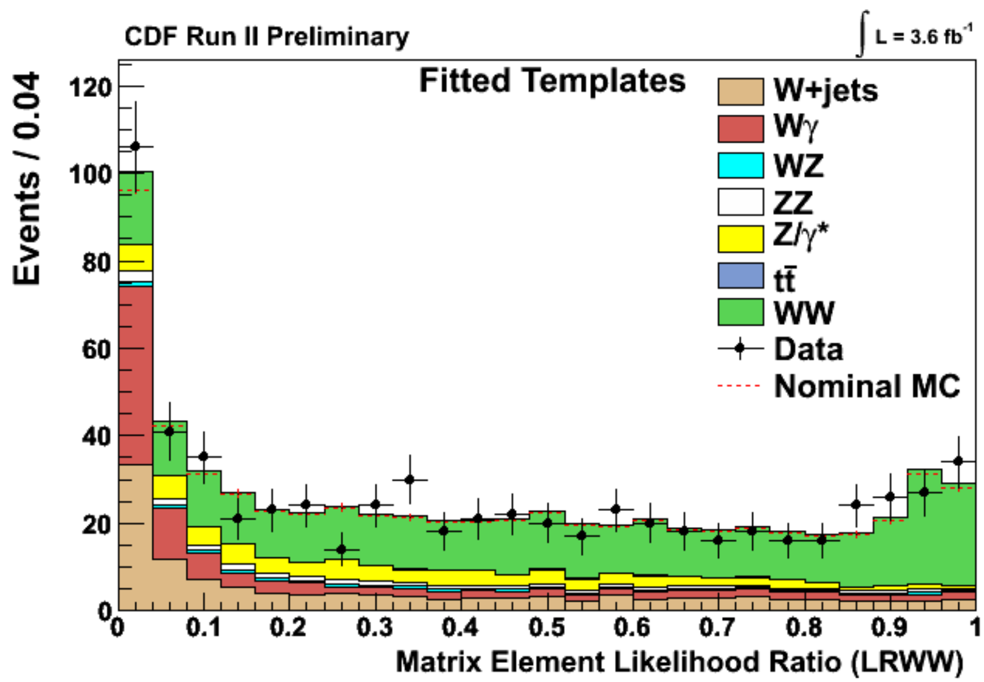


Validation of Search Techniques

- Diboson cross section measurements based on the same tools and data samples used for the $H\rightarrow WW\rightarrow l\nu l\nu$ search provide an important cross check on our background modeling and analysis techniques

$$WW\rightarrow l\nu l\nu : \sigma(WW) = 12.1\ ^{+1.8}_{-1.7}\ \text{pb}$$



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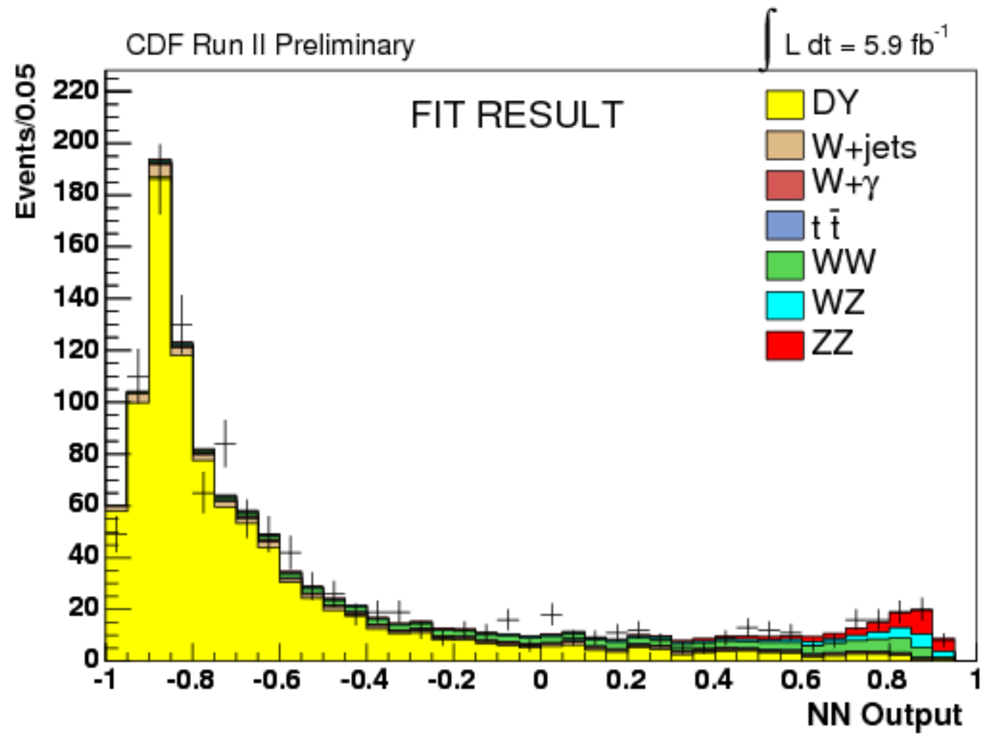
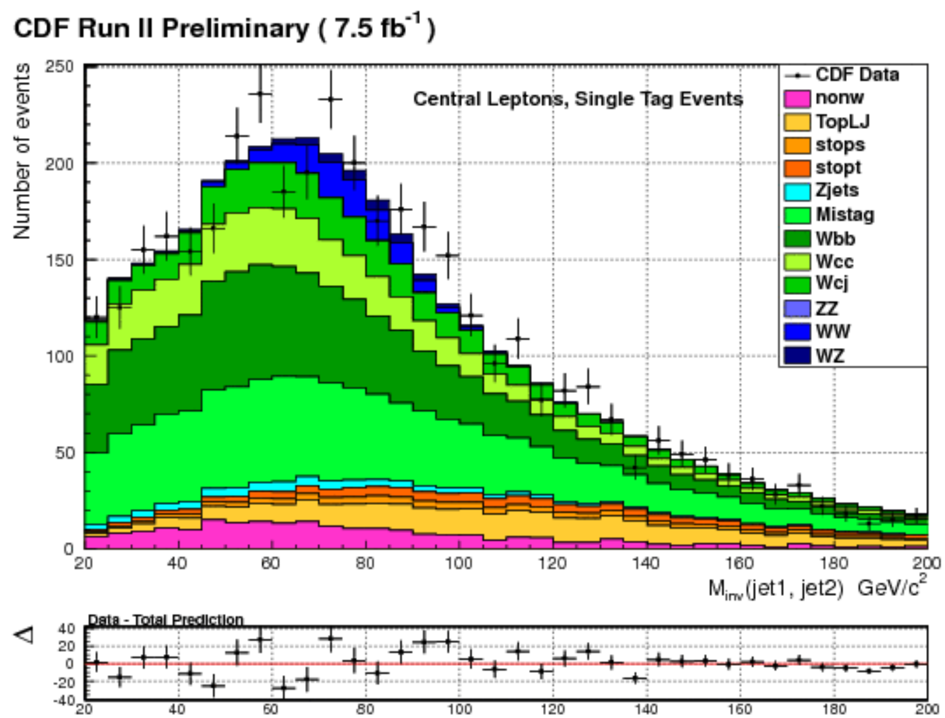
$ZZ \rightarrow ll\nu\nu$: $\sigma(ZZ) = 1.45^{+0.60}_{-0.51}$ pb



Validation of Search Techniques

- Similarly, search for semi-leptonic diboson production in the lνbb, ννbb, and llbb final states to validate our H→bb analysis techniques
- Final test is to observe WZ/ZZ (Z→bb) production by combining CDF and D0 searches in all three final states



$$\sigma(WW/WZ \rightarrow l\nu cs/l\nu bb) = 1.08^{+0.26}_{-0.40} \text{ x SM } (3.0\sigma)$$

Validation of Search Techniques

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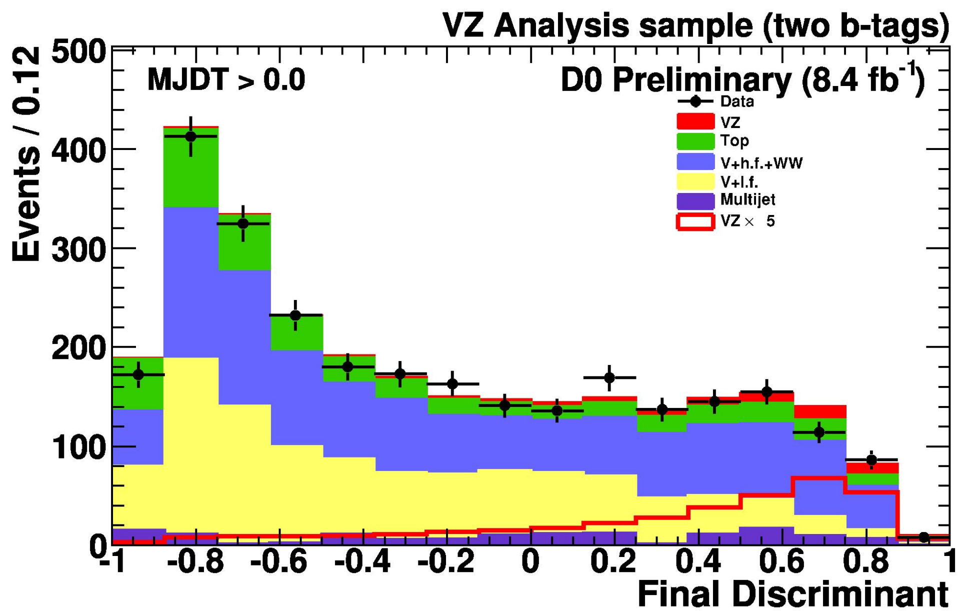
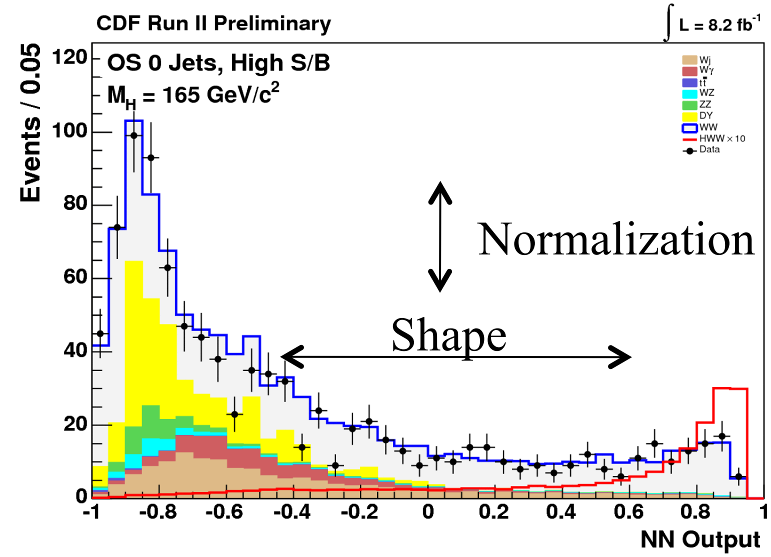


$\sigma(WZ/ZZ \rightarrow \nu\nu bb) = 1.5 \pm 0.5 \times SM\ (2.8\sigma)$

Systematic Uncertainties

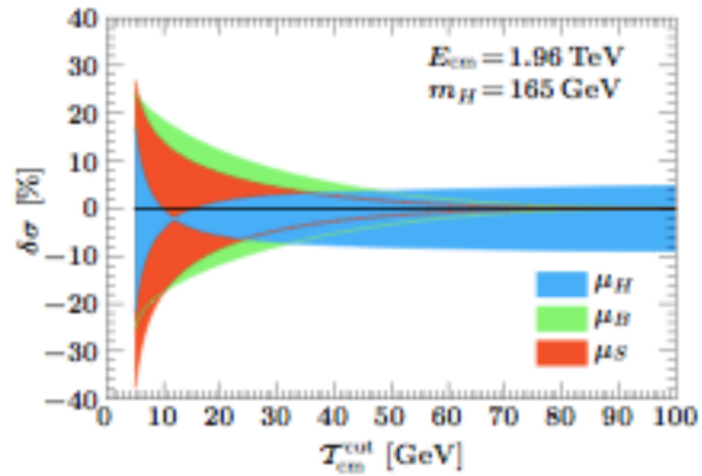
- We consider uncertainties both on the overall normalization of each signal/background process and on the shapes of the final discriminant templates for each signal/background process
- In the limit-setting procedure systematics are included as nuisance parameters, taking into account the correlations between different channels



Using this approach we are able to further constrain our background uncertainties directly from the data

Theoretical Uncertainties

- Since we combine searches focusing on different Higgs production and decay modes, cross section limits are given with respect to nominal SM predictions
- This forces us to incorporate theoretical predictions and uncertainties for signal cross sections and branching ratios
- Changed in each iteration to reflect recent theoretical developments

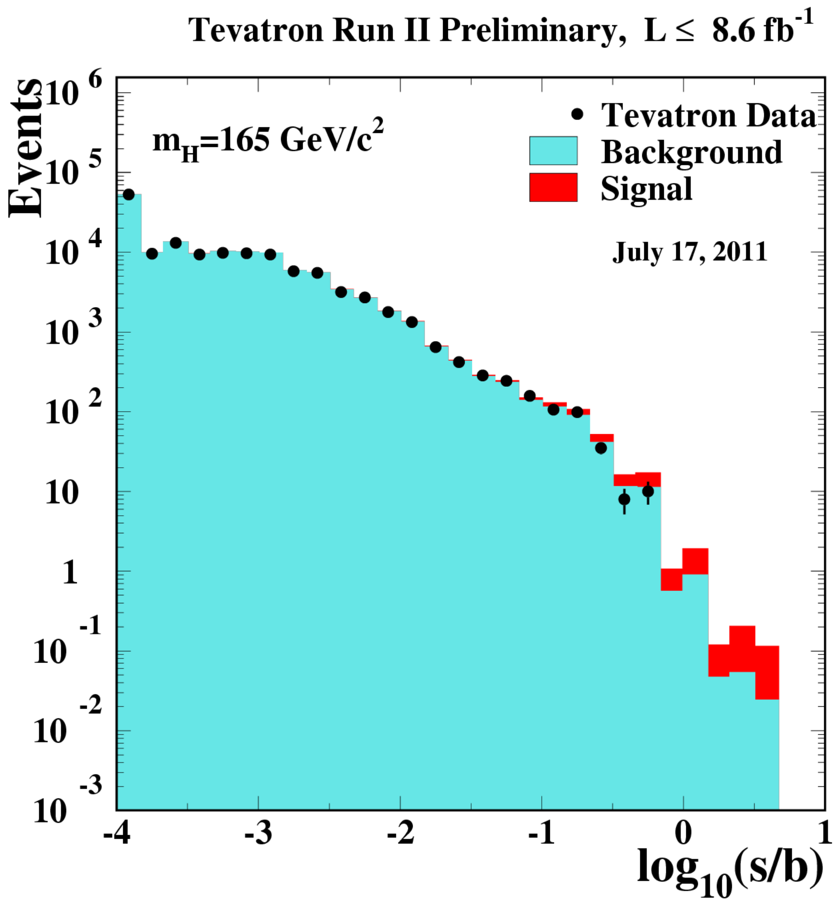


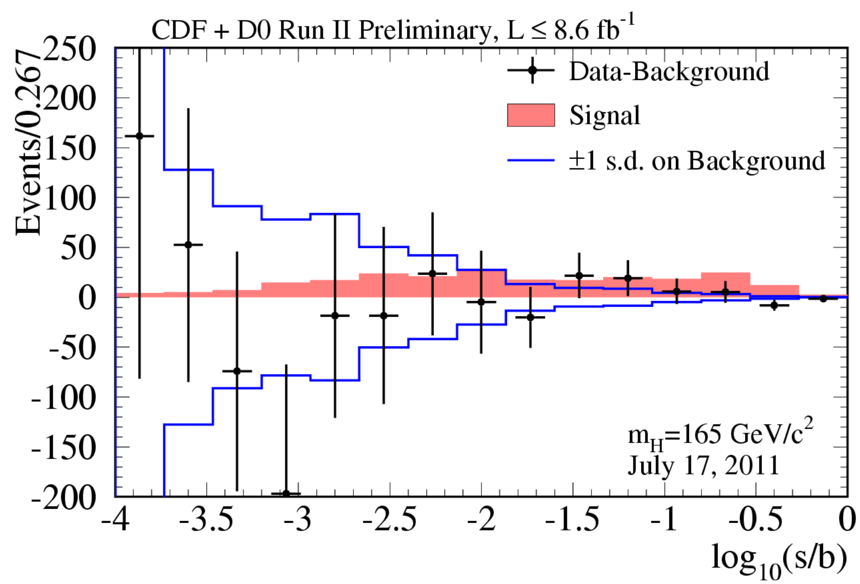
Berger et al., arXiv:1012.4480v2

channel	scale 0	scale 1	scale 2
0 jet	13.4%	-23.0%	-
1 jet	-	35.0%	-12.7%
2+ jets	-	-	33.0%

Stewart and Tackmann, arXiv:1107.2117v1

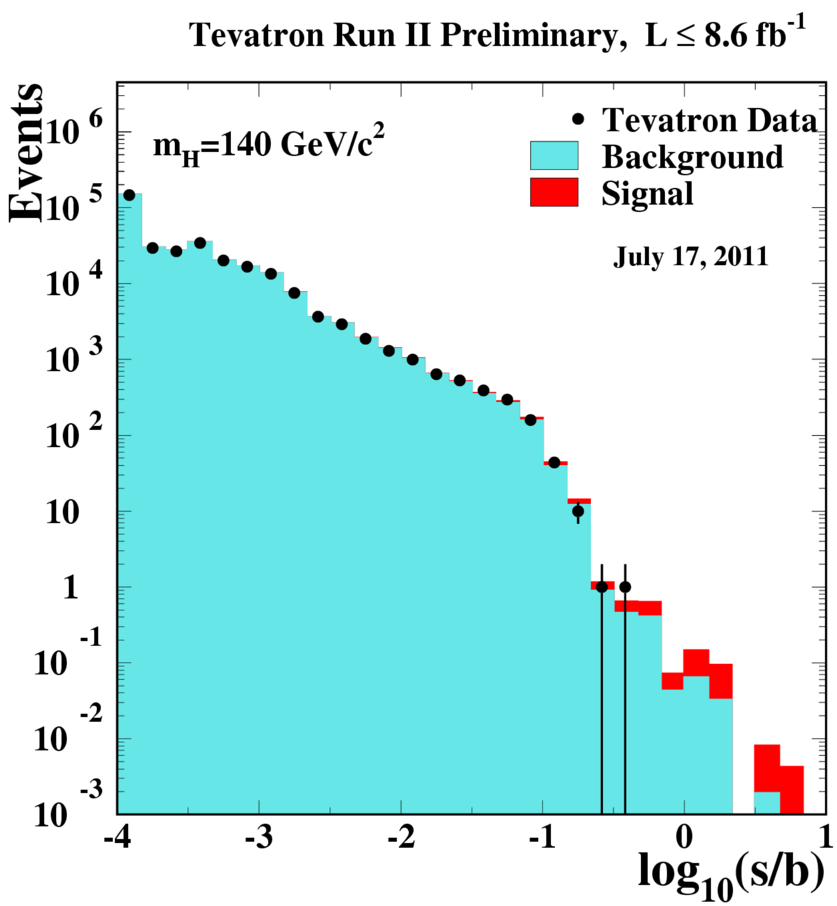
Combined Discriminants

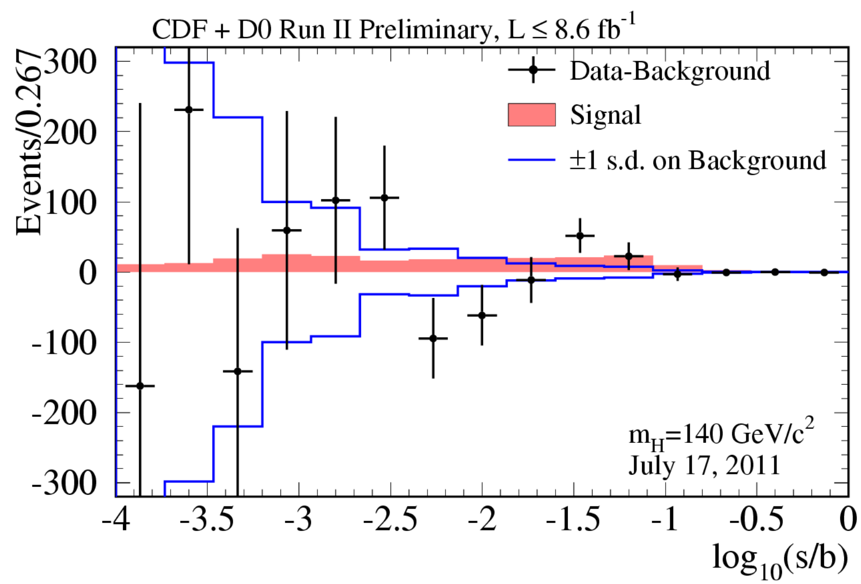




m_H = 165 GeV/c^2

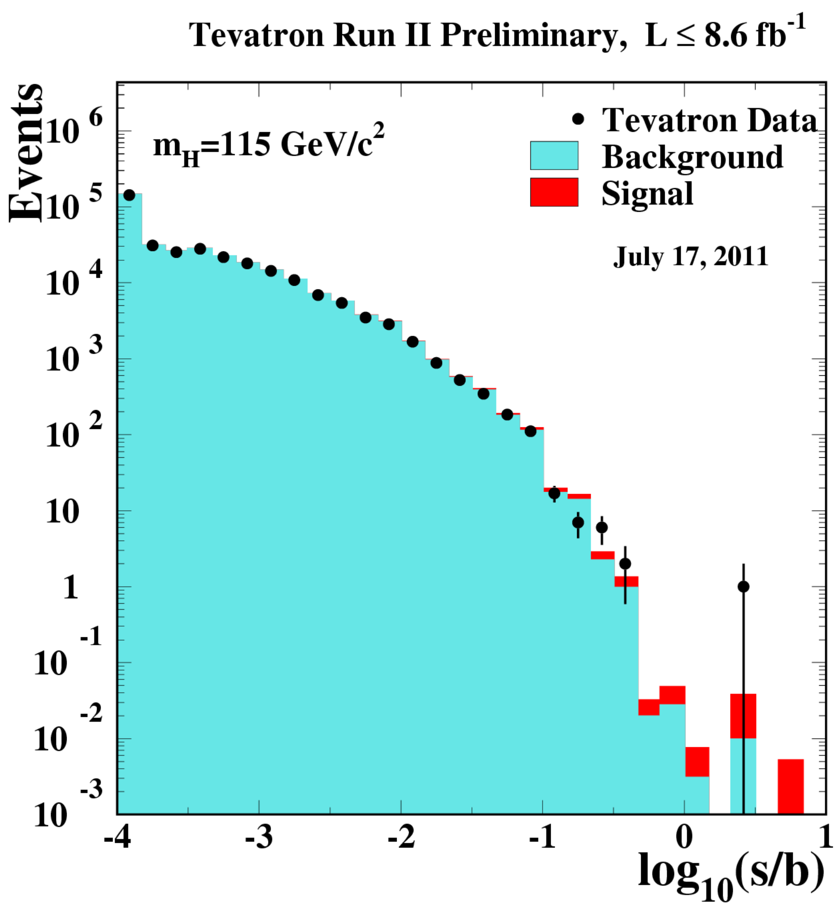
Combined Discriminants

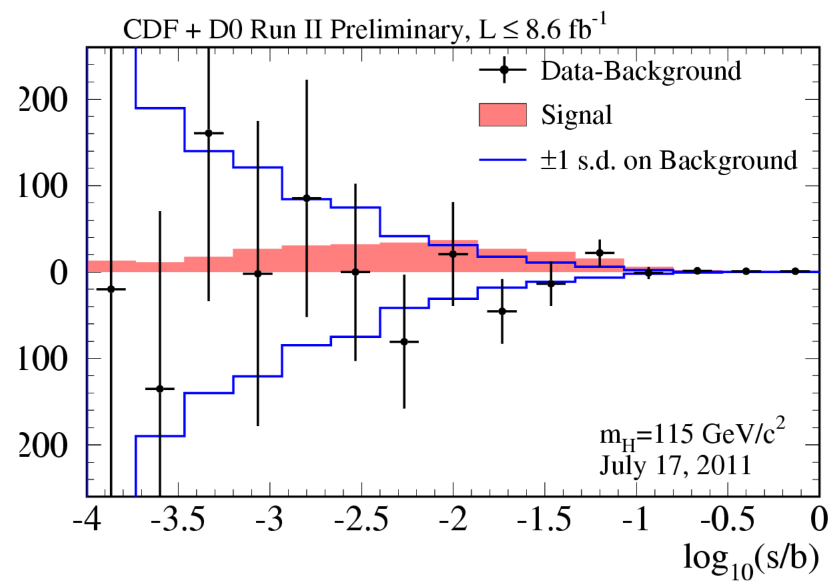




$m_H = 140\ \mathrm{GeV}/c^2$

Combined Discriminants



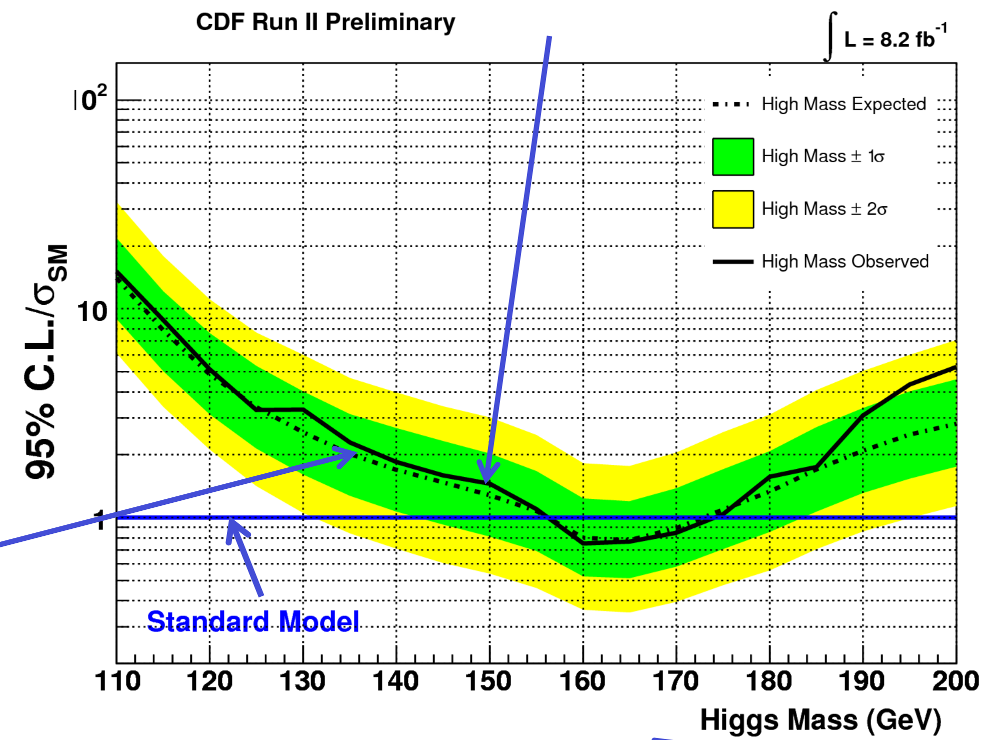


$m_H = 115\ \mathrm{GeV}/c^2$

Limit Plot Example

Observed limit (solid line) from data

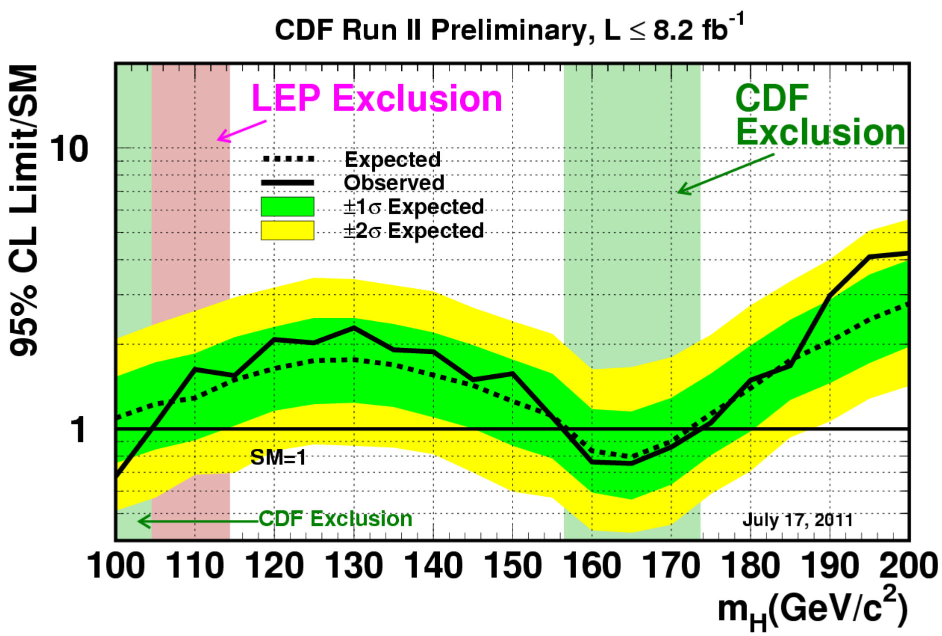
Upper cross section limit for Higgs production relative to SM prediction

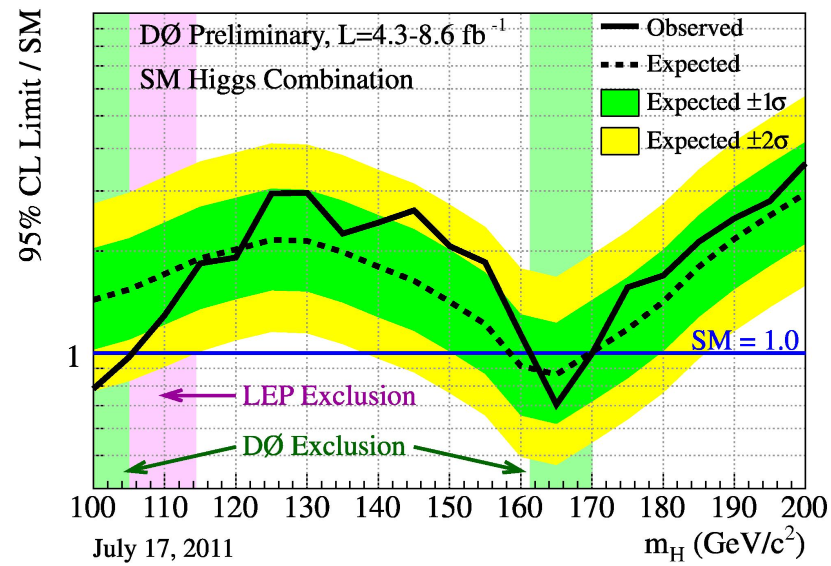


Median expected limit (dot-dashed line) and predicted 1σ/2σ (green/yellow bands) excursions from background only pseudo-experiments

Analysis repeated using different signal templates for each m_H between 100 and 200 GeV in 5 GeV steps

CDF/D0 Limits

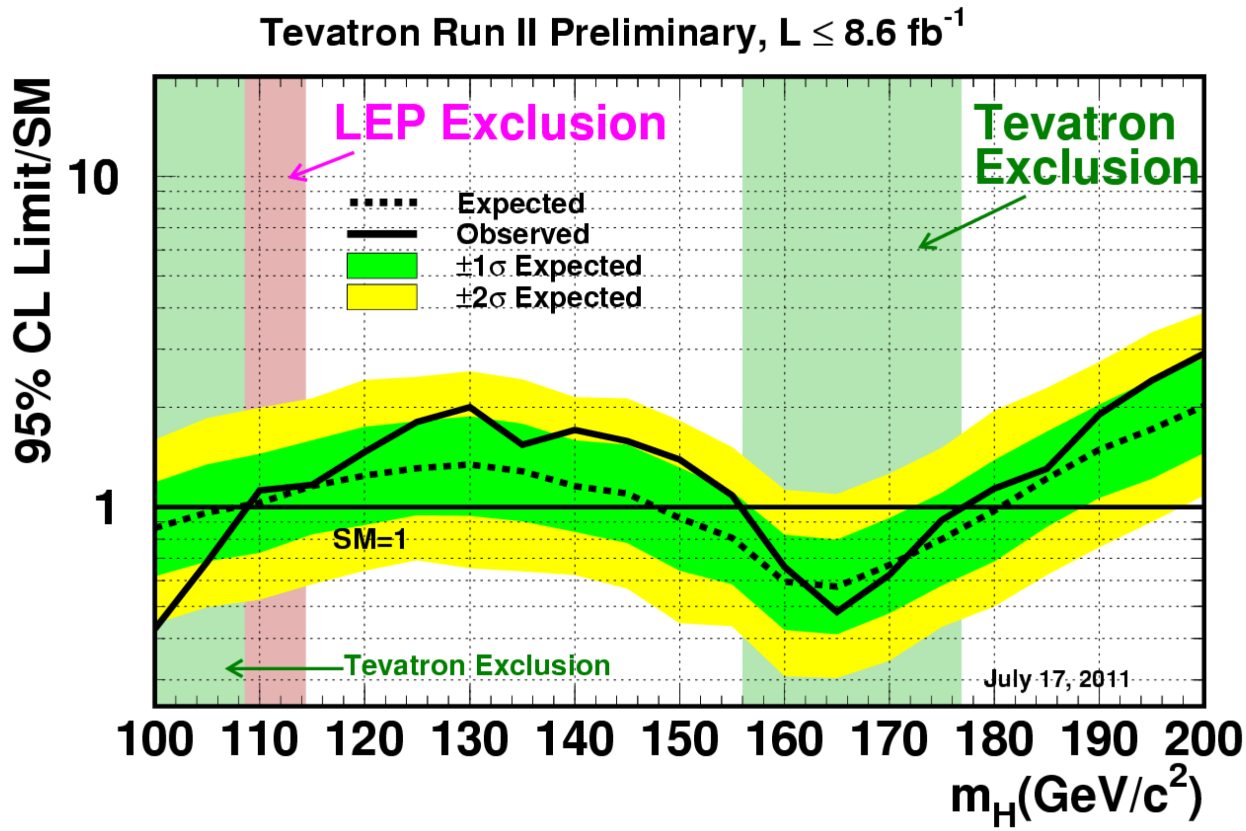




CDF

D0

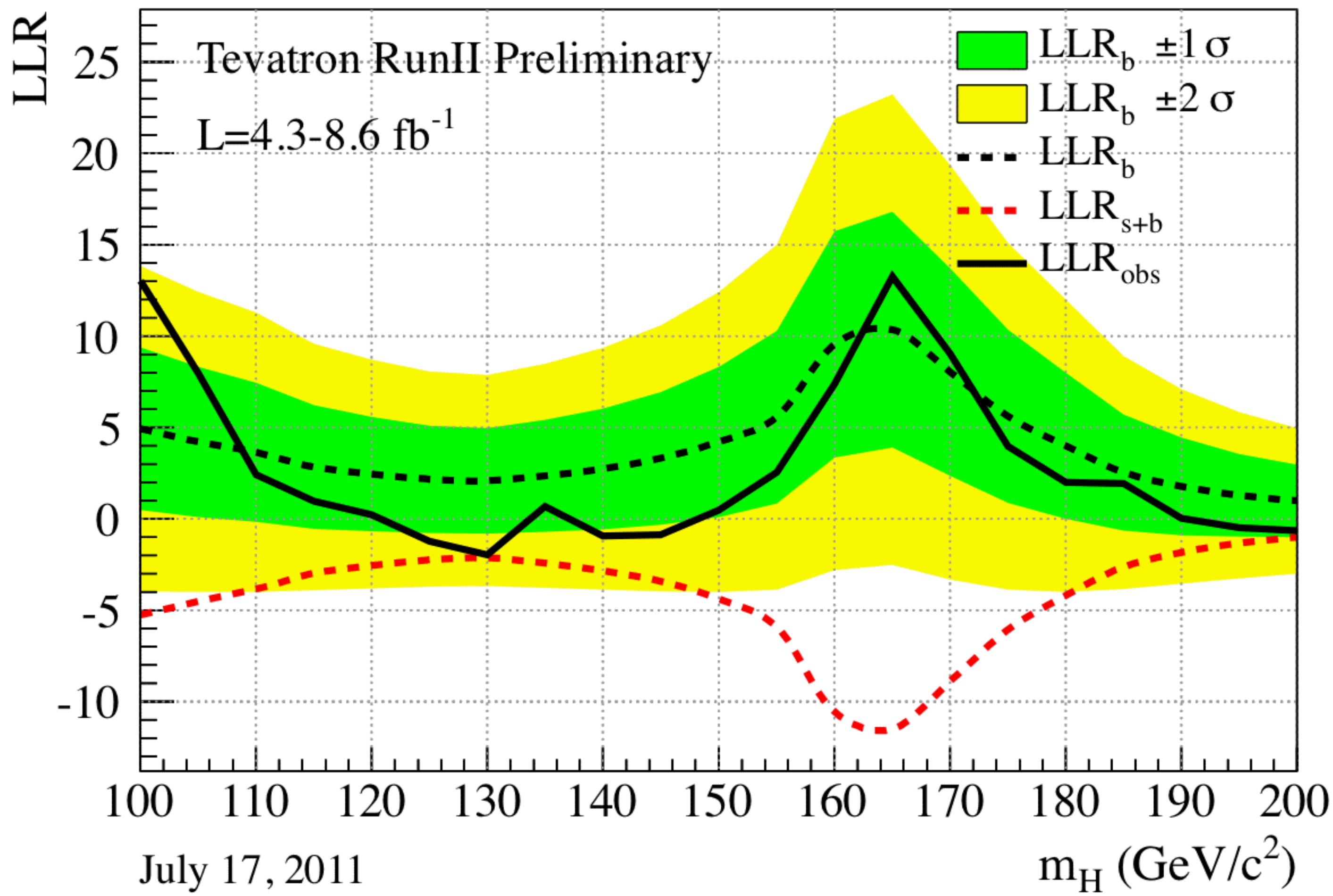
New Tevatron Combination



Observed Exclusion : 100-109 and 156-177 GeV/c^2

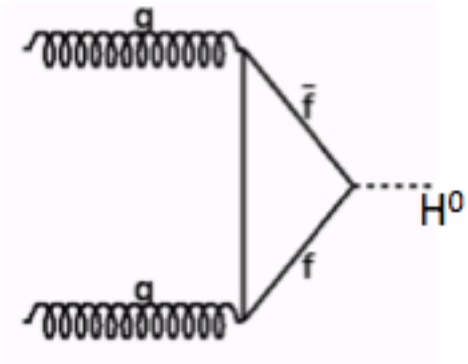
Expected Exclusion : 100-108 and 148-181 GeV/c^2

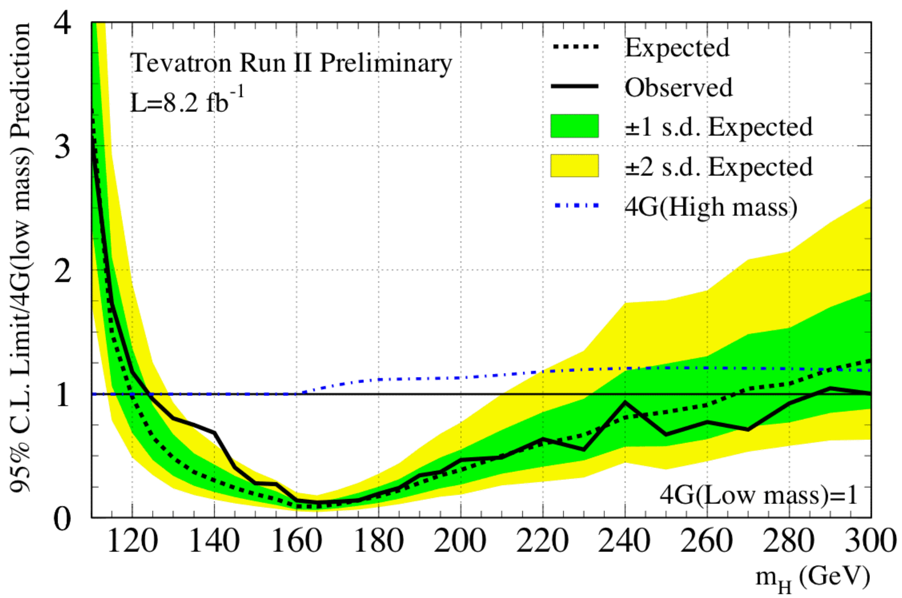
S+B versus B-only Hypotheses



Fourth Generation Interpretation

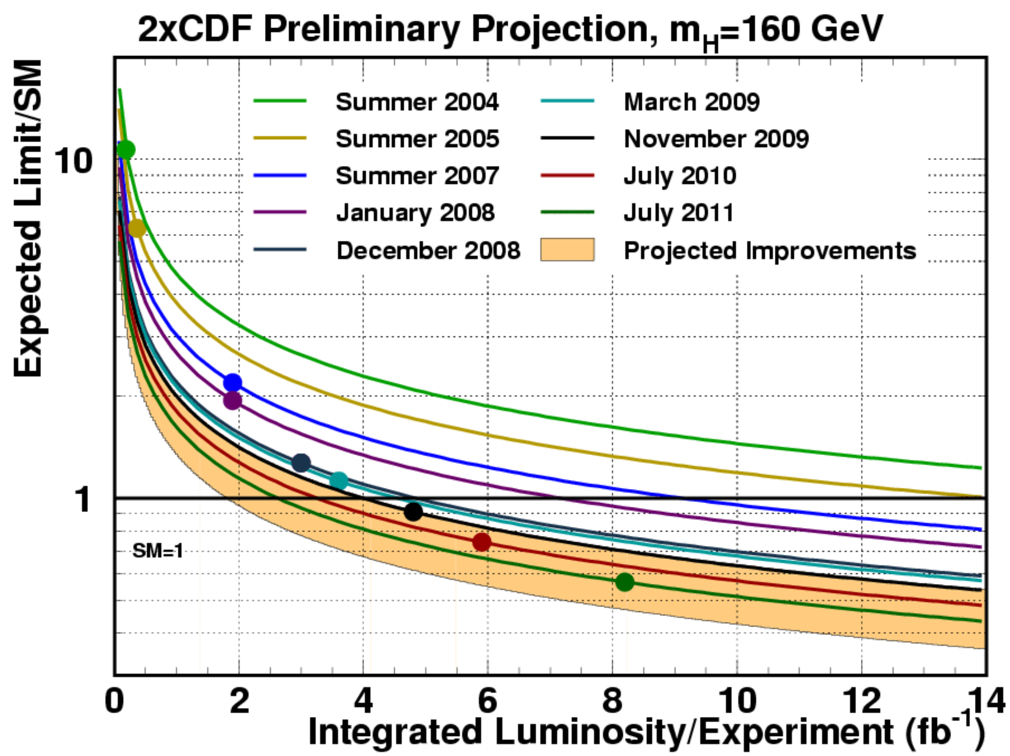
- We also interpret our high mass search results in terms of a fourth generation model
- Presence of additional quarks enhances gg→H production by as much as a factor of nine - also modifies Higgs branching ratios
- Observed exclusion : $124 < m_H < 286$ GeV





Final Steps

- We continue to obtain large improvements in search sensitivity beyond that expected from simply adding more data
- Tevatron is on track to deliver Higgs search results next spring based on the full $10 fb^{-1}$ datasets that achieve our expected sensitivity goals



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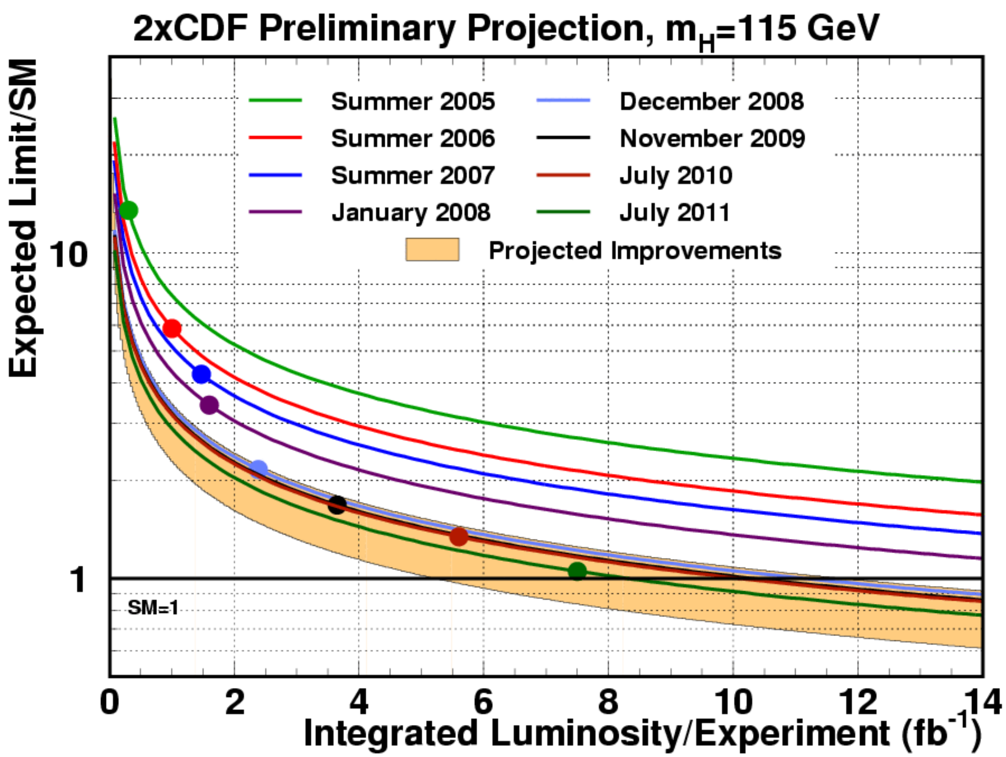
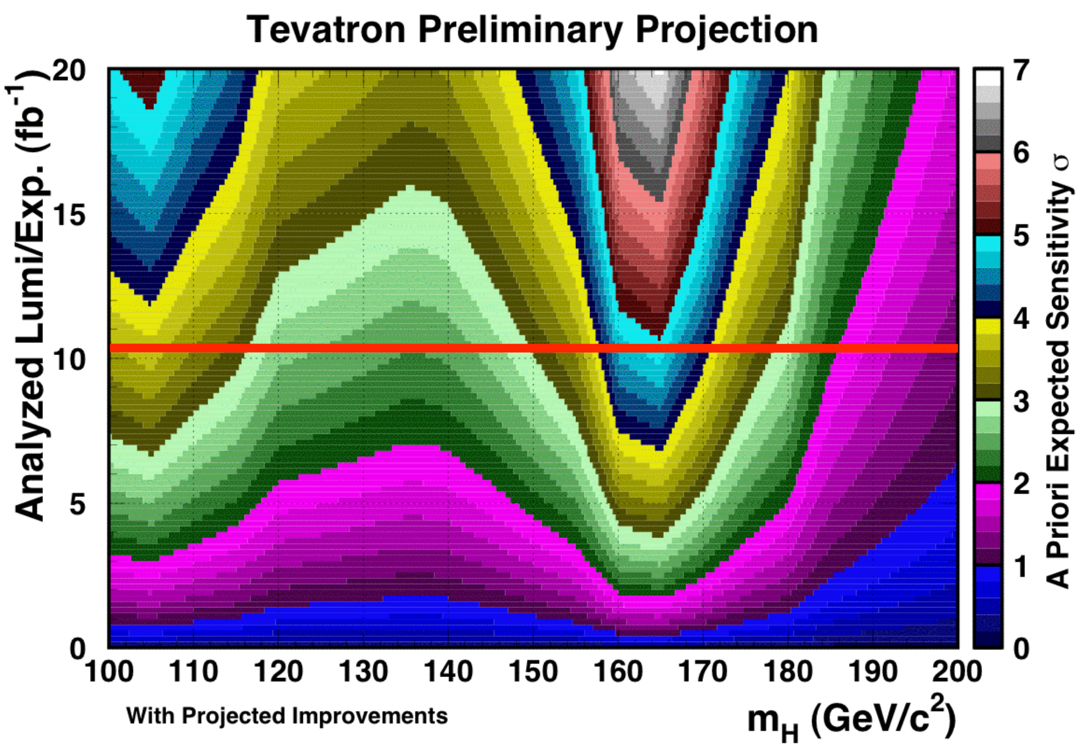


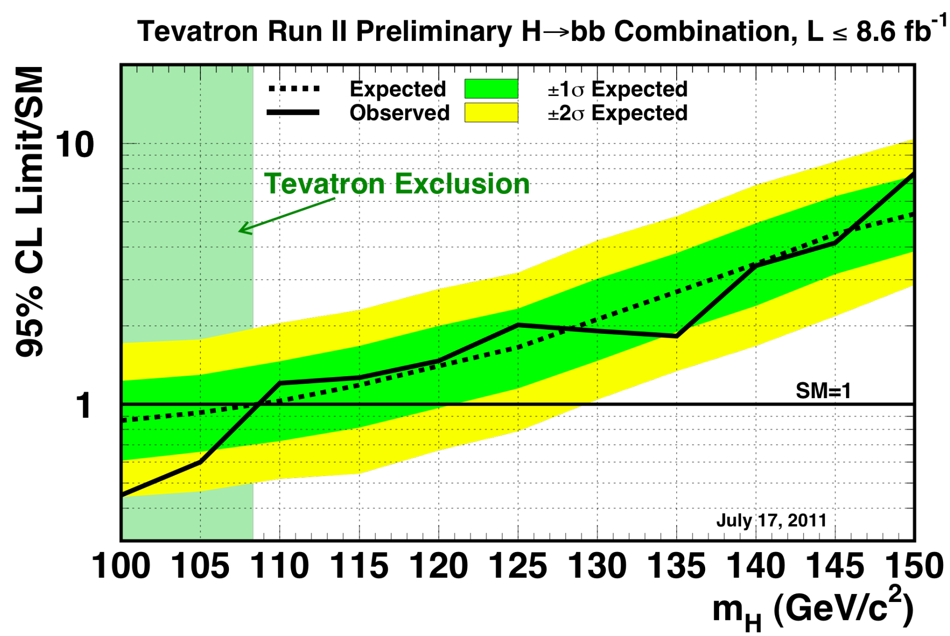
Final Steps

- This implies Tevatron 95% C.L. exclusion sensitivity over the entire Higgs mass range between 100 and 185 GeV/c^2 for next spring



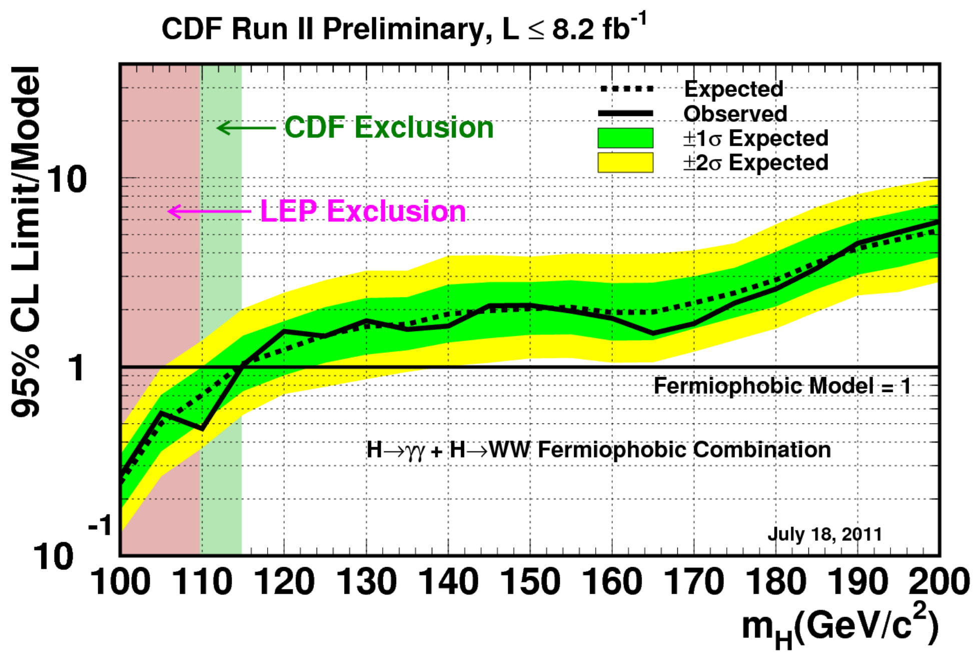
$H \rightarrow bb$

- This channel provides best sensitivity in the mass region just above the LEP bounds
- Observation of this decay mode is important for establishing that a Higgs-like signal found in other channels is in fact the SM Higgs

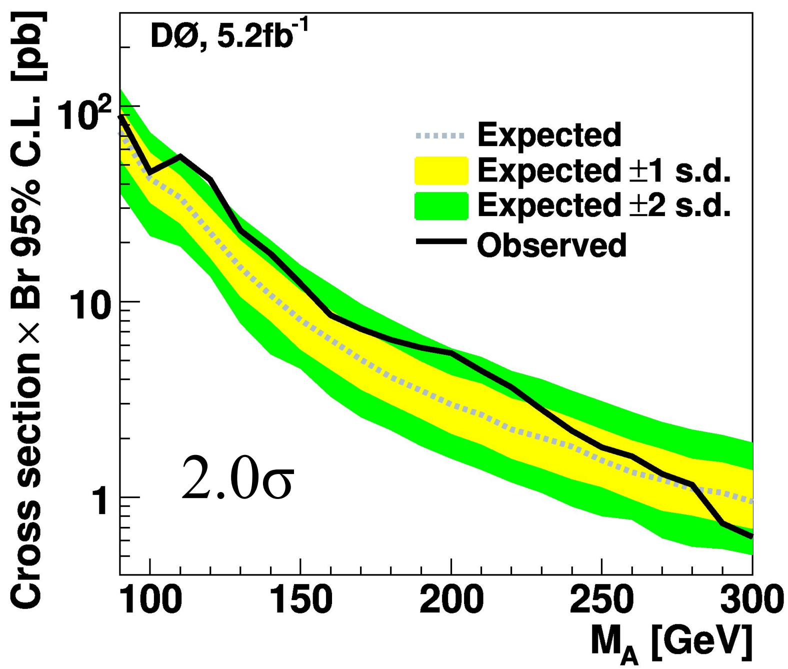


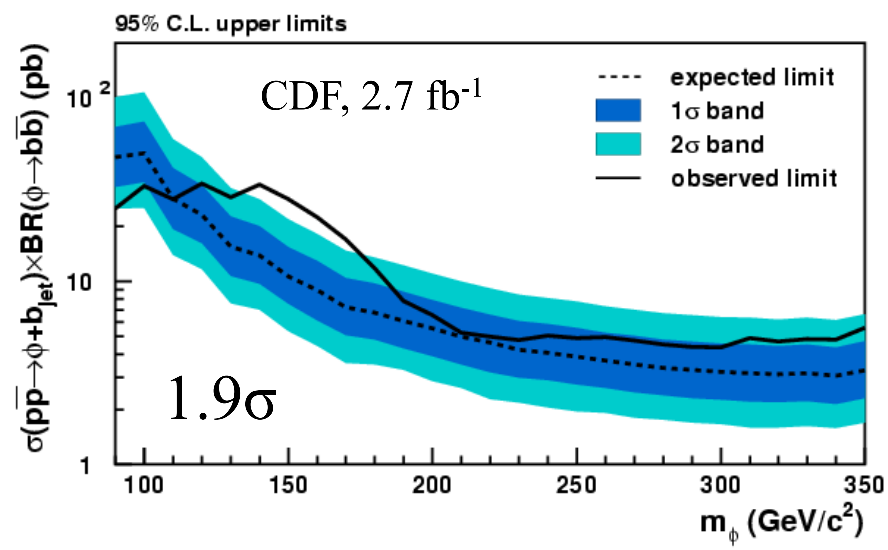
Fermiophobic Higgs

- Fermiophobic Higgs is not accessible though the dominant gluon fusion production mode
- CDF sets world-best lower mass limit of 114.8 GeV/c^2 pending soon to be completed combination with D0



BSM Higgs

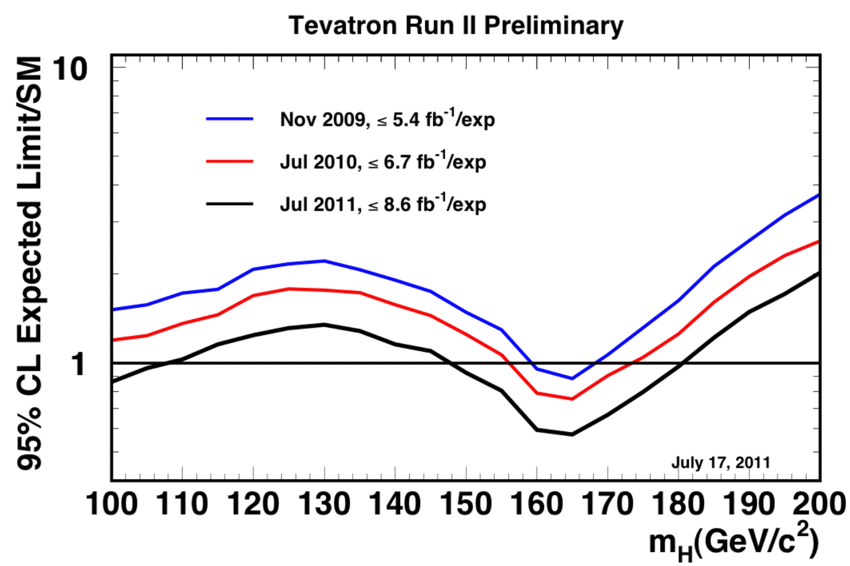




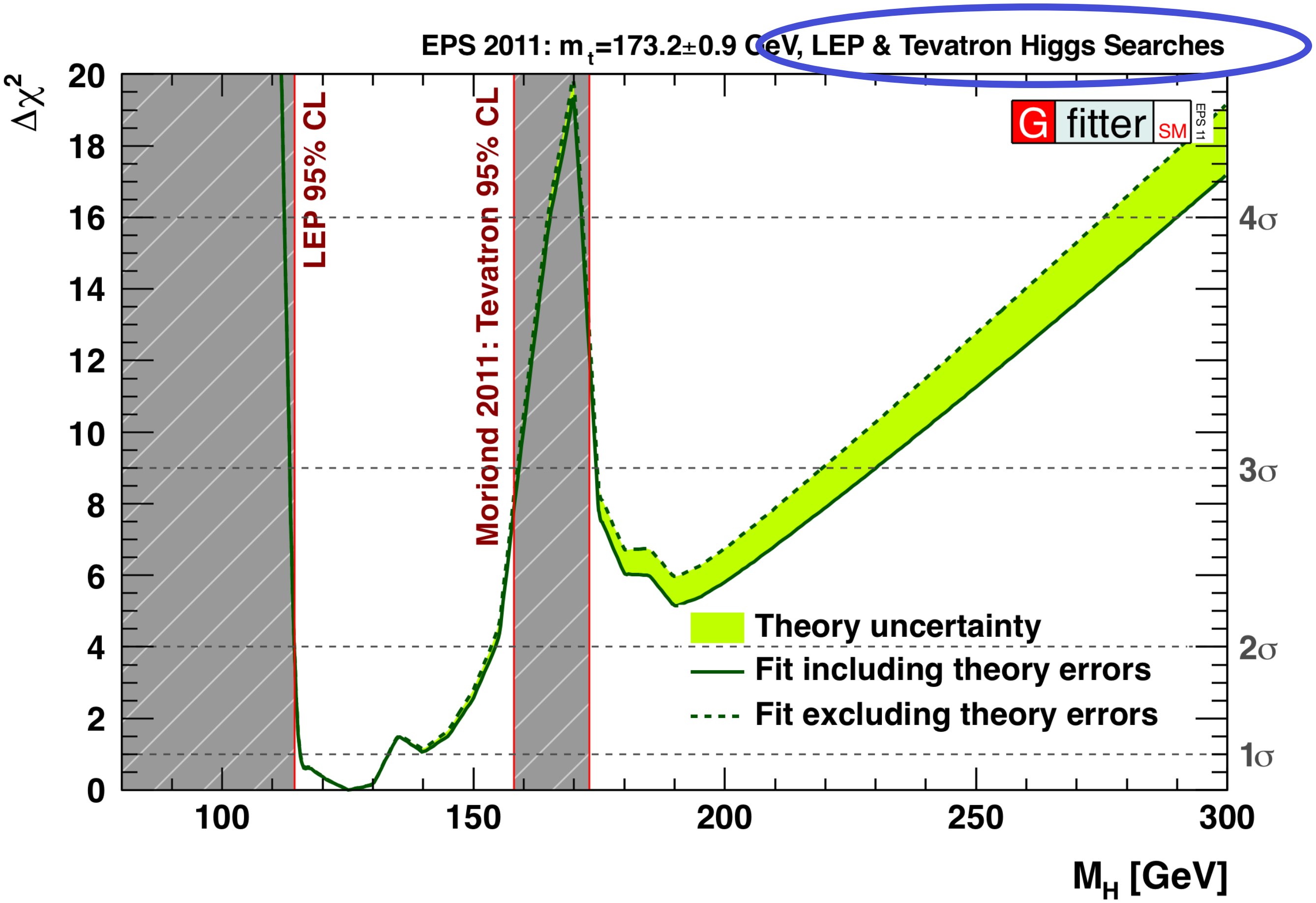
Pursuing interesting broad excesses observed by both CDF and D0 in bΦ→bbb search channel

Conclusions and Outlook

- Expect to collect over 10 fb^{-1} of analyzable data by the end of September 2011
- On track to reach 95% C.L. exclusion sensitivity over entire m_H range from 100 to 185 GeV/c^2 by next spring
- Best current sensitivity to bb Higgs decay mode
- Looking forward to a very interesting next six months



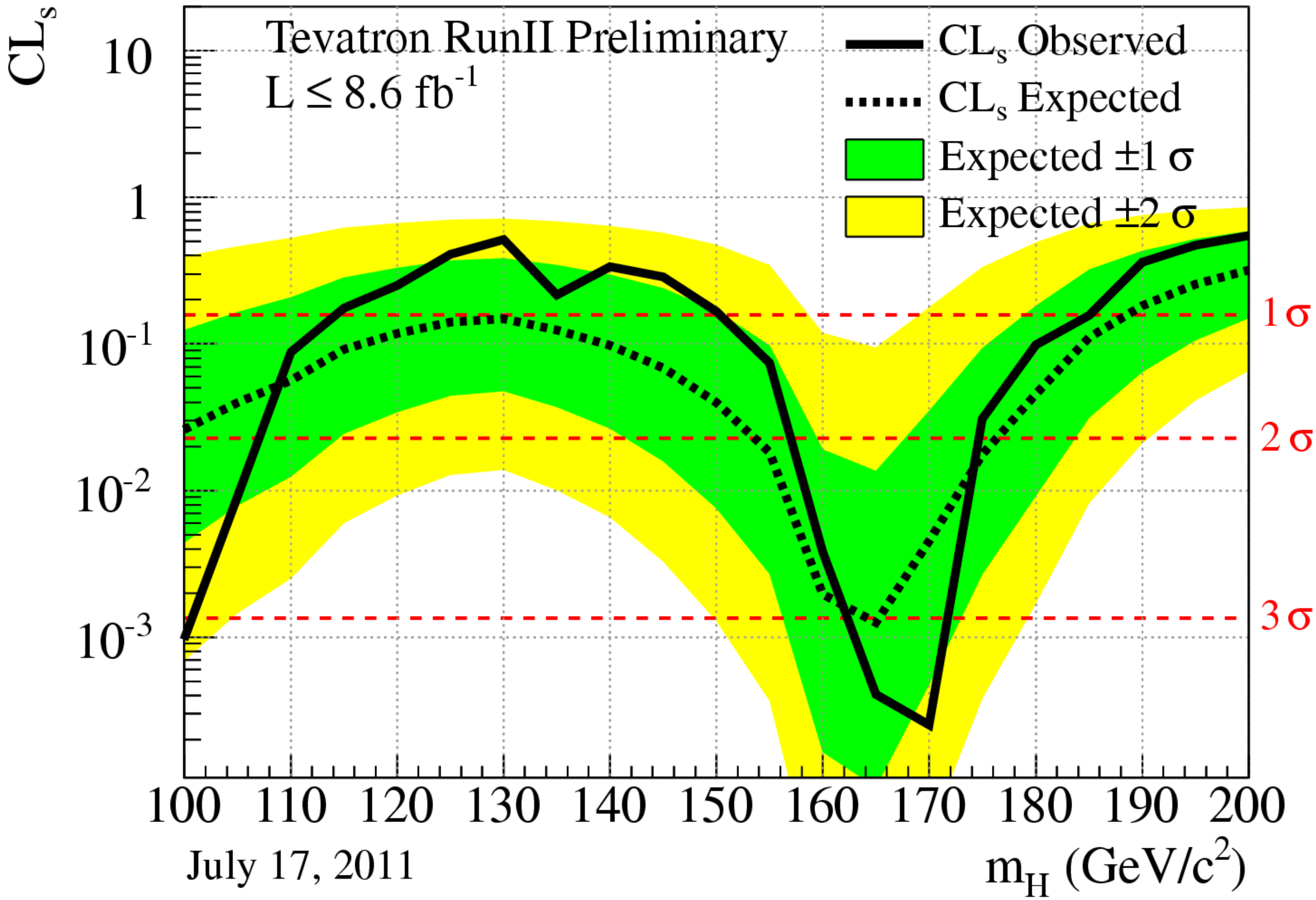
Updated Global EWK Fit



M. Baak, M. Goebel, J. Haller, A. Hoecker, D. Ludwig, K. Moenig, M. Schott, and J. Stelzer, arXiv:1107.0975v1

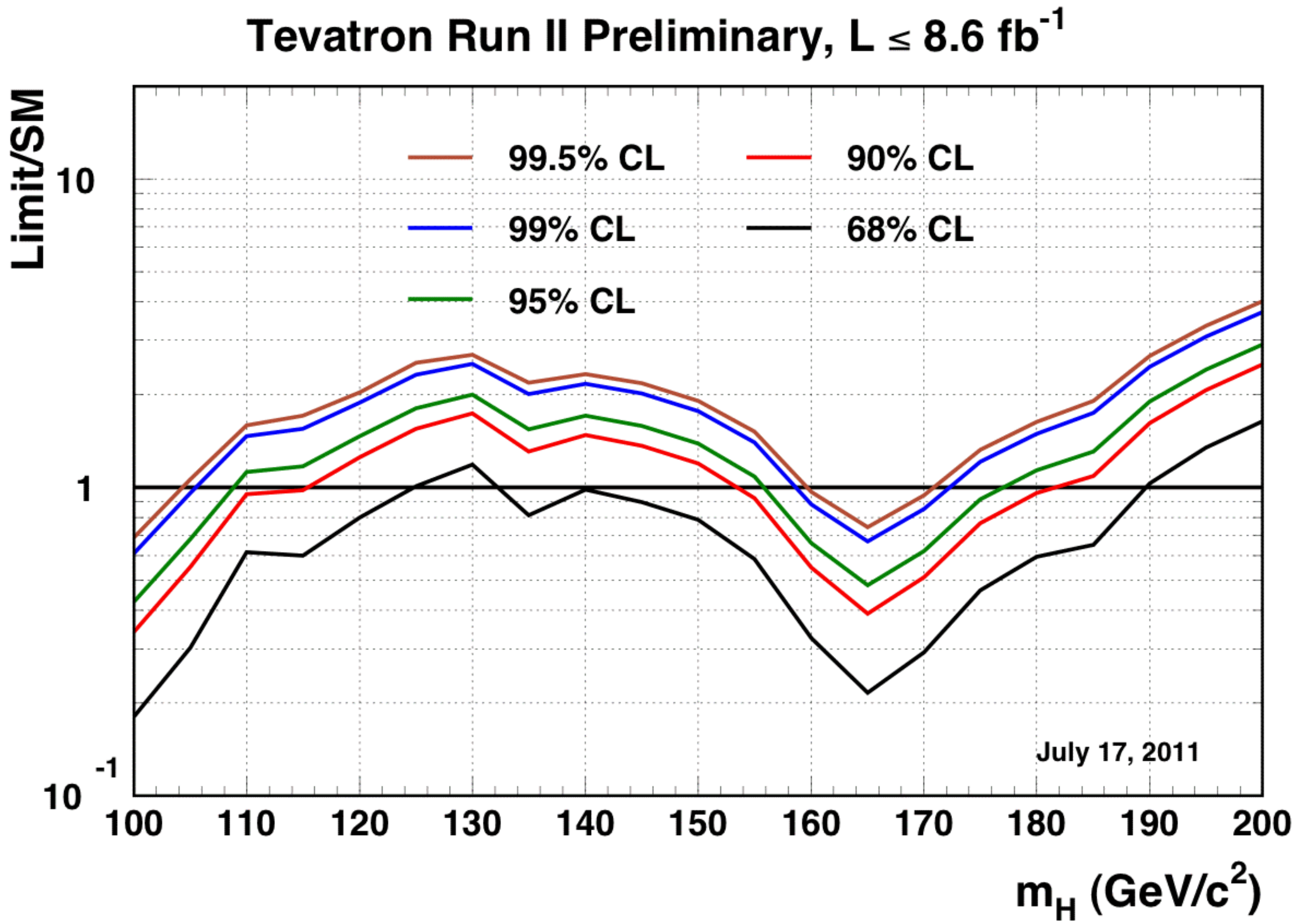
Backup Slides

CL_S Plot

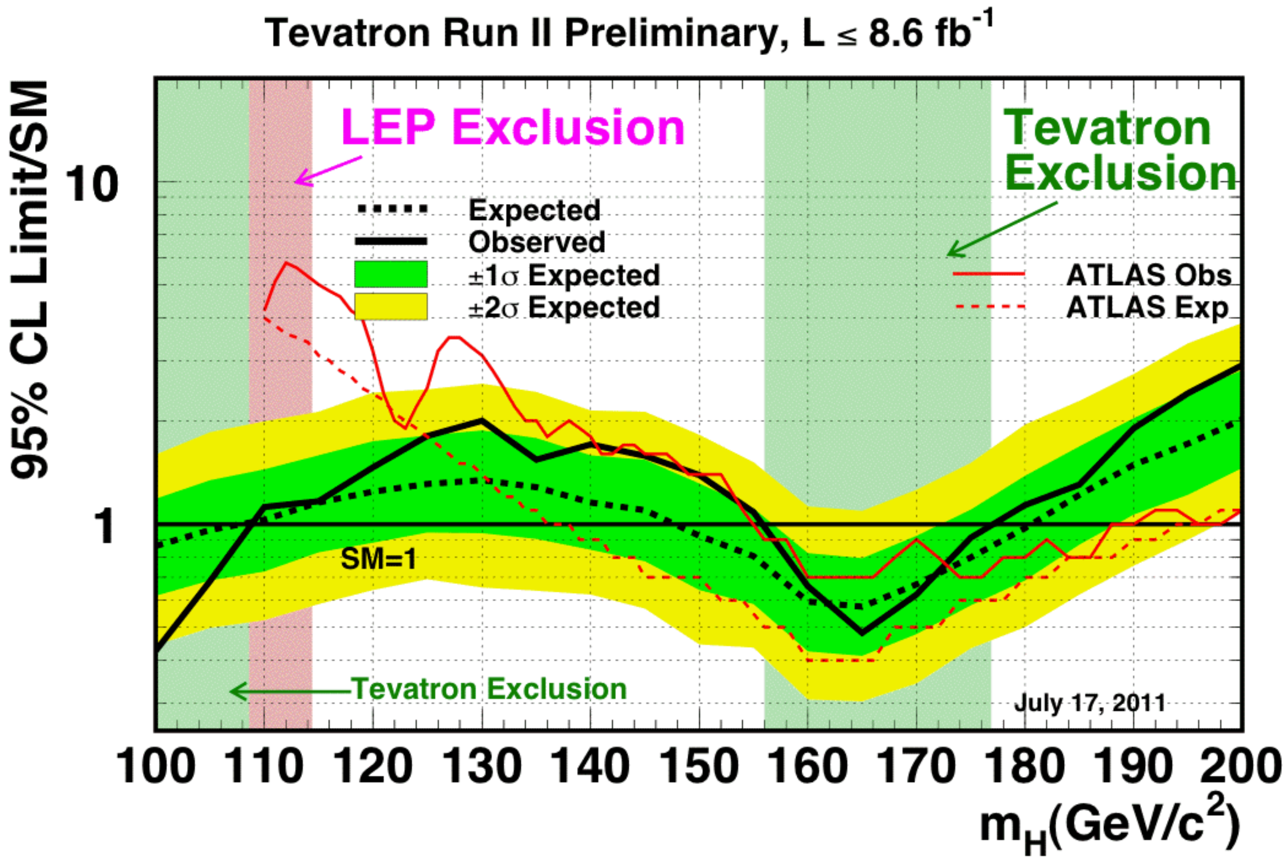


Tevatron RunII Preliminary
L ≤ 8.6 fb⁻¹
CLs Observed
CLs Expected
Expected ±1 σ
Expected ±2 σ
CLs
10
1
10⁻¹
10⁻²
10⁻³
1σ
2σ
3σ
100
110
120
130
140
150
160
170
180
190
200
July 17, 2011
mH (GeV/c²)

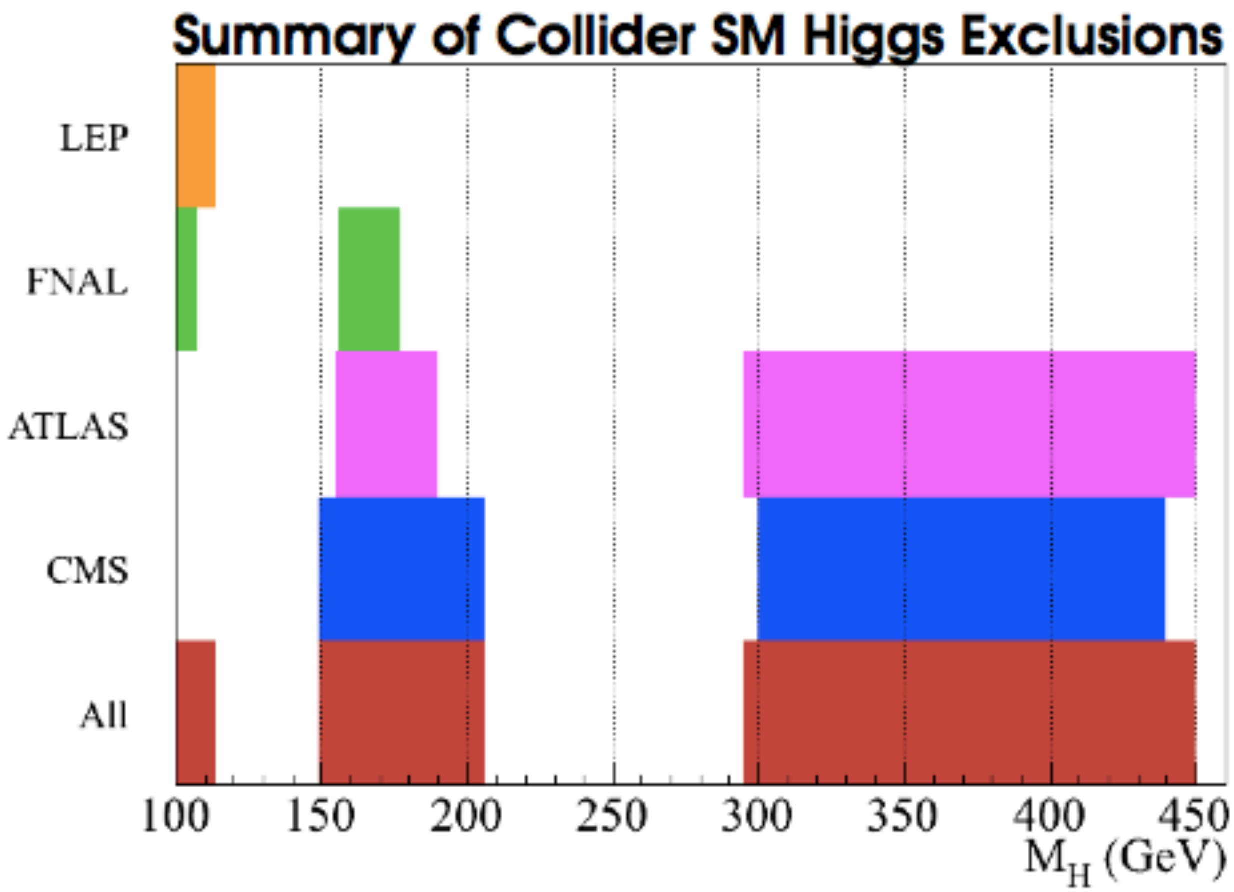
Confidence Levels



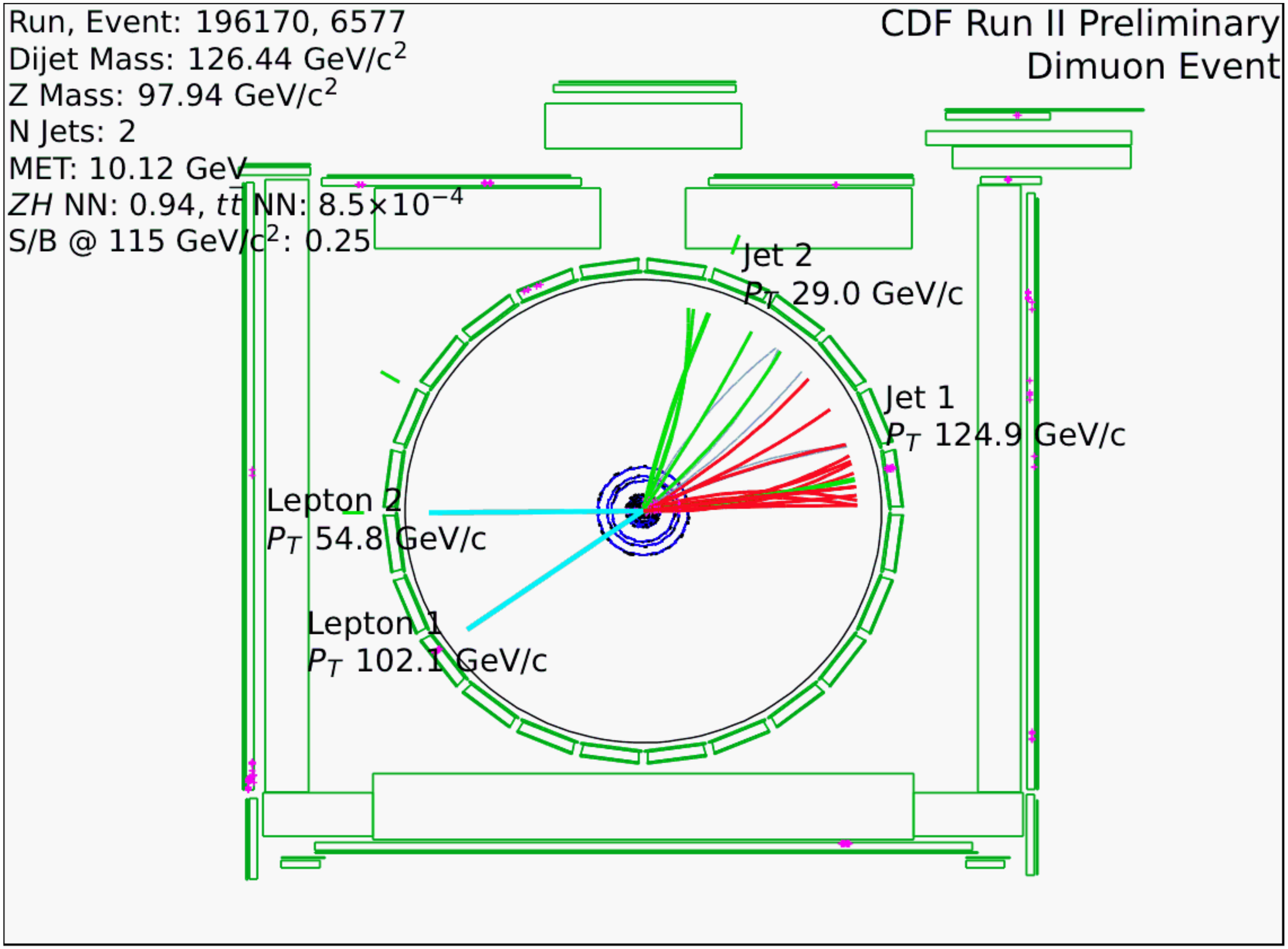
Comparison with ATLAS



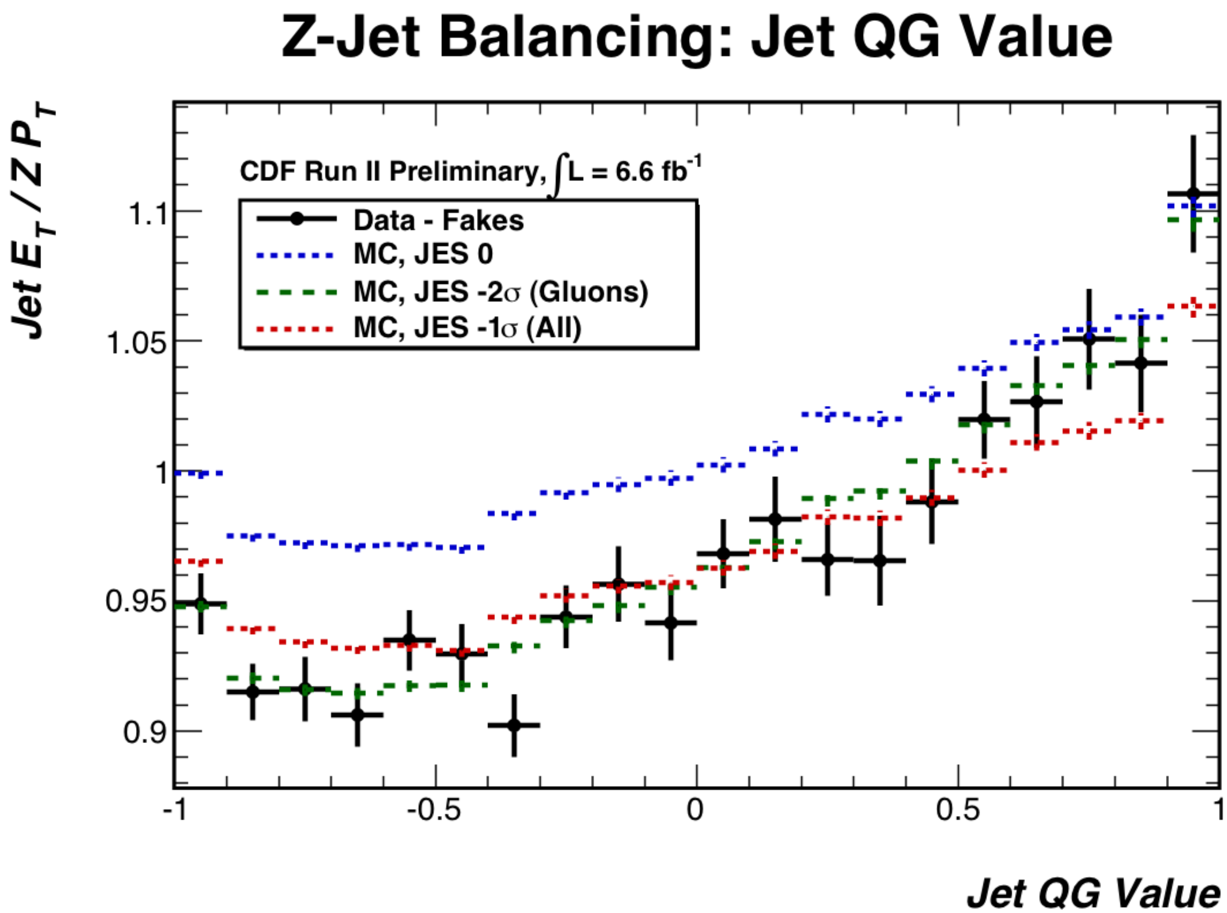
Current Exclusions



Event Display



CDF Jet Energy Scale



Gluon-like   Quark-like