Higgs in CDF

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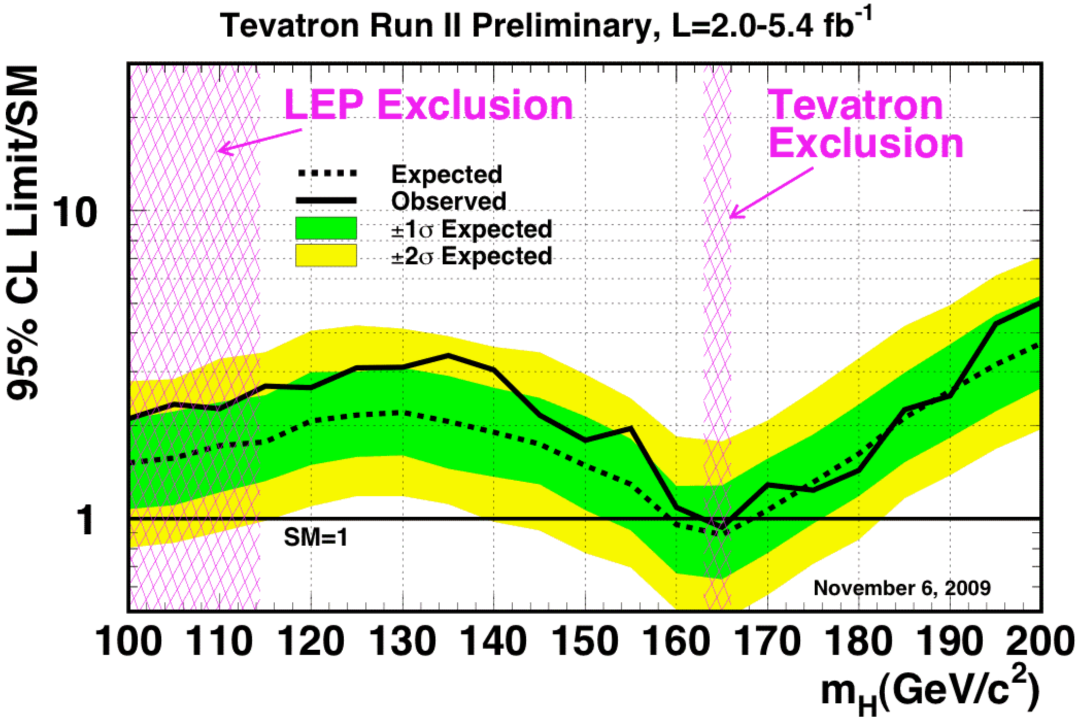
for the CDF Collaboration

Higgs Physics at the Tevatron and LHC: QCD Issues
November 19th, 2009

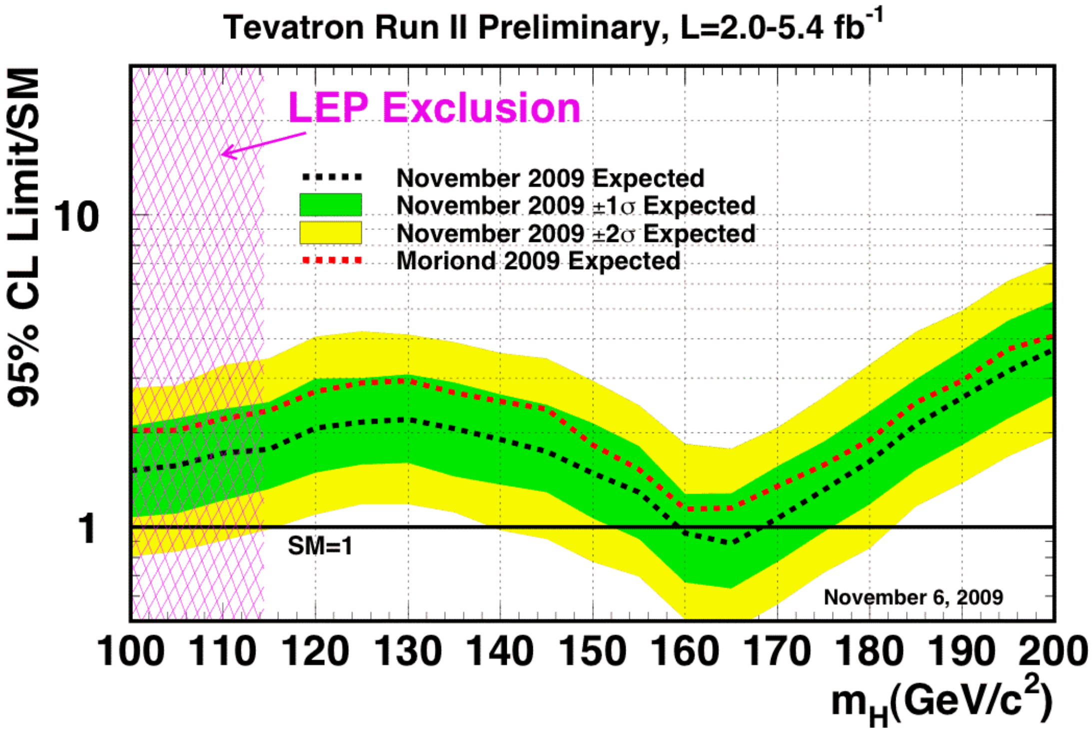
Hot off the Presses



Updated Tevatron combination released earlier this morning!

New Higgs exclusion region is between 163 and 166 GeV/c^2

Sensitivity Gains

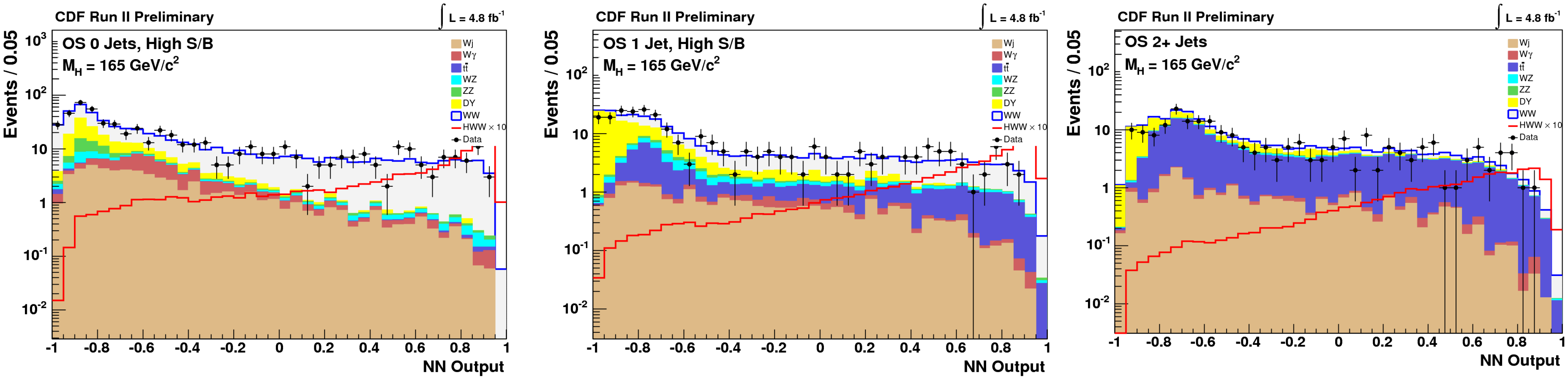


For the first time we also have an expected exclusion range from 159 to 168 GeV/c^2

Better than 2.2 x SM sensitivity for all mass points below 185 GeV/c^2

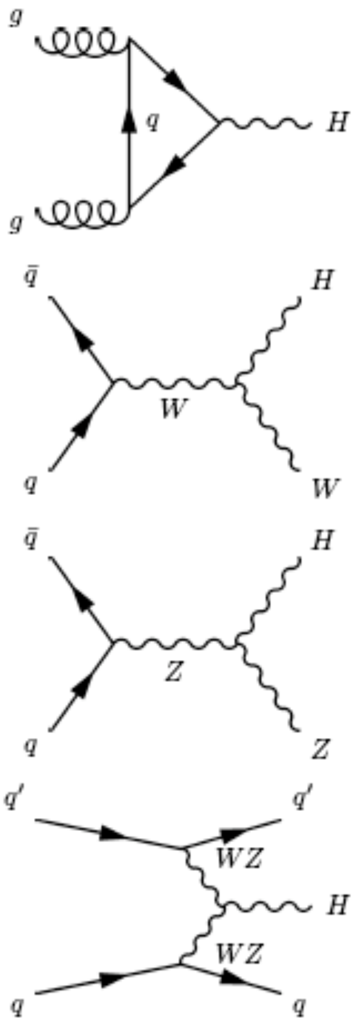
Current combination corresponds to roughly
5.1 fb^{-1} at 165 GeV/c^2
4.5 fb^{-1} at 115 GeV/c^2

CDF High Mass (H to WW) Analysis



- Select events with two opposite-charge high p_T leptons and large missing E_T
- Separate events into different channels based on number of reconstructed jets (E_T>15 GeV, $|\eta|$<2.4)
- Use multi-variant techniques to separate a potential Higgs signal from backgrounds.

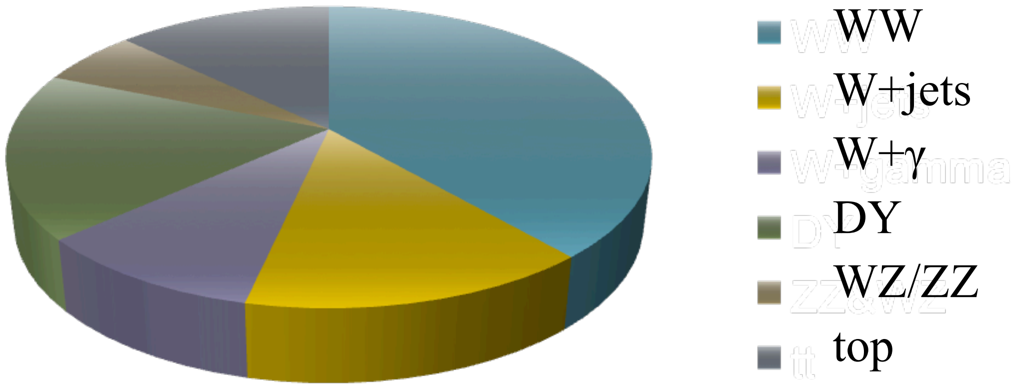
Higgs Signal Processes



Category 1 - No jets at LO (gluon fusion)

Category 2 - Multiple jets at LO (WH/ ZH associated production and vector boson fusion)

Background Processes



WW (~40%):
Modeled using MC@NLO MC

W+jets (~15%):
Data-driven modeling

W+gamma (~10%):
Baur MC

ZZ(~3%), WZ(~3%), DY (~16%), top (~13%)
Pythia MC

For MC modeled backgrounds :

Category 1 – No jets at LO
(WW, DY, and W+γ)

Category 2 – Multiple jets at LO
(WZ, ZZ, and top)

Gluon Fusion Production

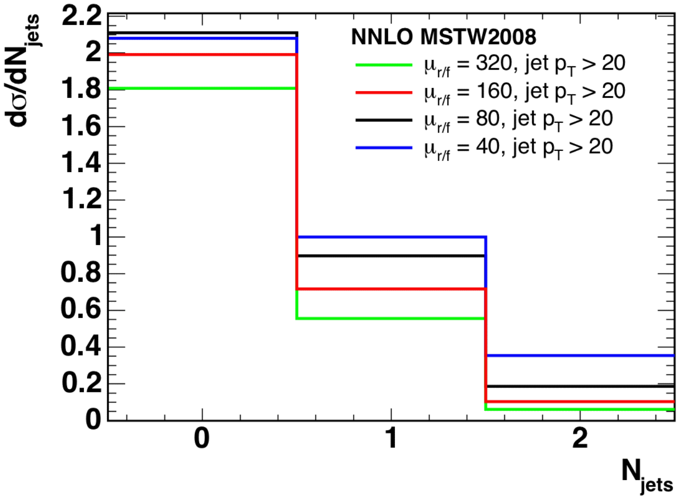
- Use cross section calculations of de Florian and Grazzini (arXiv:0901.2427v2) to normalize MC
  - Soft-gluon resummation to NNLL
  - Proper treatment of b-quarks to NLO
  - Inclusion of two-loop electroweak effects
  - MSTW2008 Parton Density Functions
  - $\mu_F = \mu_R = m_H$
- In good agreement with calculations of Anastasiou, Boughezal, and Petriello (arXiv:0811.3458v2)
  - $\mu_F = \mu_R = m_H/2$

Cross Section Uncertainties

- Higher-order QCD radiative corrections
  - Independently vary μ_F and μ_R between $0.5m_H$ and $2.0m_H$, within the constraint $0.5 < \mu_F/\mu_R < 2.0$
- PDF model
  - Use 40 alternative grids associated with MSTW2008 NNLO PDF to evaluate
- An additional complication at CDF is that cross section uncertainties coming from scale changes are topology dependent (e.g. dependent on number of jets criteria used to define channels) Anastasiou et al., arXiv:0905.3529v2

Cross Section Uncertainties (cont.)

- CDF relies on differential cross section uncertainties versus # of jets from Anastasiou et al.
    - 0 jets : +5%, -9%
    - 1 jet : +24%, -22%
    - 2+ jets : +78%, -41%
- These uncertainties are treated as correlated across jet bins and as correlated with the inclusive cross section uncertainty taken by D0

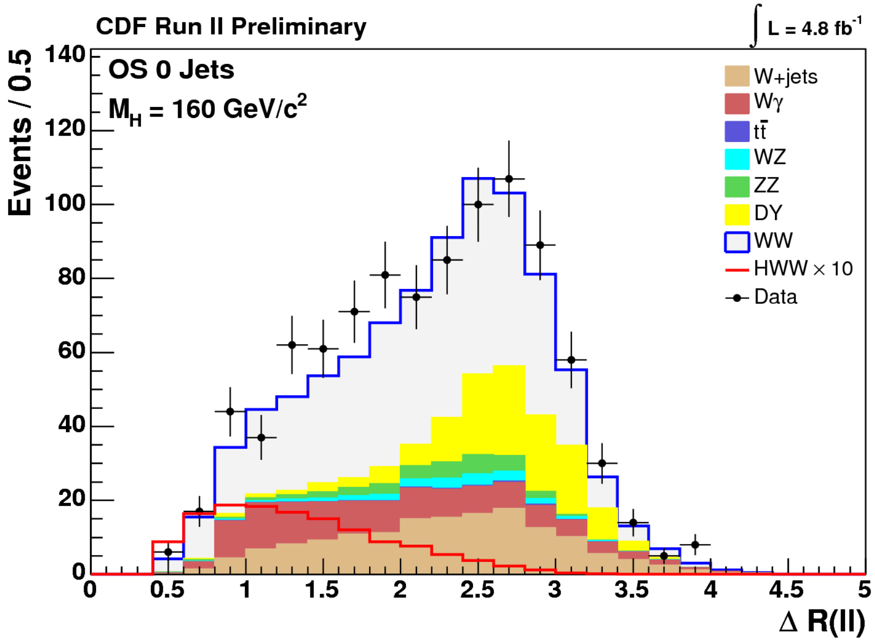


CDF reproduction of the calculations used in determining these uncertainties (using HNNLO program)

Cross Section Uncertainties (cont.)

- Since the perturbative calculation used to determine the differential cross section uncertainties does not have all the bells and whistles associated with the calculation of inclusive cross section uncertainties, there is a resulting mismatch in the inclusive cross section uncertainty obtained from the two approaches
  - Inclusive calculation (at m_H=160) : +9.1%,-7.7%
  - Differential calculation (at m_H=160) : +13.9%,-14.2%
- PDF uncertainties are calculated for inclusive cross section only and are applied across all jet bins as an uncorrelated, flat uncertainty

Shape uncertainties

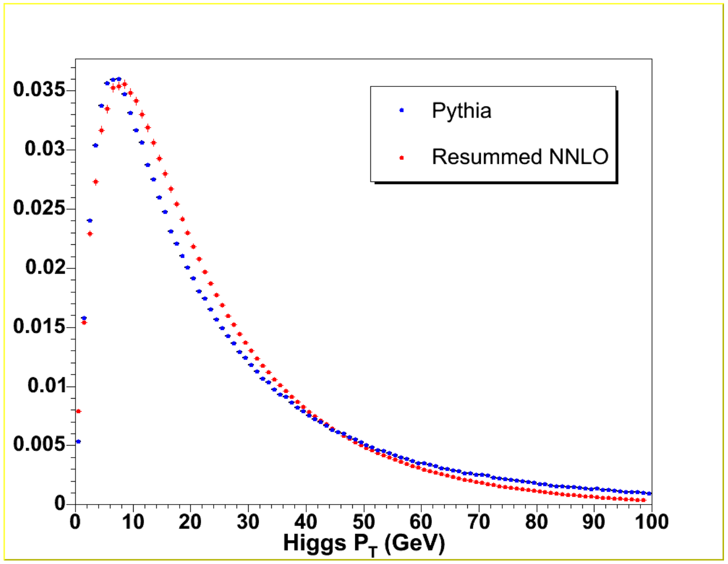


A variety of kinematic variables are used as inputs to the multi-variant techniques used to separate signal and backgrounds

In the end, variables describing the angular separation between the leptons are most important

We believe that to model these variables properly, the most important things to get correct in the simulation are spins and boost (Higgs p_T)

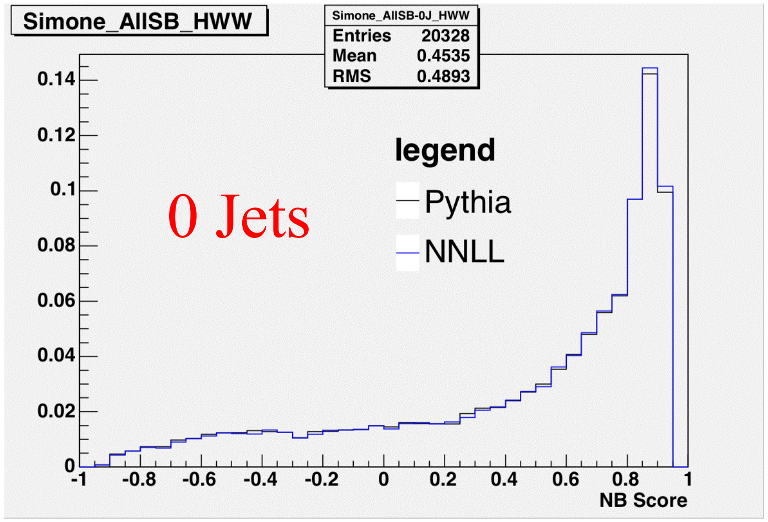
Simulation of gg to H

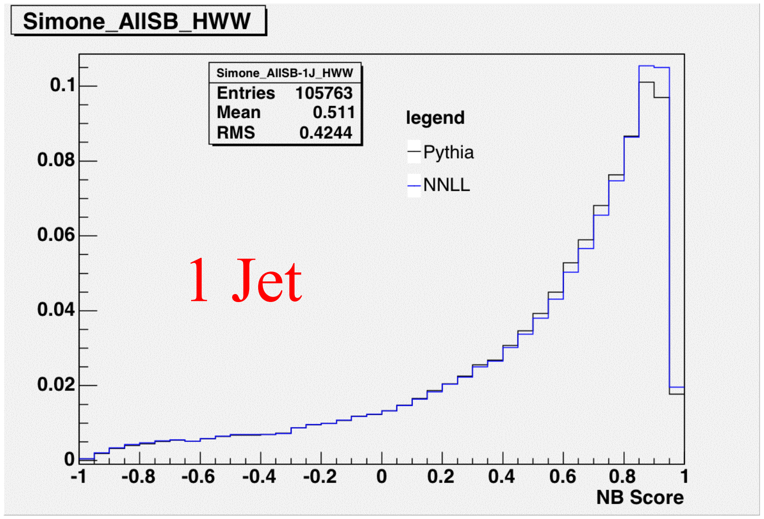


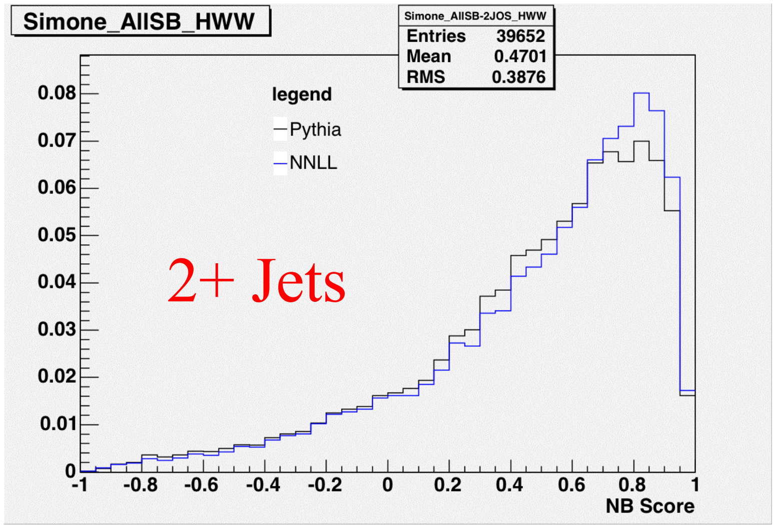
We use PYTHIA to simulate gluon fusion Higgs production (believe that spins are properly modeled)

In order to have the best possible modeling of the boost, we re-weight the PYTHIA events versus Higgs p_T to match the spectrum obtained from the calculations of Anastasiou et al.

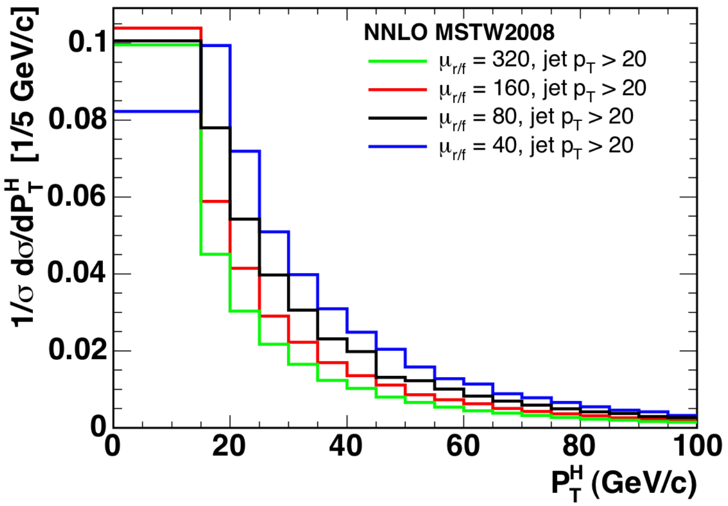
Effect of Re-weighting

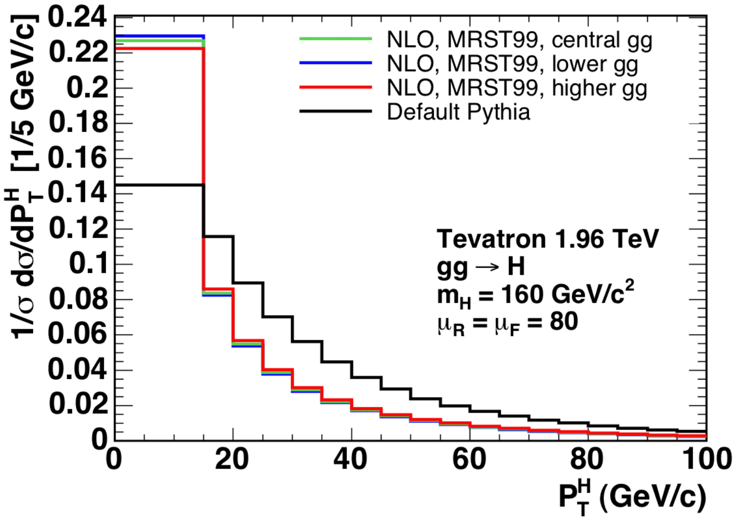






Modeling Uncertainties





Use the HNNLO program to calculate Higgs p_T spectrum for alternate scale and PDF choices

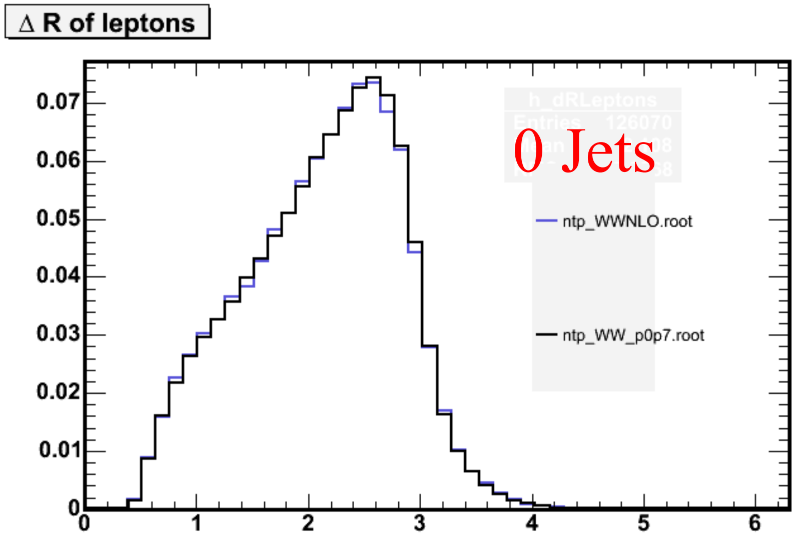
Use the observed difference between Higgs p_T spectra from nominal and modified settings to obtain an additional re-weighting (on top of the default PYTHIA re-weighting described previously)

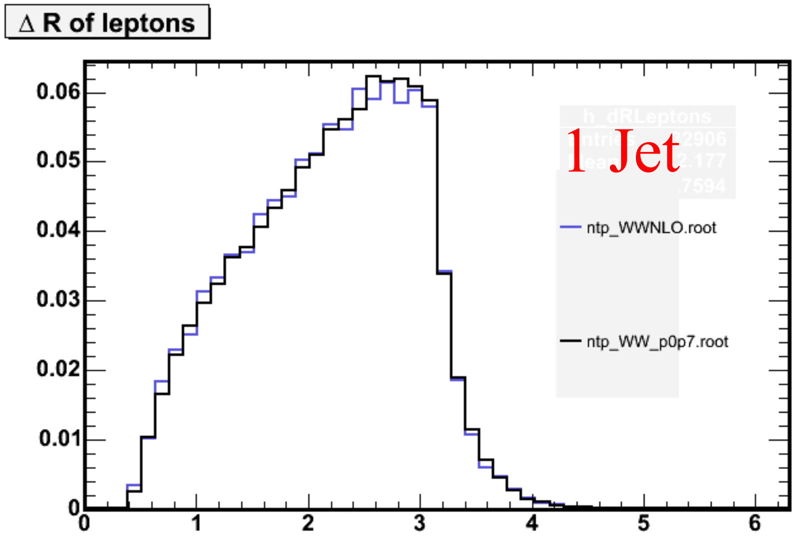
Assign acceptance and shape uncertainties based on the various sample re-weightings

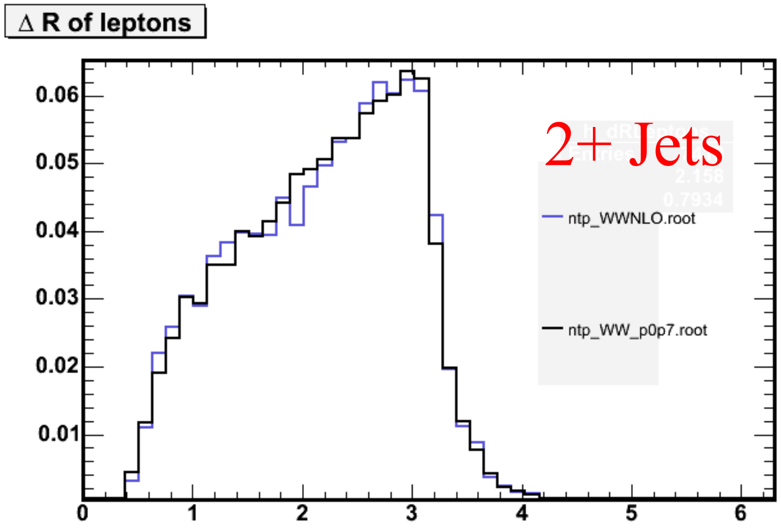
WW Background

- This is our most important background (most closely mimics the kinematics of Higgs signal)
- As with the Higgs signal, we want to correctly model spins and boost
- For modeling WW, we have put a significant amount of effort into interfacing the MC@NLO generator into our simulation package
  - Properly models spins as long as each potential lepton decay channel (9 total) are simulated separately
  - Currently, interfaces to HERWIG for showering (creating an interface to PYTHIA is on our wish list)

PYTHIA versus MC@NLO



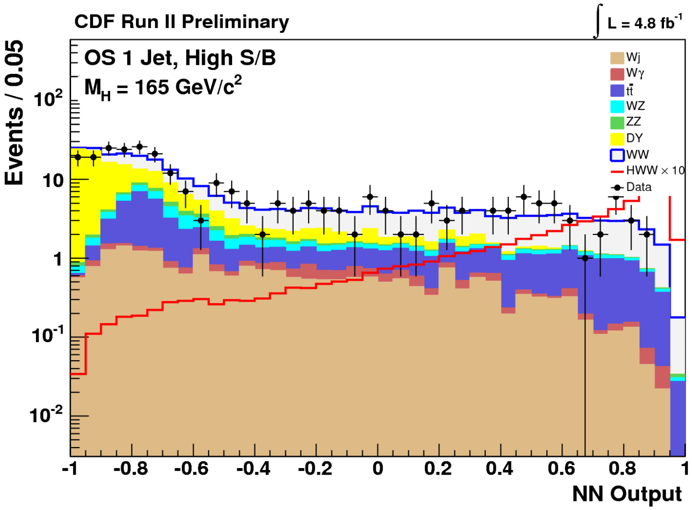


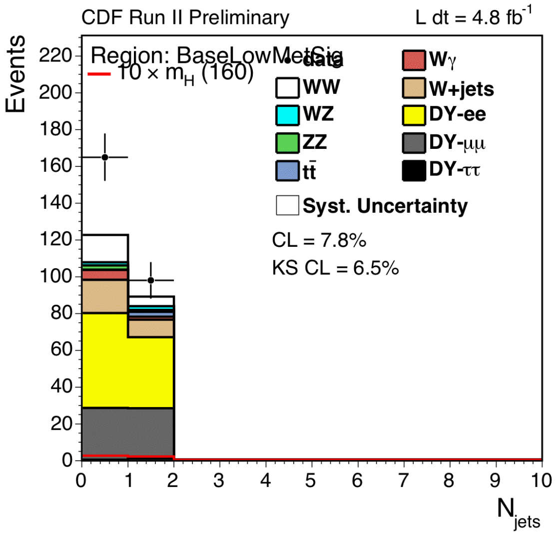


Diboson Odds and Ends

- For normalizing simulated diboson samples, we use NLO MCFM calculations
- Getting exact normalizations for these backgrounds is not so critical since the fit to the final NN output distribution does a good job constraining these
- To obtain acceptance and shape uncertainties for the WW background model, run MC@NLO at generator level with different scale and PDF choices. Reweight events in default reconstructed MC@NLO sample to match WW p_T spectra obtained using each variation (analogous to method described for gg to H sample)

Drell-Yan Background



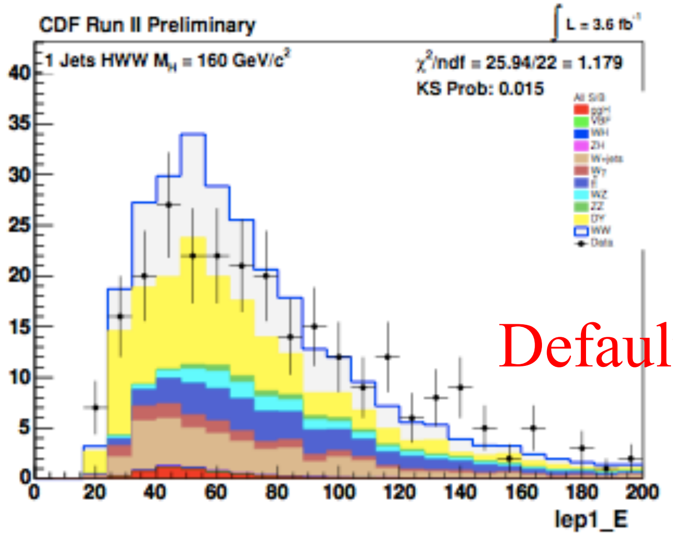


Not our most important background since the NN typically provides good separation between DY and signal events

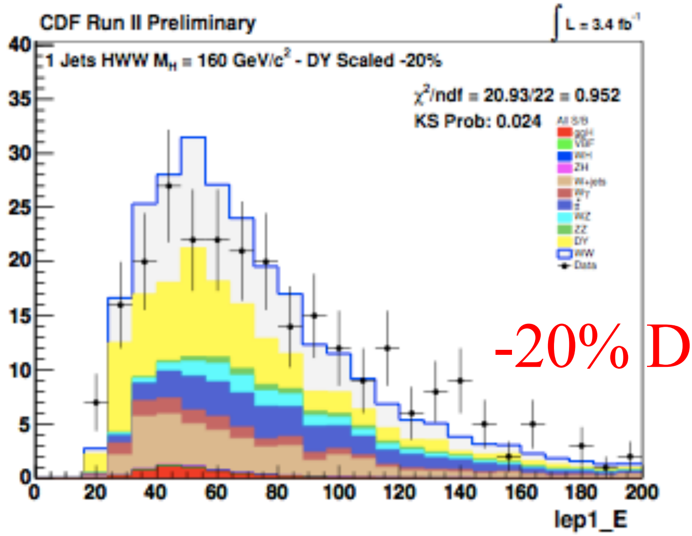
However, hard to model DY events with high missing E_T and particularly difficult to predict the N_{jets} distribution

Many different potential sources of uncertainties (jet energy scale, higher-order diagrams, different missing E_T sources for different jet topologies, etc…)

Effect on Signal Region Modeling



Default



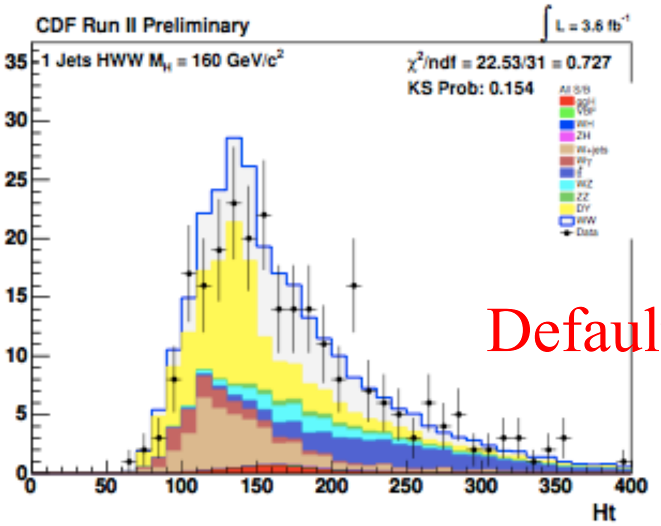
-20% DY

In one jet channel where DY background is most significant, typically see a 20-30% overestimation from PYTHIA model

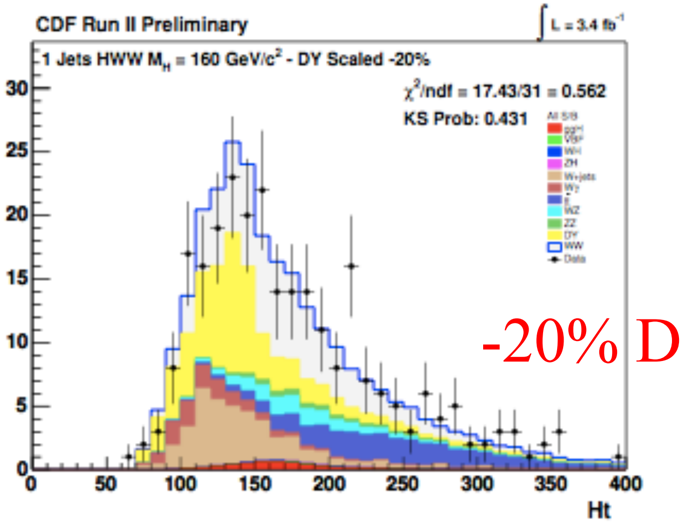
Simple re-scaling of DY contribution results in good overall modeling of kinematic variables

Currently assign large DY normalization uncertainties, uncorrelated between jet bins, to account for discrepancies

Effect on Signal Region Modeling



Default



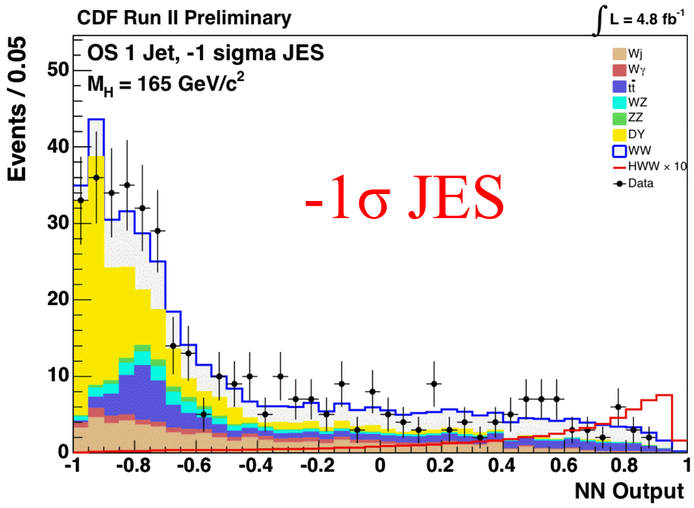
-20% DY

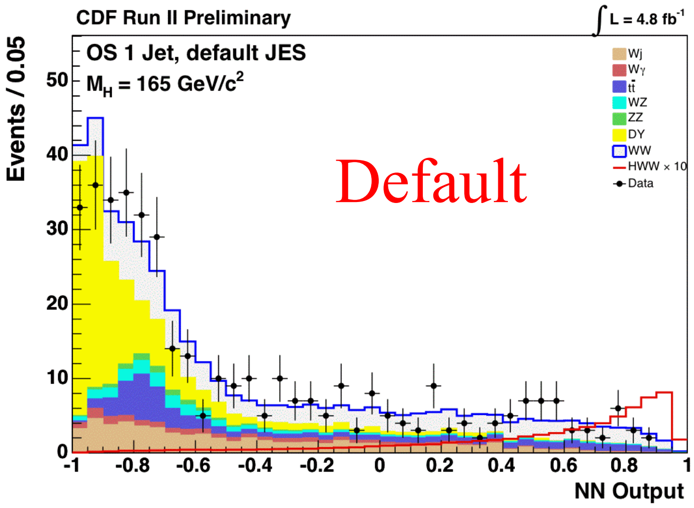
Working on improved DY background modeling

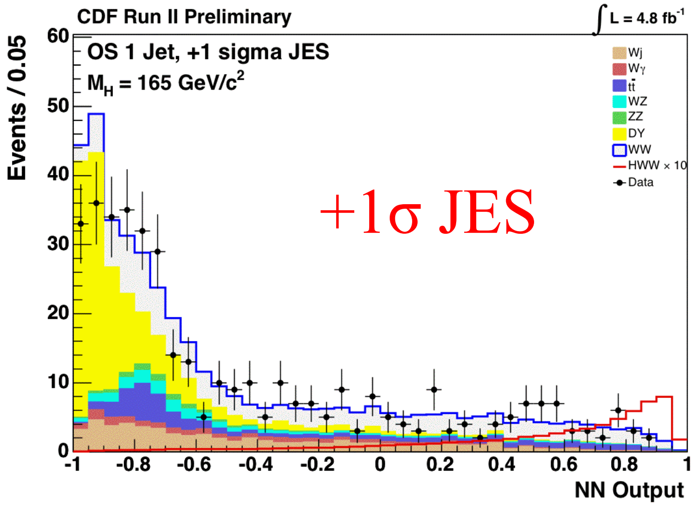
As a first step, attempt to (1) reweight events versus Z p_T to match RESBOS template and (2) use PYTHIA Tune B which is designed to produce correct Z P_T distribution

Neither of these adjustments leads to modified predictions at a level consistent with the observed discrepancies

Jet Energy Scale Effects

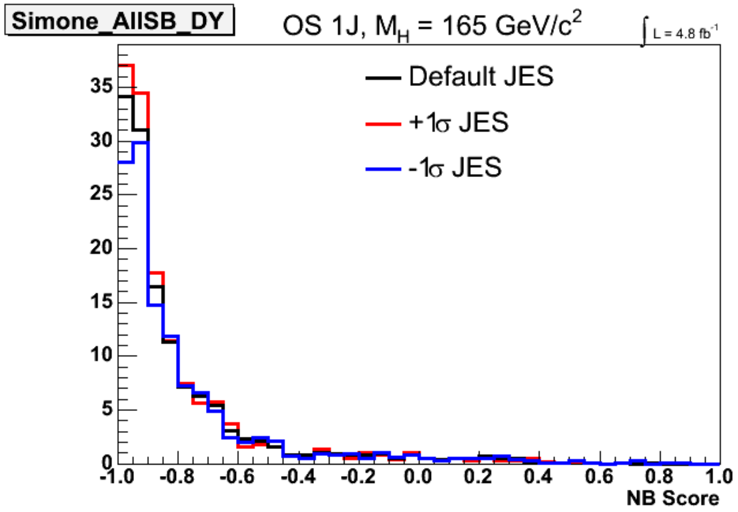




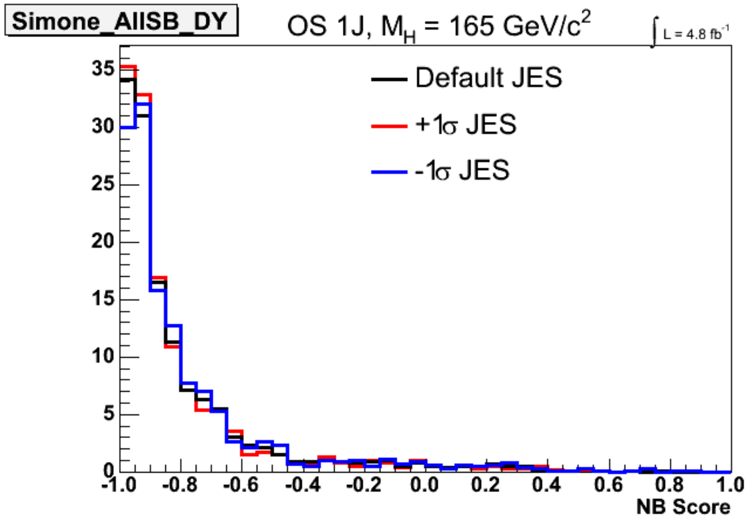


Interestingly, JES variations seem to have the biggest effect (data prefers -1sigma variation)

JES Uncertainties



DY JES Normalization Uncertainty

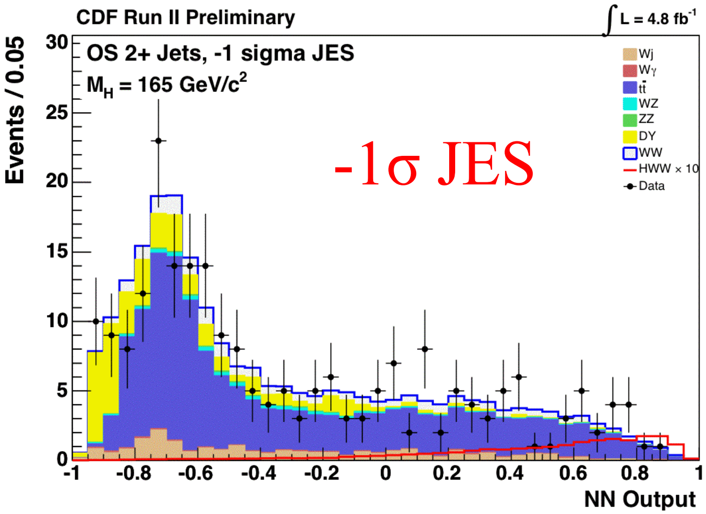


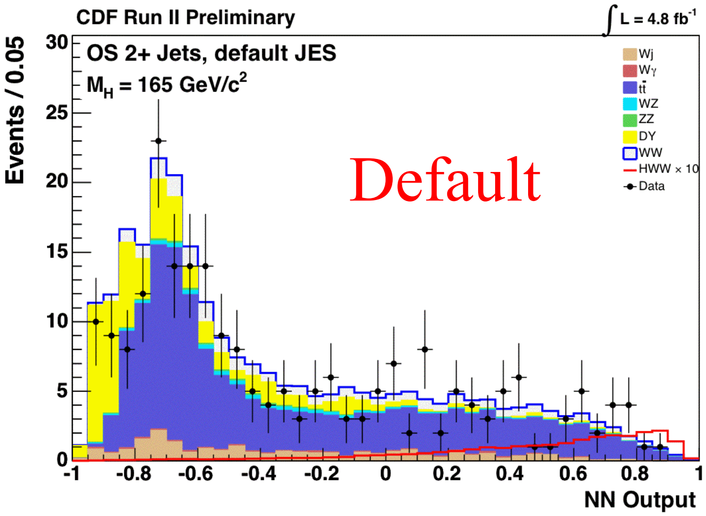
DY JES Shape Uncertainty

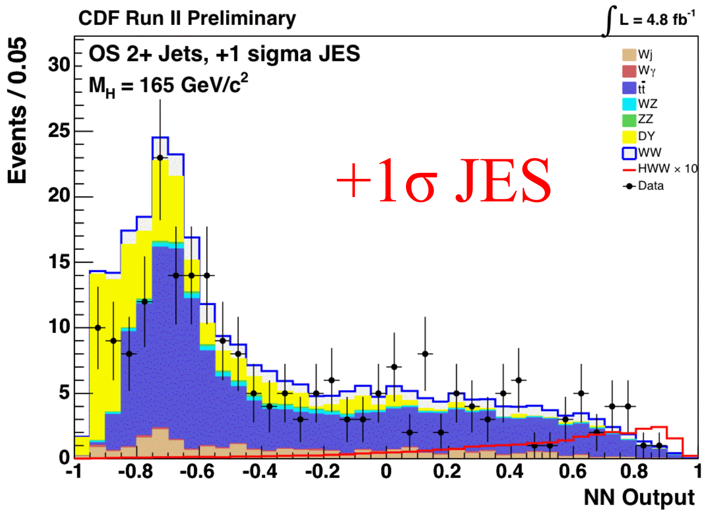
Normalization Uncertainty : +4.5% , -6.8%

Effect of adding shape uncertainty on cross section limit : 2.32xSM to 2.38xSM

Jet Energy Scale Effects (2+ Jets)

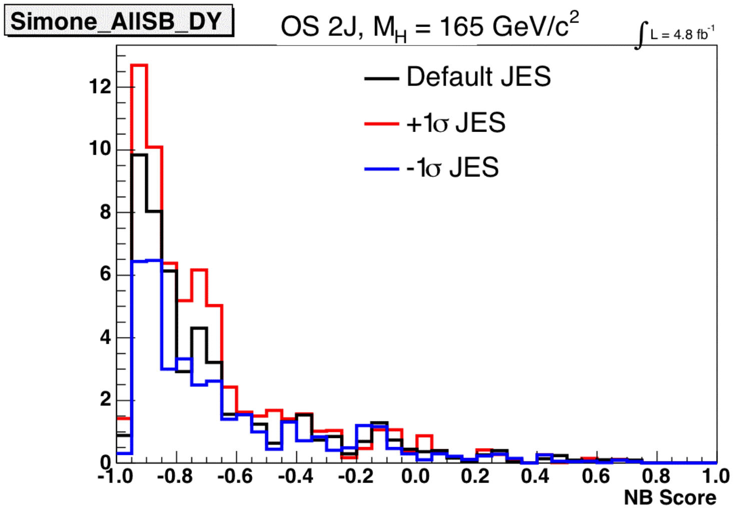




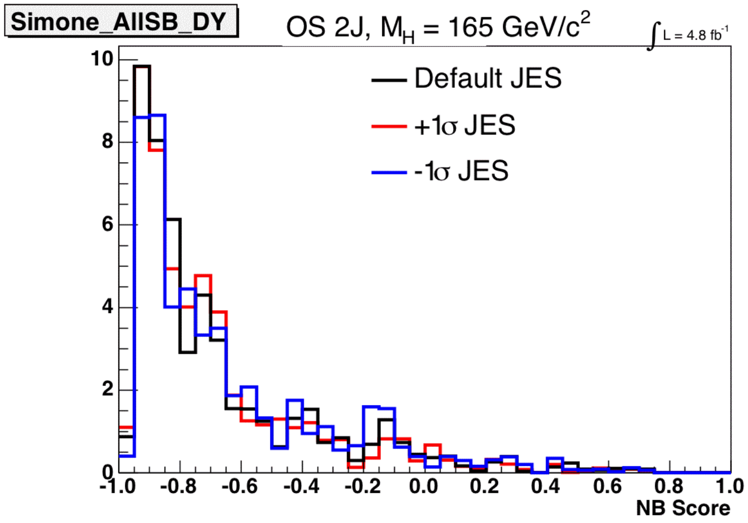


Data also seems to prefer -1sigma JES variation in the 2+ Jets channel

JES Uncertainties (2+ Jets)



DY JES Normalization Uncertainty



DY JES Shape Uncertainty

Normalization Uncertainty : +29.4% , -25.5%

Effect of adding shape uncertainty on cross section limit : 3.25xSM to 3.30xSM

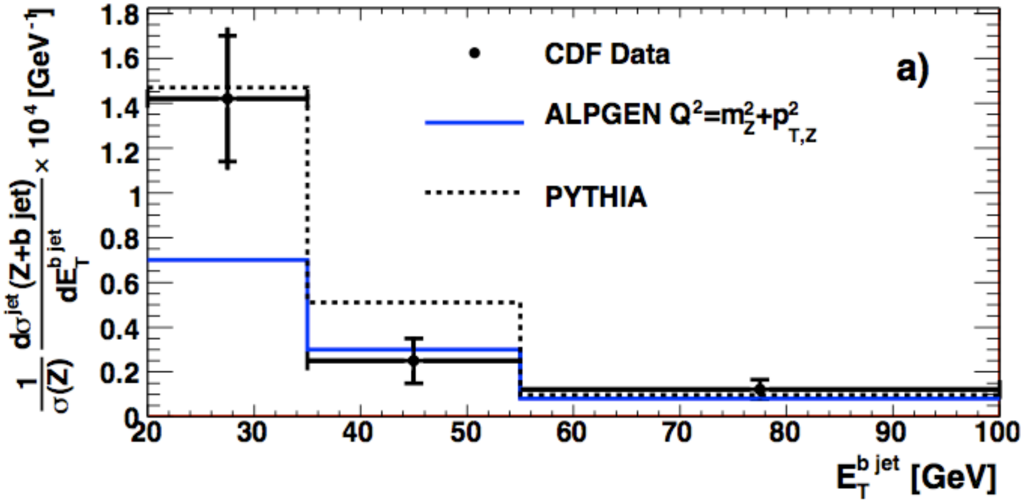
Moving Forward

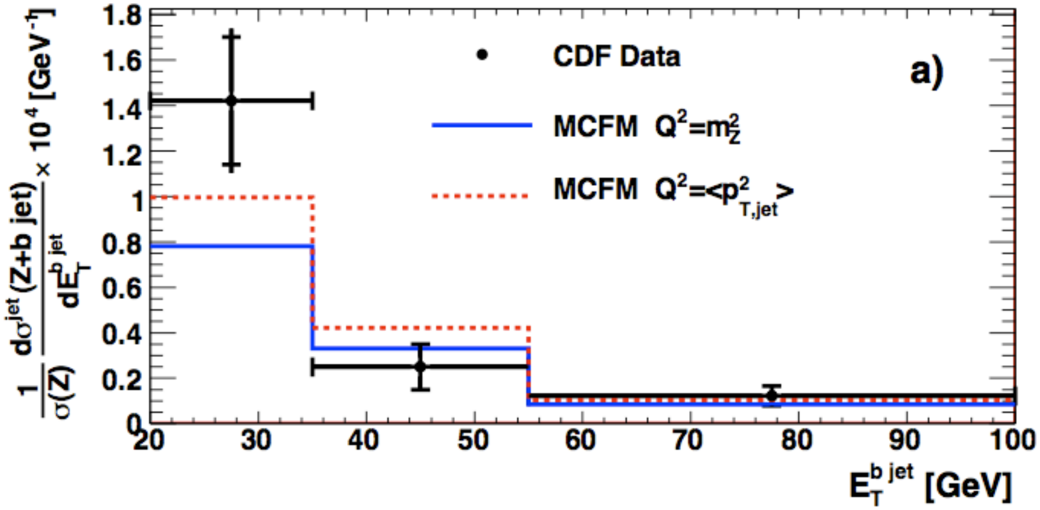
- In order to increase signal acceptance, we continue to consider new final states and run into new theoretical issues
- For example, currently working on incorporating tri-leptons. WZ background for tri-lepton final state has no jets at LO. Would like to upgrade WZ simulation to MC@NLO, but manual indicates that MC@NLO does not properly generate spin information for this process.

Low Mass Higgs Searches

- Not planning to say a lot about theoretical issues related to low mass searches
- Backgrounds in these samples are typically modeled using ALPGEN W/Z + n parton samples developed in conjunction with top quark analyses
  - We run into the typical sorts of problems where for example angles between trailing jets are not always modeled quite properly
  - Heavy flavor components of these backgrounds are normalized from data, but kinematic shapes are taken from simulation

Z + Heavy Flavor





Low Mass Higgs Searches

- One important issue to bring up is ISR/FSR modeling
  - Since dijet invariant mass is one of the most important kinematic inputs for separating potential signal and background, it’s important to model how often an ISR/FSR jet takes the place of a primary jet in the invariant mass calculation
  - A number of analyses also include “loose” jet information as an additional kinematic input to the multi-variant discriminant and in these cases kinematic modeling of these extra jets is important

Low Mass Higgs Searches

- We have struggled to settle on the both the default PYTHIA ISR/FSR settings and the settings used to assign ISR/FSR uncertainties
- One issue is that the parameters used to control the relative amount of ISR/FSR radiation overlap with those used to tune the underlying event and the Z p_T spectrum (PYTHIA Tune A and Tune AW)
- Some have noted that the Tune AW default settings in particular are set to fairly non-physical values and adjusting these further into the non-physical region does not make a lot of sense.

PYTHIA ISR/FSR Settings

- Assistance from theorists on identifying the correct settings would be a great help. To potentially facilitate discussion, the parameter values currently used by CDF for Higgs generation are shown here

Process	**Name**	**Kt Sigma parp 91**	**Kt Max parp 93**	**Q^2 Min parp 62**	**Kt^2 parp 64**
Default GF/VBF	Tune AW	2.10	15.0	1.25	0.2
Default WH/ZH	Tune A	2.50	15.0	1.25	1.0

ISR/FSR Uncertainties

Process	**λ_{QCD} (HS) parp 1**	**λ_{QCD} (SPS) parp 61**	**λ_{QCD} (TPS) parp 72**	**k-fac (SE) parp 71**	**k-fac (TE) parp 64**
Default WH/ZH	0.250	0.183	0.183	4.0	1.0
+1σ WH/ZH	0.146	0.292	0.292	8.0	0.5
-1σ WH/ZH	0.146	0.073	0.073	2.0	2.0

Are we double-counting uncertainties by using these settings?

Conclusions

- Tevatron continues to rapidly improve the sensitivity of its Higgs searches
- Doubling the current dataset helps a lot but does not by itself provide SM sensitivity for all Higgs mass values below 185 GeV/c^2
- Much work is still needed on both experimental and theoretical issues to achieve this goal