Search for H->WW and measurement of the WW cross section

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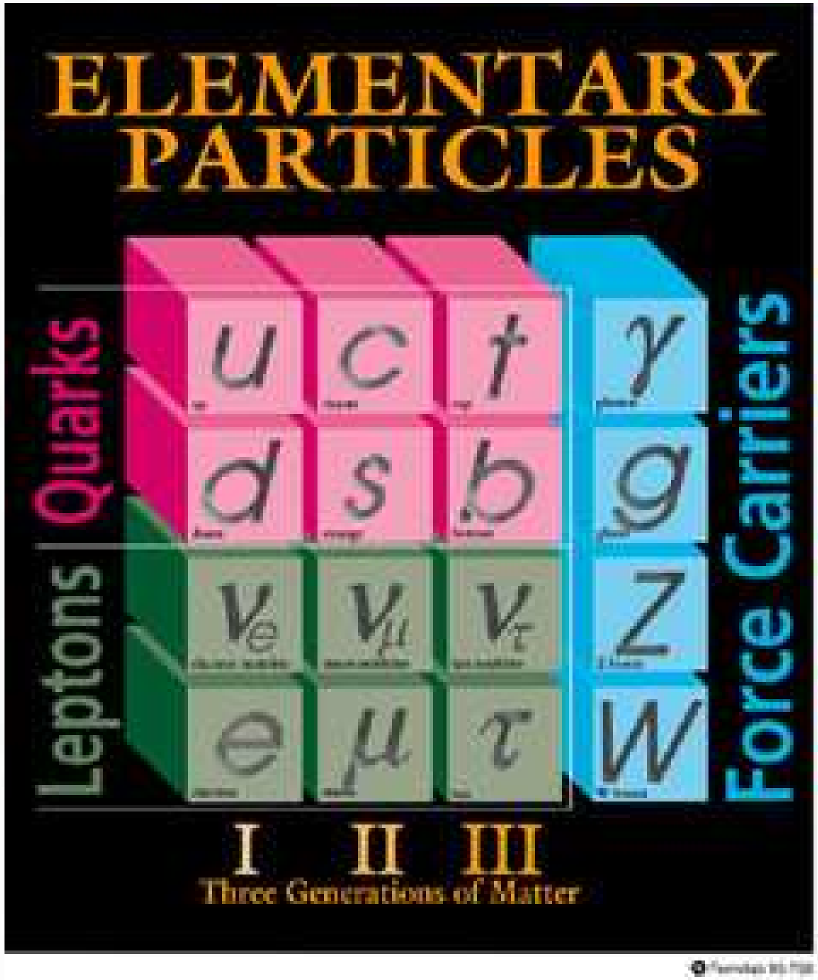
Outline

- Introduction
- Experiment
- Simulation
- Analysis
- Results
- Conclusion

The Standard Model

- Twelve fermions (plus corresponding antiparticles) that make up matter
- Three fundamental forces carried by four vector bosons
- Mass asymmetry between W/Z and photon
- One scalar boson: Higgs Boson, predicted but not yet observed



EW Symmetry Breaking and the Higgs

- A Higgs or Higgs-like mechanism is needed
- Gives mass to the W and Z bosons through spontaneous symmetry breaking
- Predicts the existence of Higgs Boson, which couples to particle mass

W Mass: gv/2

$$\mathcal{L}_{W,H} = -\frac{1}{2}W^{+}_{\mu\nu}W^{-\mu\nu} + \frac{1}{4}g^2v^2W^{+}_{\mu}W^{-}_{\mu} + \frac{1}{2}(\partial_u H)(\partial^u H)$$
$$-v^2\lambda H^2 + \frac{1}{2}g^2 vHW^{+}_{\mu}W^{-}_{\mu} + \frac{g^2}{4}H^2W^{+}_{\mu}W^{-}_{\mu}$$

H Mass: 2λv^2

HWW Interaction

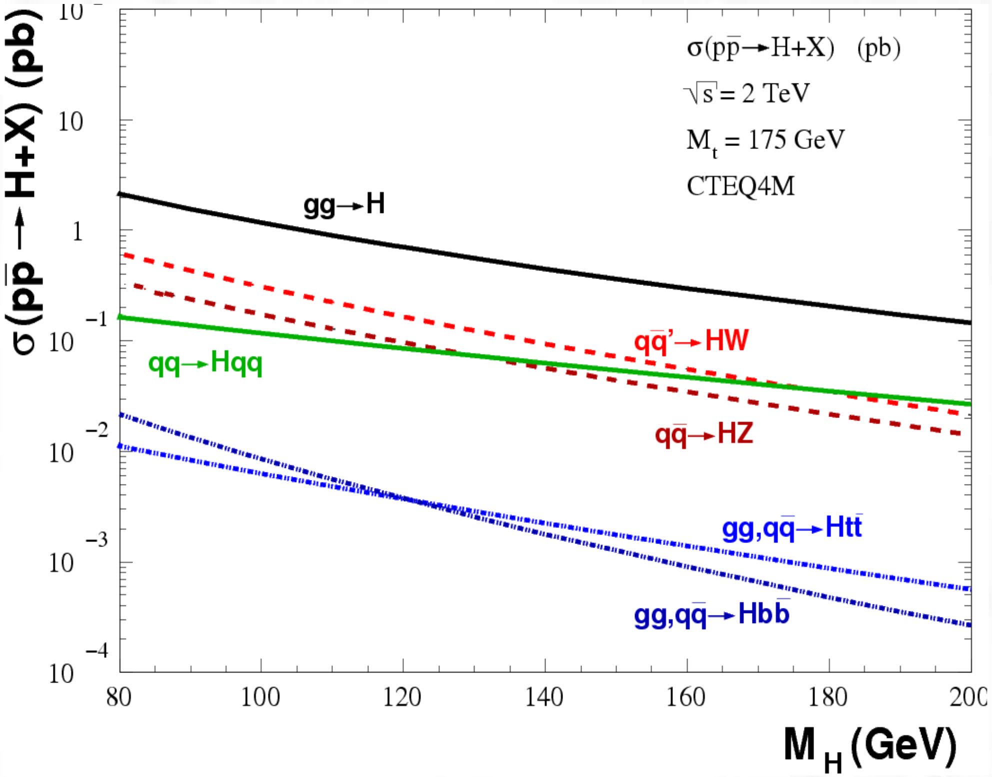
- Fermions could gain mass by the same method

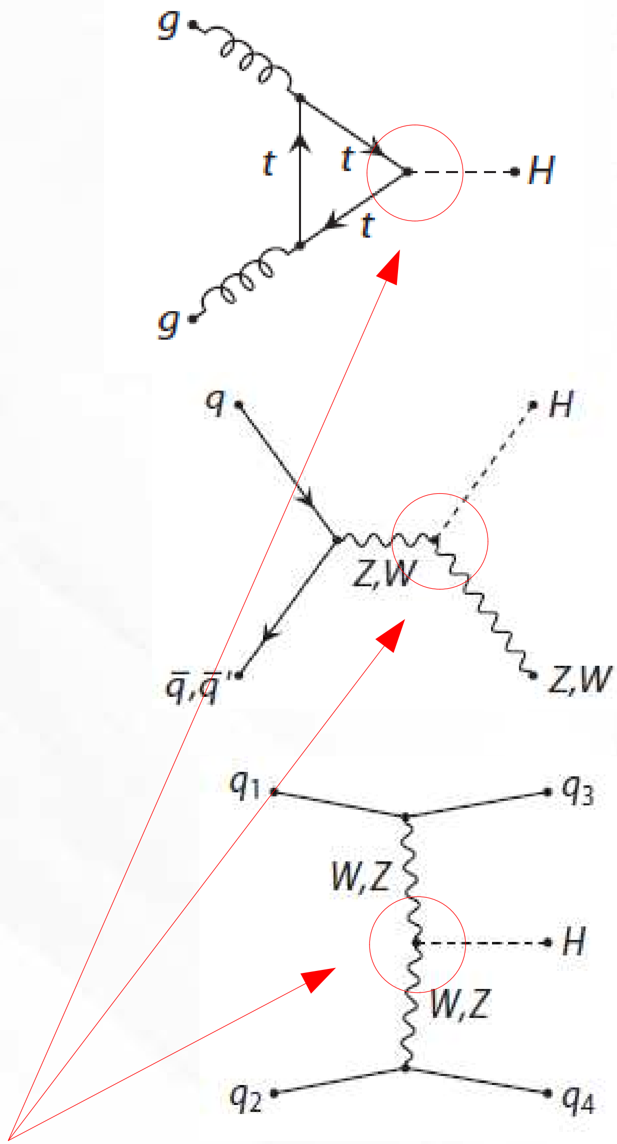
  Mass: $\frac{g_f v}{\sqrt{2}}$ Coupling: $\frac{g_f}{\sqrt{2}}$

- All particles couple to Higgs proportional to their mass

Higgs Production at CDF

- gg fusion is dominant overall
- Here we study H->WW+2 jets
- Associative production and vector boson fusion become comparable and distinctive due to extra gauge boson or forward jets

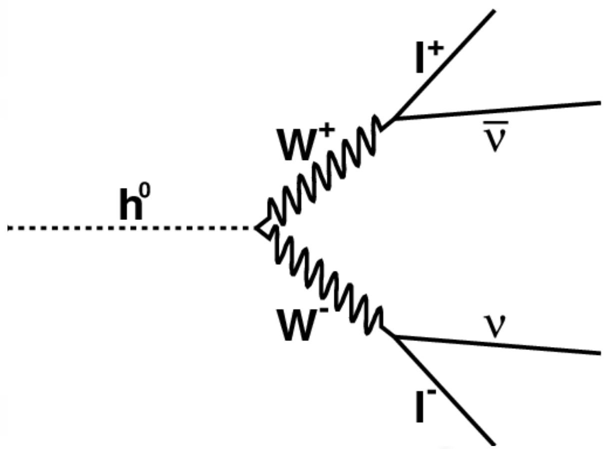


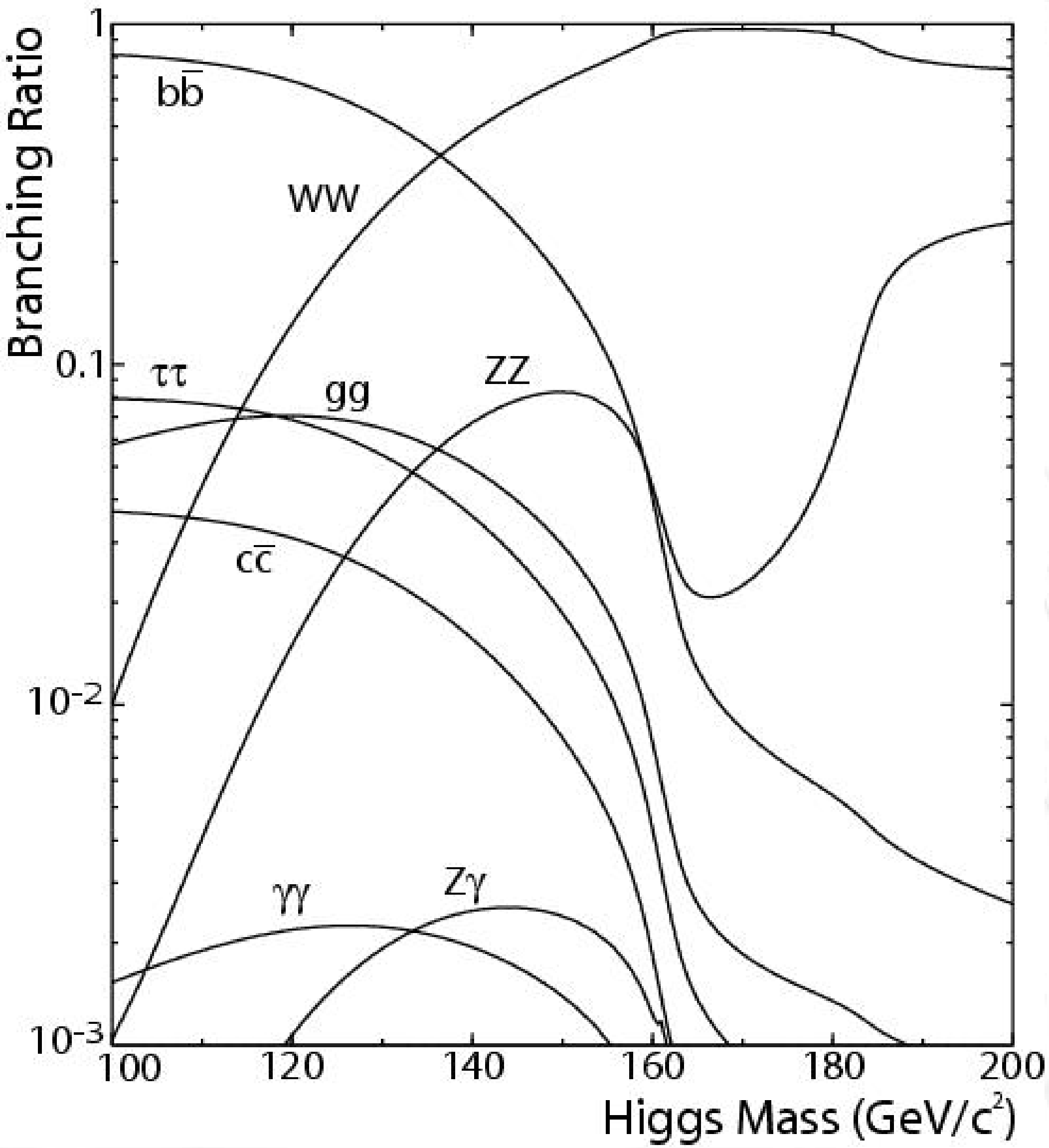


Coupling proportional to mass

Higgs Decay

- H->WW is the leading contributor above 123 GeV
- Leptonic W decay (33% BR) is easier to study
- Require W->e,μ or W->τ->e,μ
- Leptons can come from H->WW or associated gauge boson

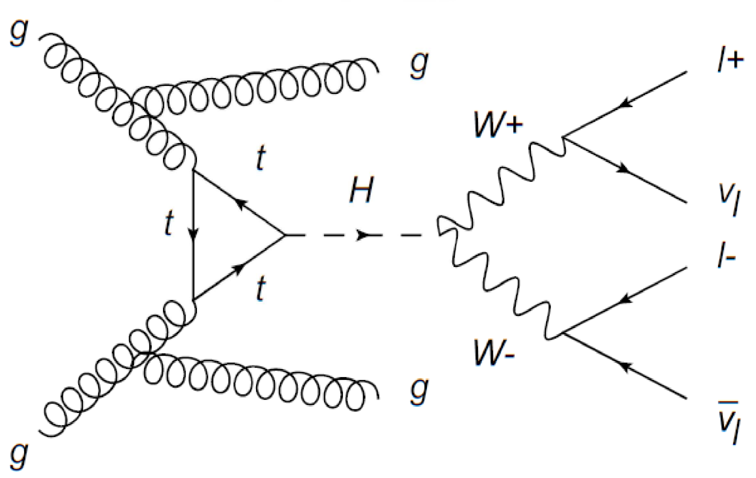




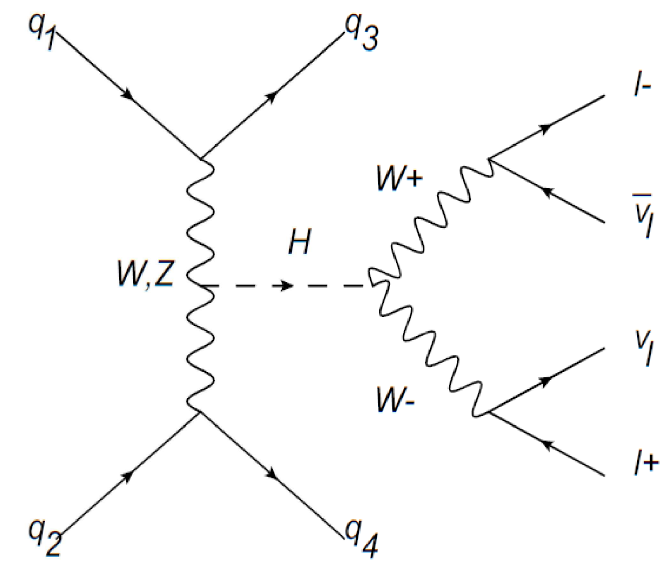
Final State

Require exactly two leptons, Met, and 2 or more jets

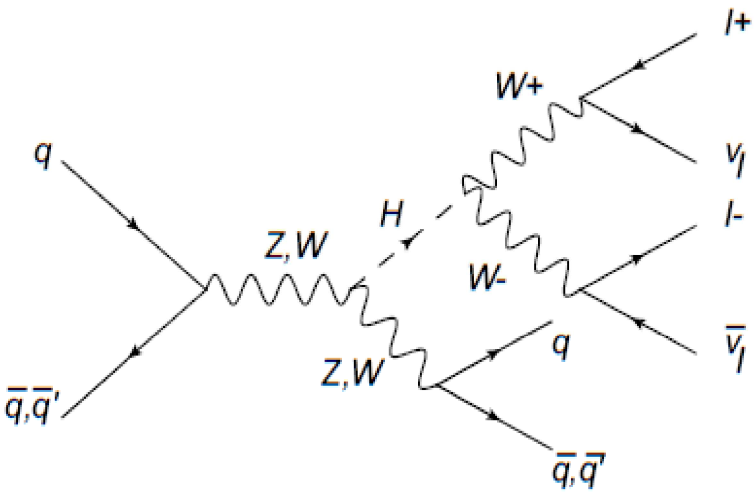
- Gluon fusion with ISR



- Vector boson fusion

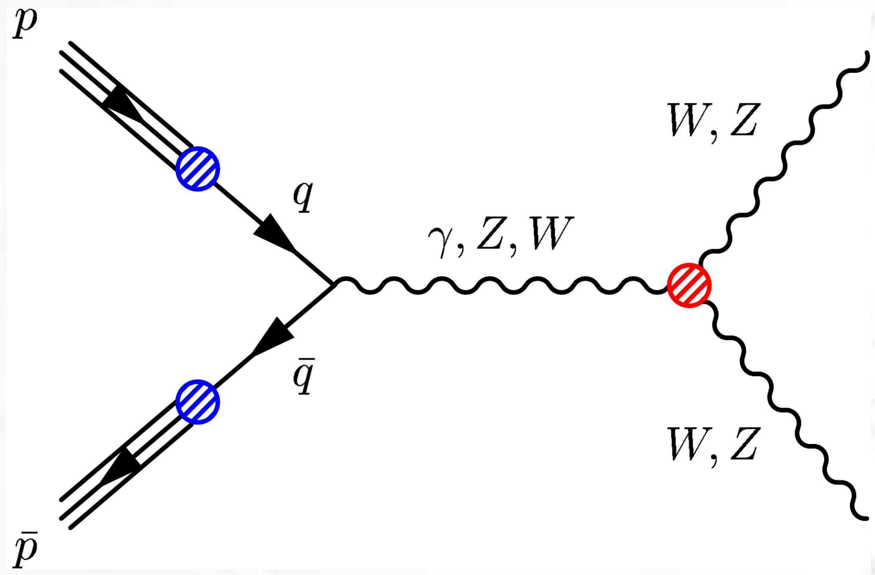


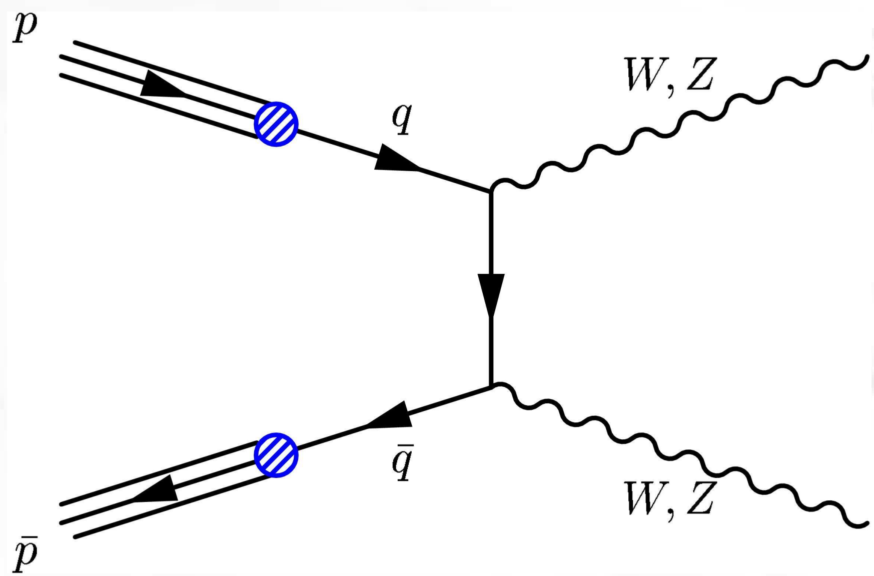
- Associative production with hadronic decay



WW Production

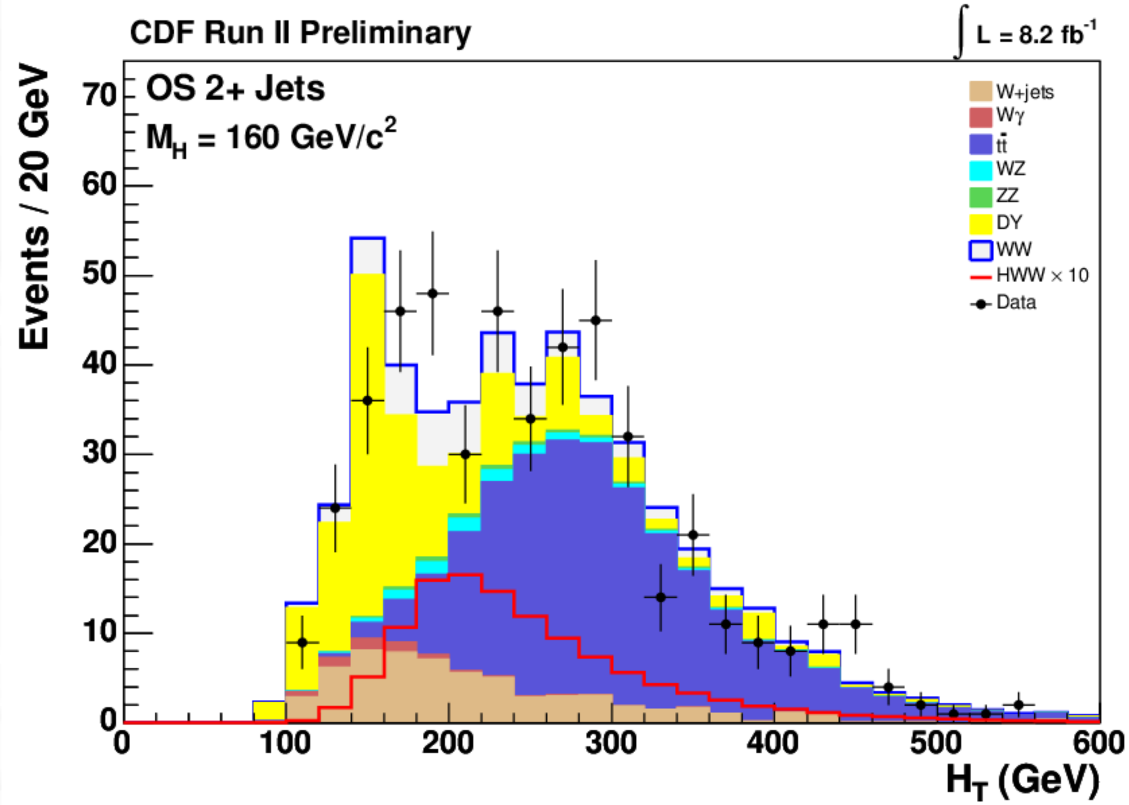
- Significant background for Higgs search
- pp->WW+2jets is a NNLO process
- Tests NNLO MC that is needed for Higgs search
- Triple gauge coupling
- Sensitive to new physics





Dominant Backgrounds

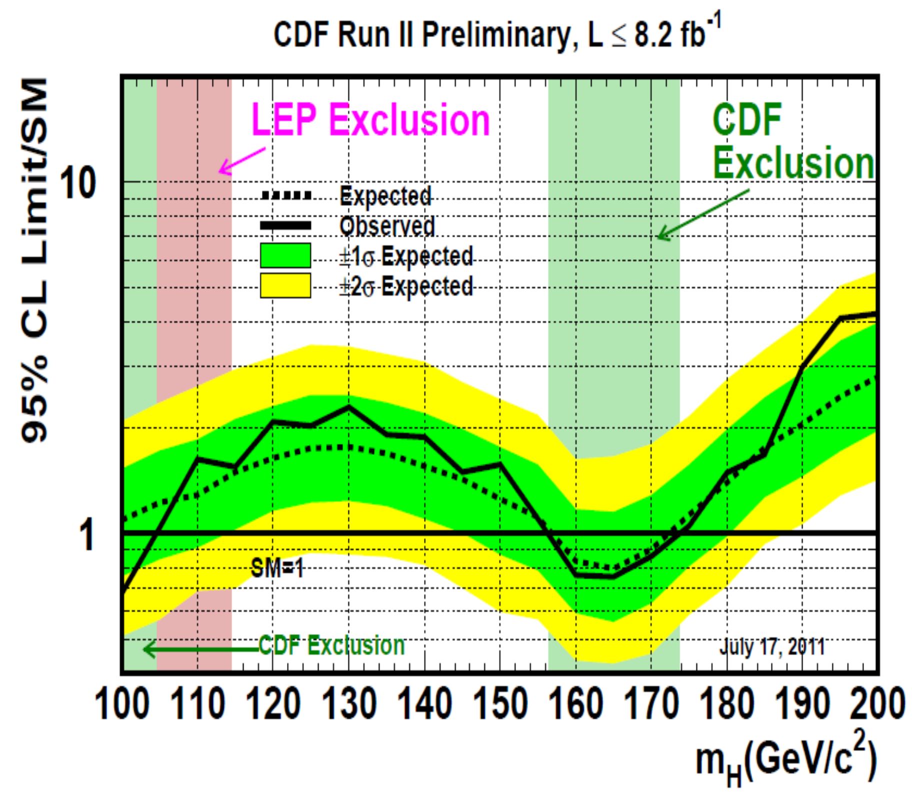
- ttbar (t->Wb)
- Drell-Yan (Jet mismeasurement resulting in missing Et)
- WW
- W+jets
- W+gamma
- WZ
- ZZ



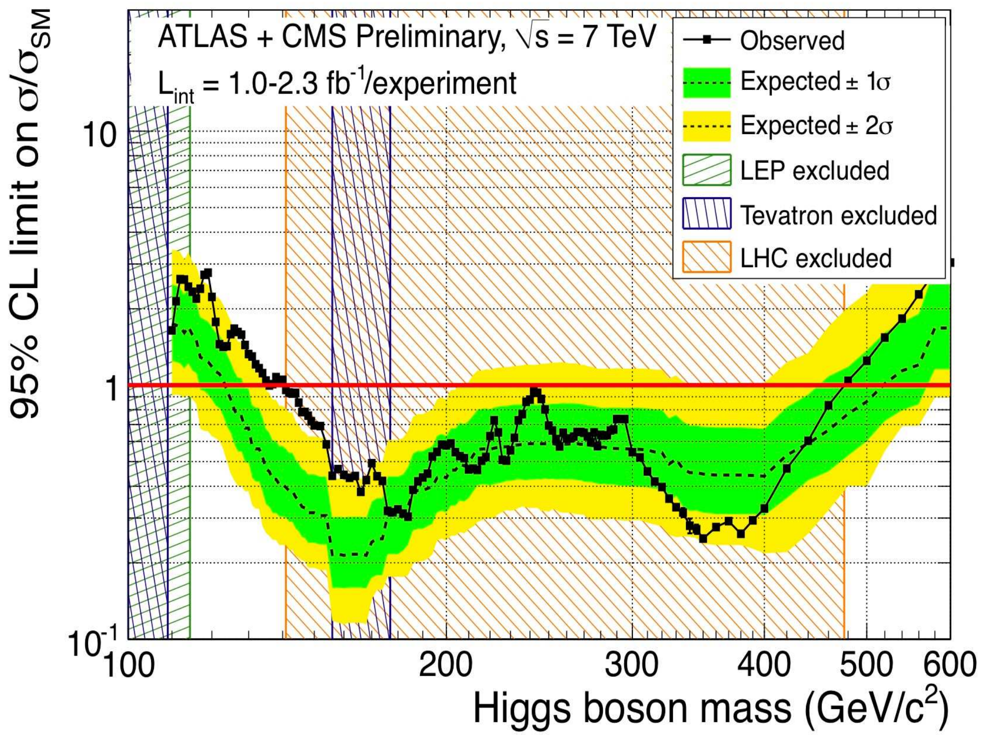
Scalar sum of transverse energy of leptons, met, and jets

Current State of Higgs Exclusion

Limit set by Tevatron



Limit set by LHC



LHC observes an excess around 130 GeV, where H->WW is still the most powerful contributor to the CDF analysis

Limitations of Previous Analysis

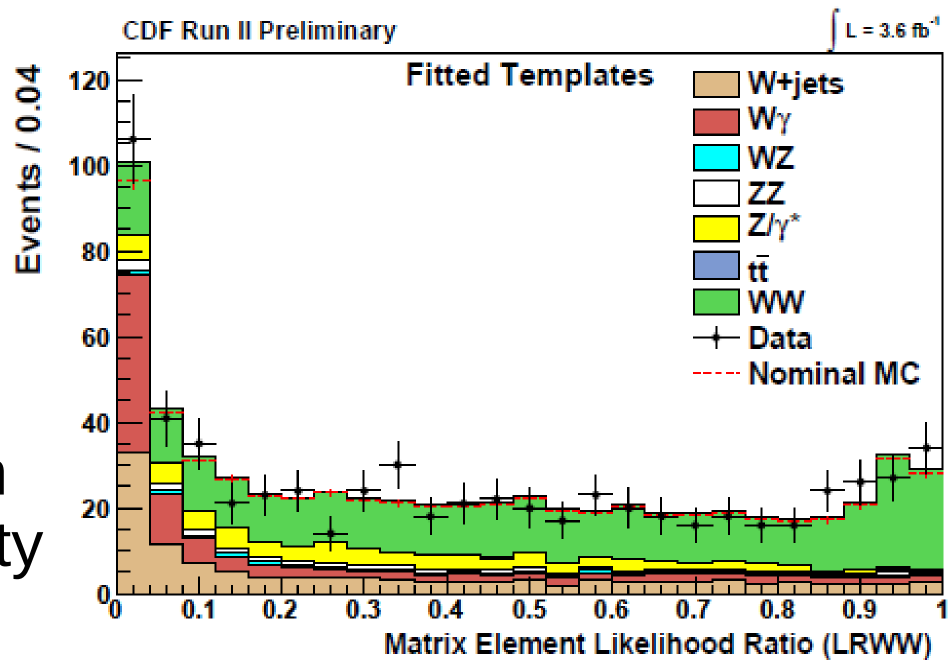
- Used Pythia to generate H->WW signal and most backgrounds
- Used NLO MC to generate WW backgrounds
- MC is tuned to properly model the reconstructed momentum of the vector bosons and vector boson pairs
- Does not reproduce the kinematics of the individual jets
- Dijet masses can be used to detect W or Z bosons, or the signature forward jets of VBF
- We update the background MC to NNLO where appropriate

Current WW Cross Section Measurement

- CDF
- Uses 3.6 fb^-1
- Used matrix element based likelihood ratios
- Only events with no reconstructed jets
- 12.1+/-0.9 (stat) +1.6/-1.4 (syst)

- D0
- Uses 224-252 pb^-1
- Cut based analysis
- Uses Pythia to model WW
- 13.8 +4.3/-3.8 (stat) +1.2/-0.9 (syst)

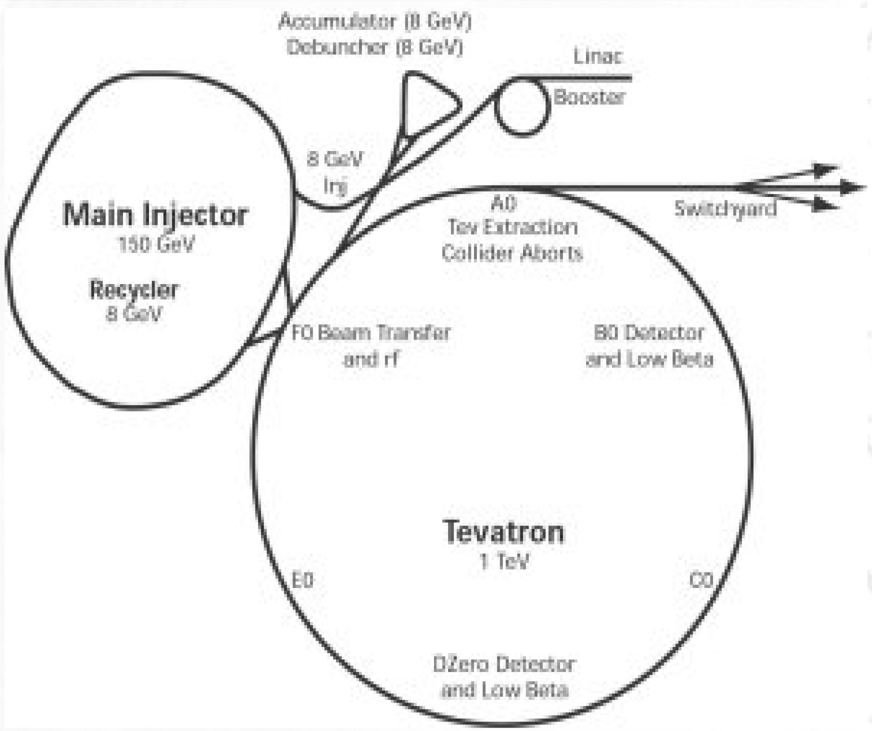
- Our measurement
- Will use full dataset
- Will use NNLO MC
- Will measure differential cross section as a function of jet energy and multiplicity
- First measurement of massive diboson production with 2 jets

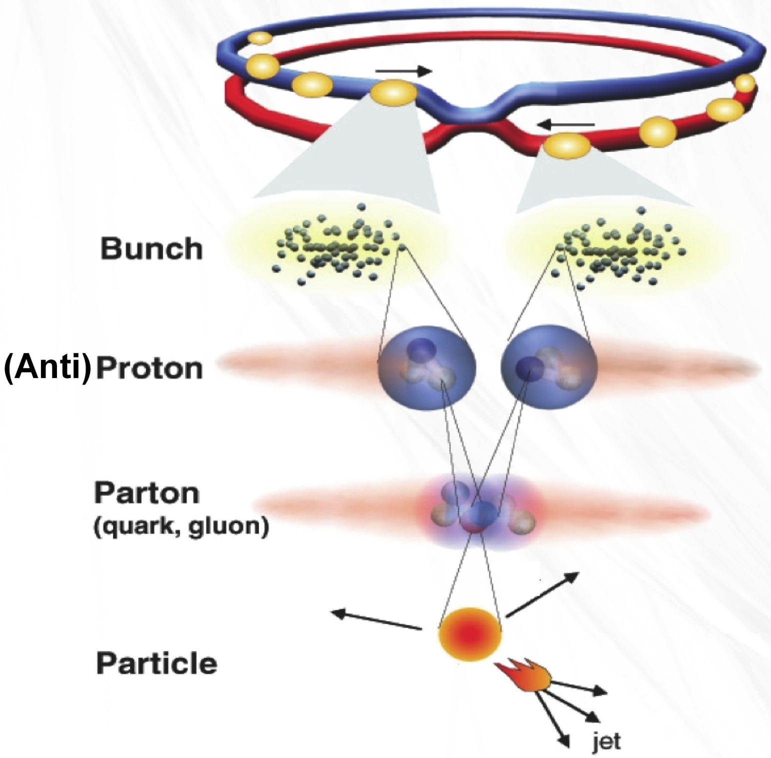


CDF data and templates

The Tevatron

- Proton-antiproton collider
- 1km radius → 21 μs revolution time
- Sqrt(s) = 1.96 TeV

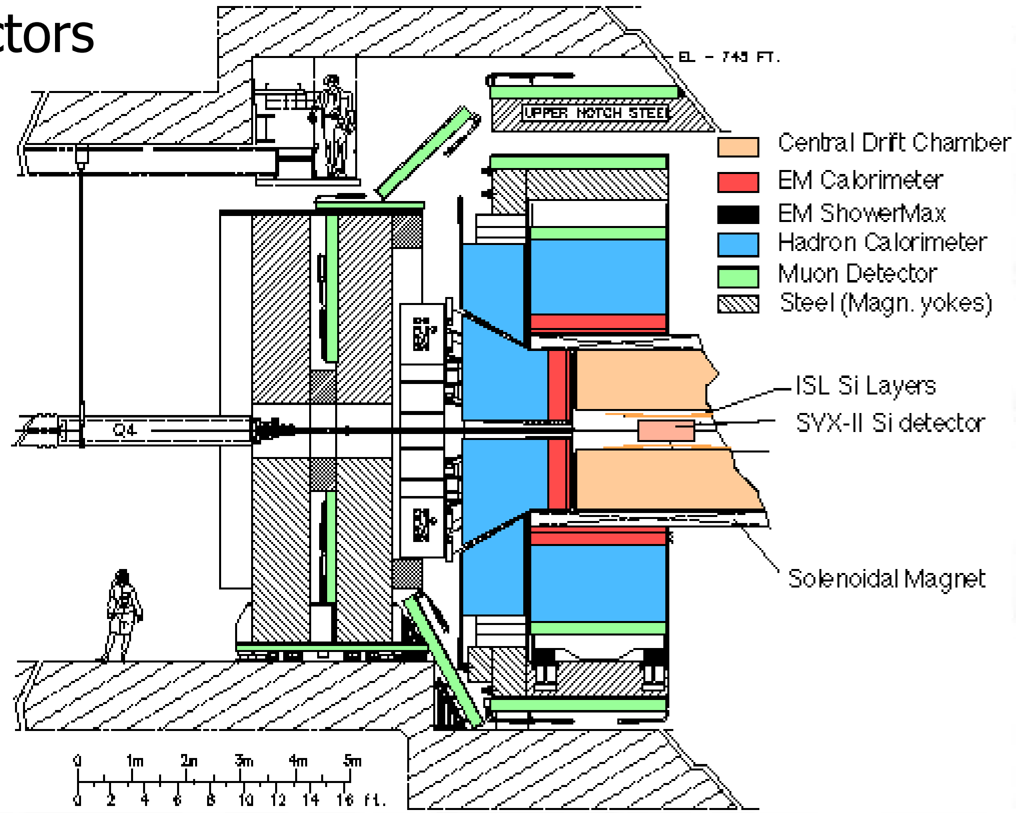




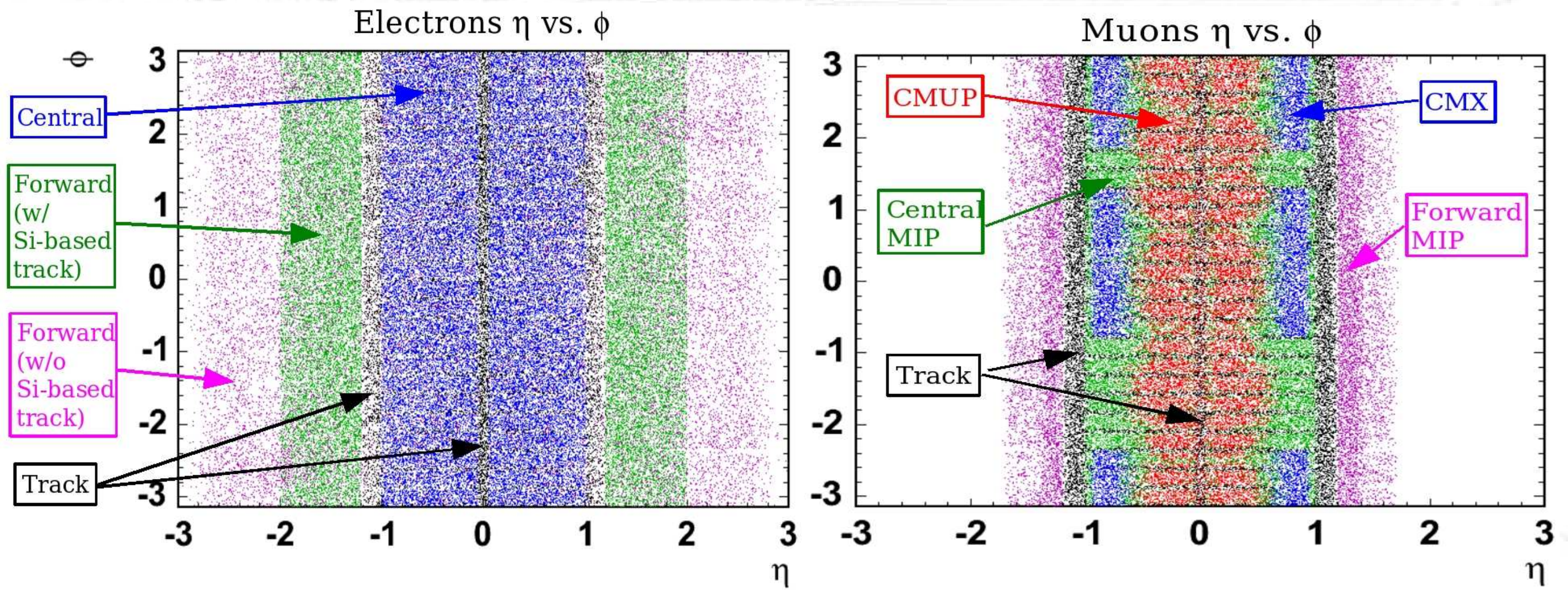
- 36 bunches per beam
- 3E11 protons and 0.8E11 pbars per bunch
- Luminosity: 4E32 cm^-2 s^-1
- Work presented today uses 8.2 fb^-1
- Final result will use 9.97 fb^-1

The CDF Detector

- Silicon Detector
  - Silicon microstrip detectors
  - $|\eta|<2.0$
- Central Outer Tracker
  - Drift chamber
  - $|\eta|<1.0$
- EM(H) Calorimeters
  - Pb(Fe)/scintillator
  - $|\eta|<3.6$ (central+plug)
- Muon detectors
  - Wire chambers in proportional mode
  - Combined coverage out to $|\eta|<1.5$
  - Scintillator tiles provide triggering and timing information



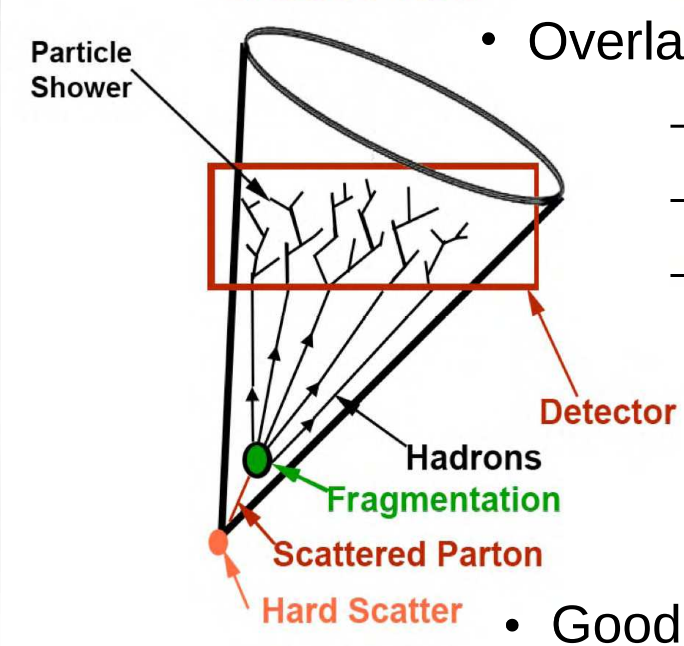
Lepton Coverage



- Two categories of electron (forward and central)
- Eight categories of muon (corresponding to different detector elements)
- Maximal acceptance, no overlap

Jet Identification

- Jets leave tracks in silicon and deposit energy in calorimeters
- JETCLU reconstructs the jet from its energy deposits
    - Find seed towers with Et > 1 Gev
    - Form preclusters of radius 0.5 in η-Φ space
    - Find Et weighted center of cone, form clusters of radius 0.5 from towers with Et > 100 MeV
    - Iterate until tower list is unchanged
    - Ratcheting: Once added, towers are not removed
    - Overlap:
        - Total overlap: the smaller cluster is absorbed
        - Overlap > 0.75: the clusters are combined
        - Overlap < 0.75: the overlap is assigned to the closest center



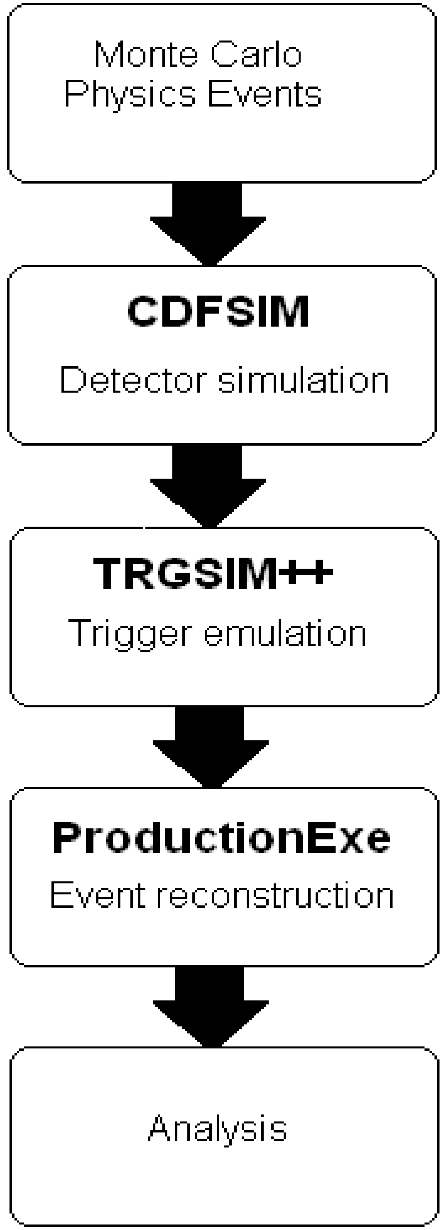
- Good mass reconstruction for dijet objects

Generation of Physics Events

- Alpgen
  - Tree-level matrix element calculator
  - Emphasis on high jet multiplicites
  - Generates diboson and Drell-Yan events
- Pythia
  - Leading order MC
  - Used for ttbar and higgs events
- Wγ generated with Baur ME generator
- Pythia handles fragmentation and hadronization
- W+jets sample comes from data with fake leptons (not MC)

Detector Simulation, Event Reconstruction

- Monte Carlo events are passed to CDFSim
- Uses Geant 3, simulates CDF detector
- TRGSIM++ simulates trigger response
- ProductionExe reconstructs events
  - Identical to data reconstruction
- Passed to analysis code



Corrections to the Monte Carlo

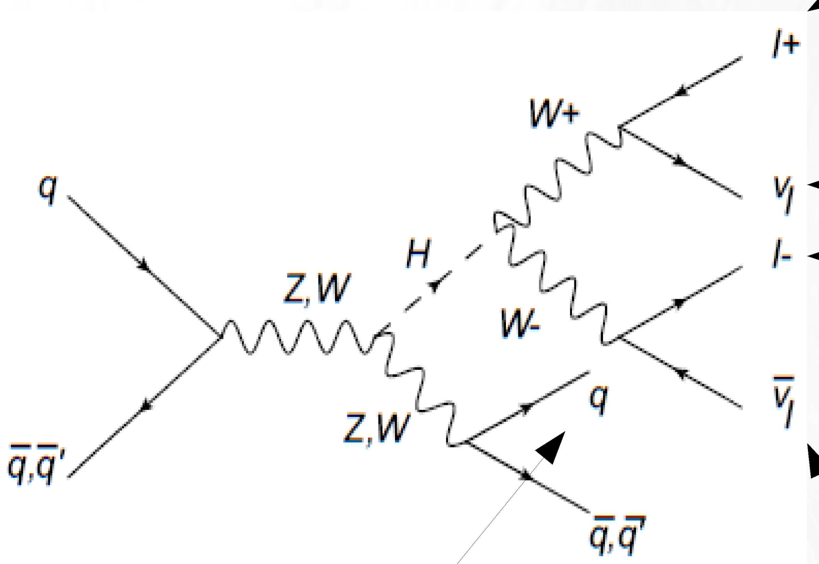
$$\frac{\sigma \times \mathcal{B} \times \epsilon_{\mathrm{filter}} \times \epsilon_i^{\mathrm{trg}} \times s_i^{\mathrm{lep}} \times \epsilon_{\mathrm{vtx}} \times \mathcal{L}_i}{N_i^{\mathrm{gen}}(|Z_0| < 60\ \mathrm{cm})}$$

- σ: Cross section
- β: Branching fraction
- ε_filter: Filter efficiency
- ε^trg: Trigger efficiency
- s^lep: Lepton ID scale factor
- ε_vtx: Z vertex position requirement efficiency (run dependent)
- L: Luminosity of dataset (dependent on lepton category)
- N_gen: Number of events generated

Other corrections

- WW: rescaled to account for box diagrams
- ggH: reweighted to match NNLL differential cross section predictions

Event Selection



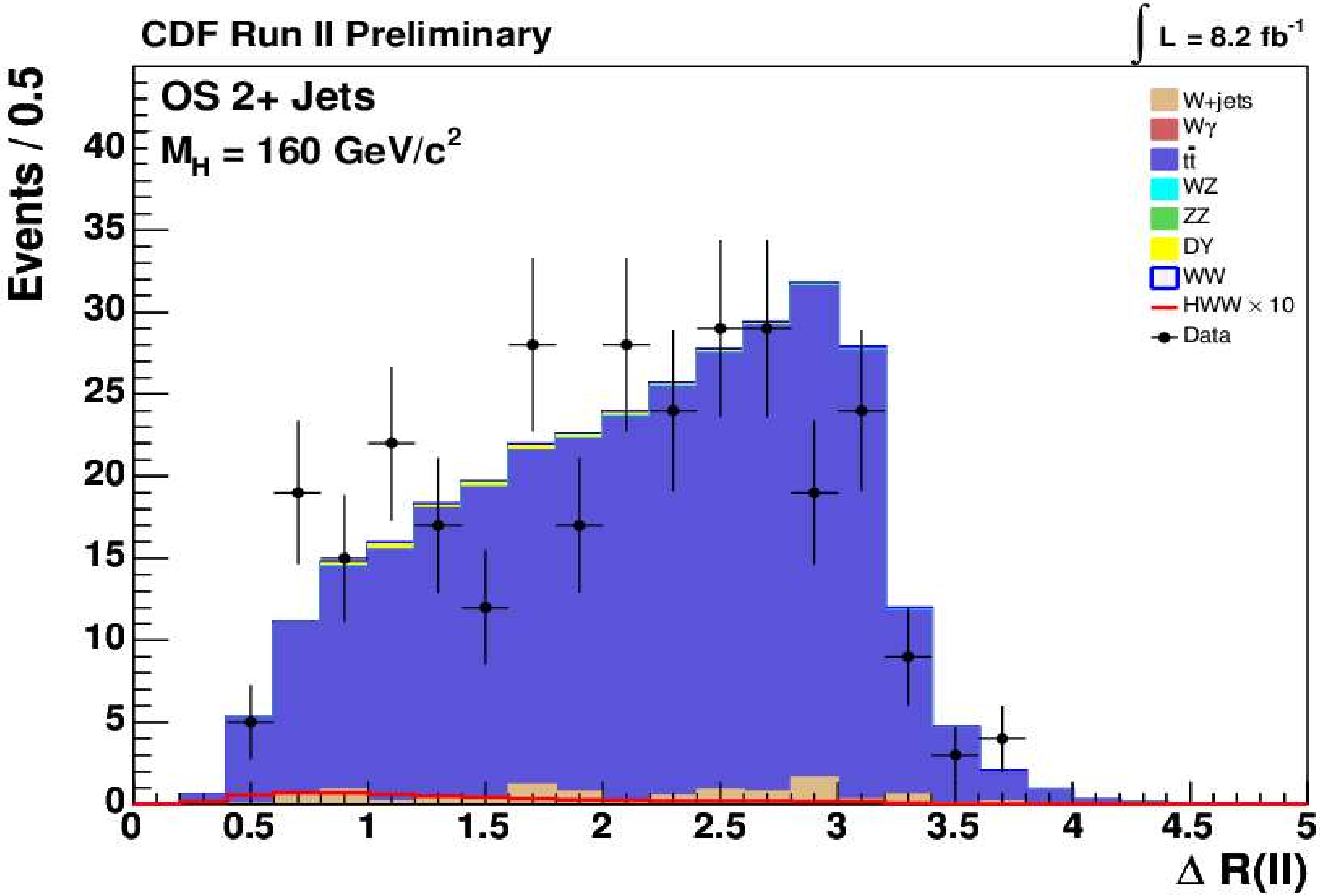
- Exactly two leptons
  - Leading Et(Pt) > 20 Gev, Second Et(Pt) > 10 Gev
  - Z position within 4 cm of each other
  - Track Pt within ΔR=0.4 < 10% of lepton Et(Pt)
  - M_ll > 16 GeV
- 2 or more jets
  - Et > 15 Gev
  - $|\eta| < 2.5$
- MetSpec > 25 Gev, > 15 Gev for electron-muon events (Met perpendicular to the nearest jet or lepton within 90°)
- Veto events with a tight secondary vertex btag
- Final signal to background discrimination will be performed using a neural net

Control Regions

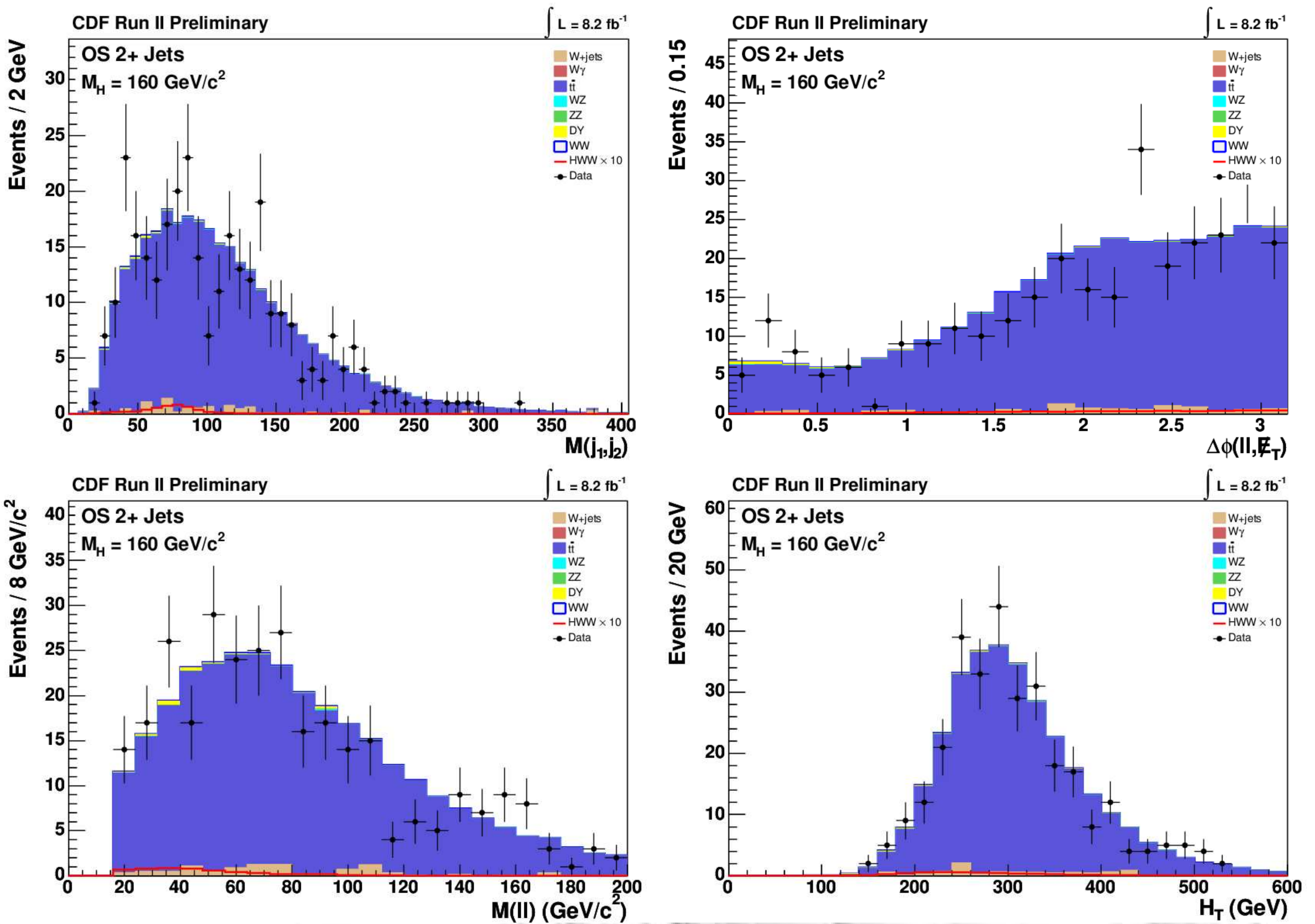
- Build three control regions to study modeling of specific backgrounds
- Top Control Region
  - Requiring one or more btags gives us a nearly pure sample of ttbar events
- Drell-Yan Control Region
  - Most Drell-Yan Met comes from jet mismeasurement
  - Require Z peak, same flavor leptons, loosen Met requirement
- WW Enhanced region
  - Suppress Drell-Yan
  - Train a neural net to discriminate WW from other backgrounds
  - Avoid using jet kinematics that may not be well modeled

Top Control Region

- Events that pass event selection, except for containing at least one btag
- Presenting discriminating variables with correlation > 10%

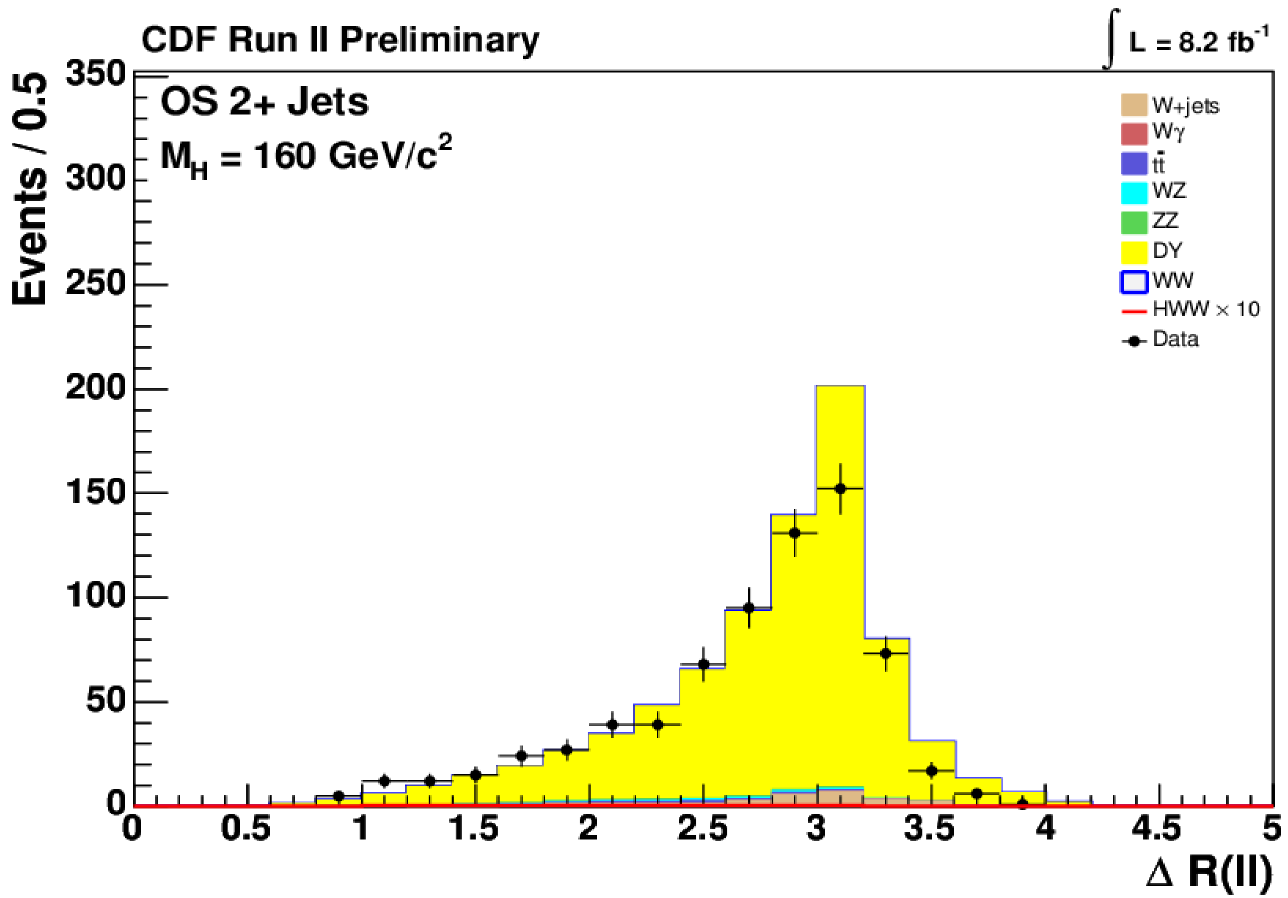


Top Control Region (2)

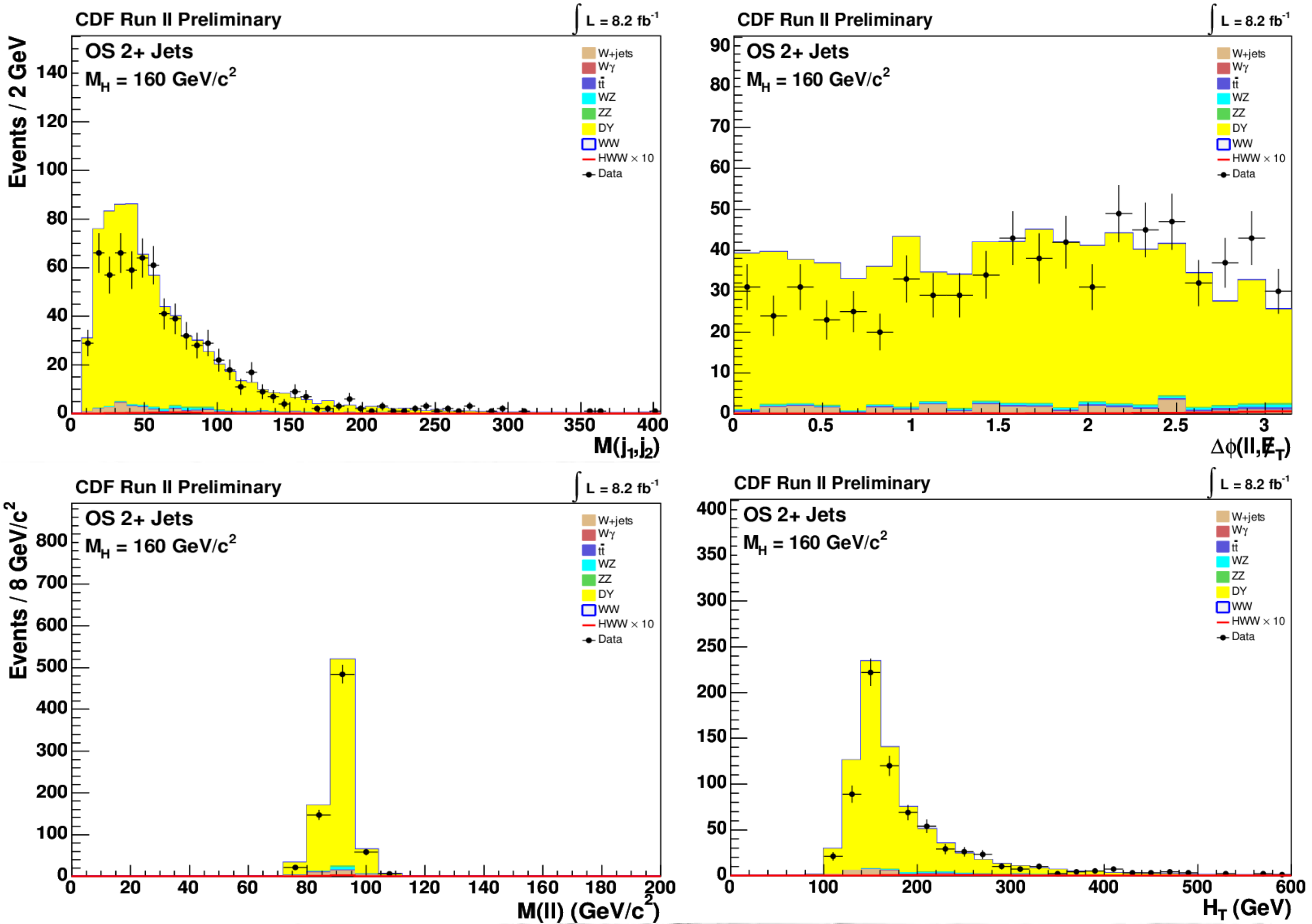


Drell-Yan Control Region

- 15<MetSpec<25 (Met perpendicular to the nearest jet or lepton within 90°)
- 76<Mll<106
- ee, μμ, or e/μ + track
- 2 or more jets
- Btag veto

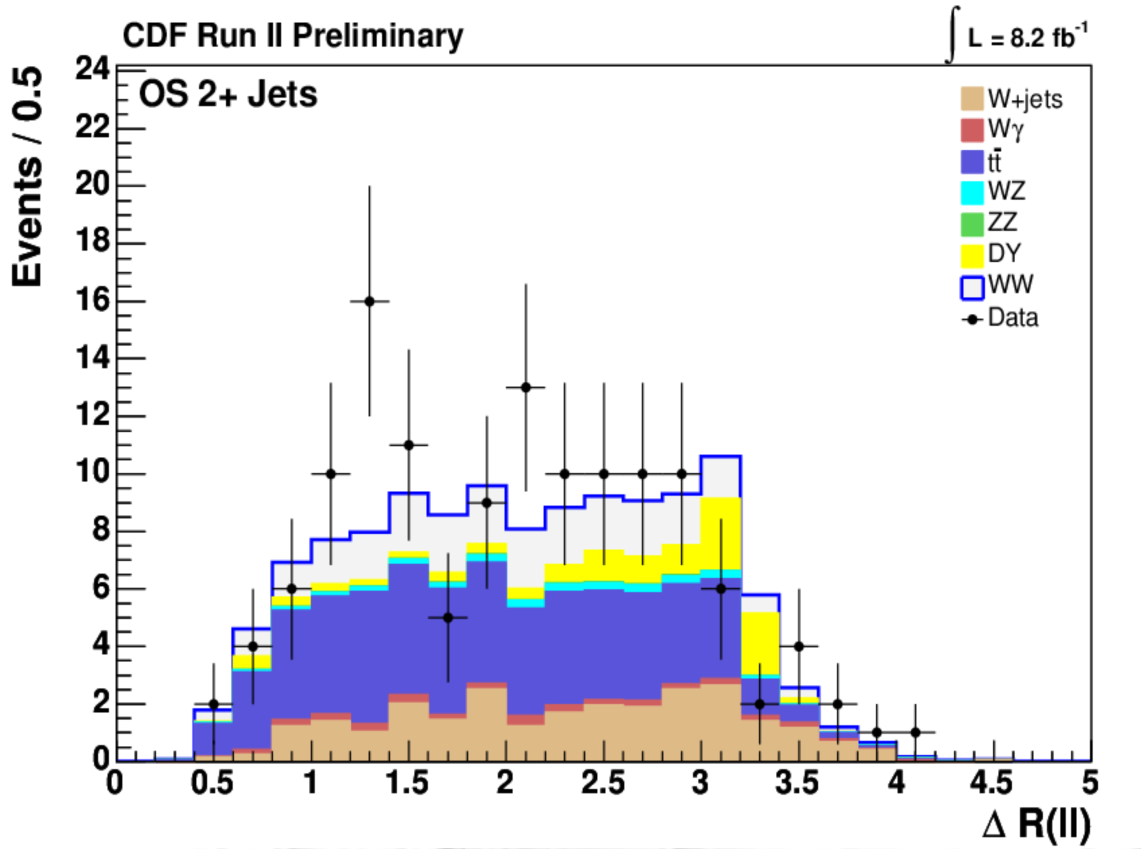


Drell-Yan Control Region (2)

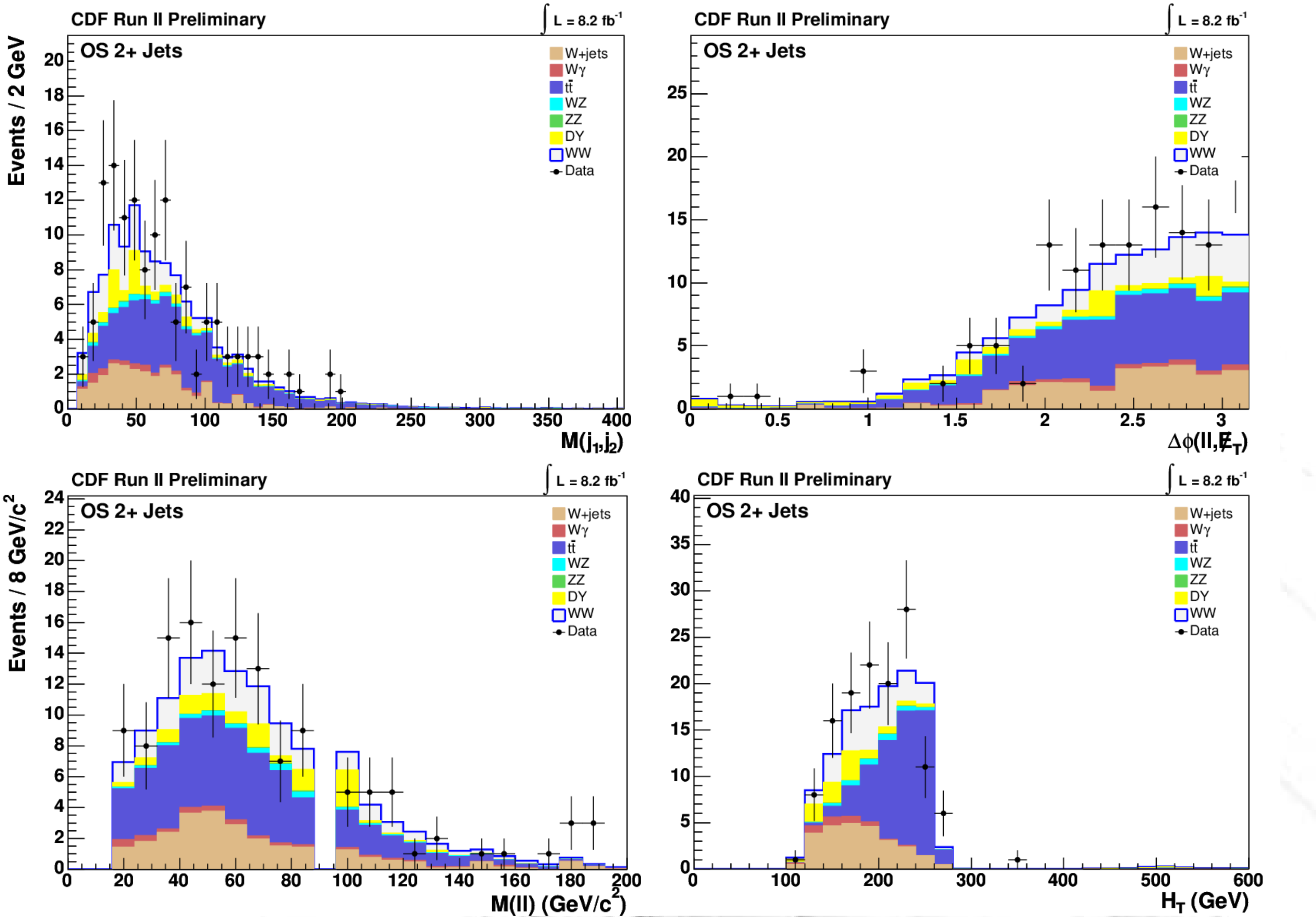


WW Enhanced Region

- Suppress Drell-Yan by cutting Met/√(Et) < 2, 86<M(ll)<96
- Train a neural net to discriminate WW from other backgrounds
- ΔR(ll), ΔΦ(ll), ΔΦ(ll,Met), Pt(jj), Pt(l1), Pt(l2), Ht, M(ll)

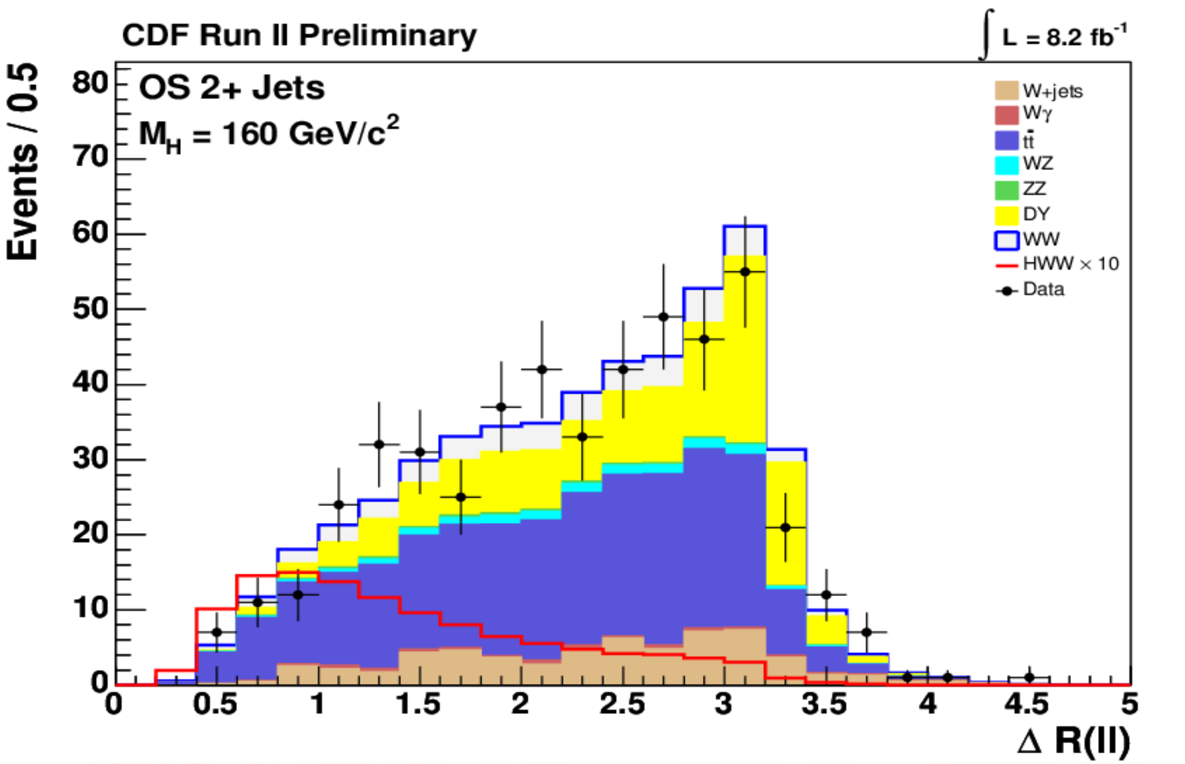


WW Enhanced Region (2)



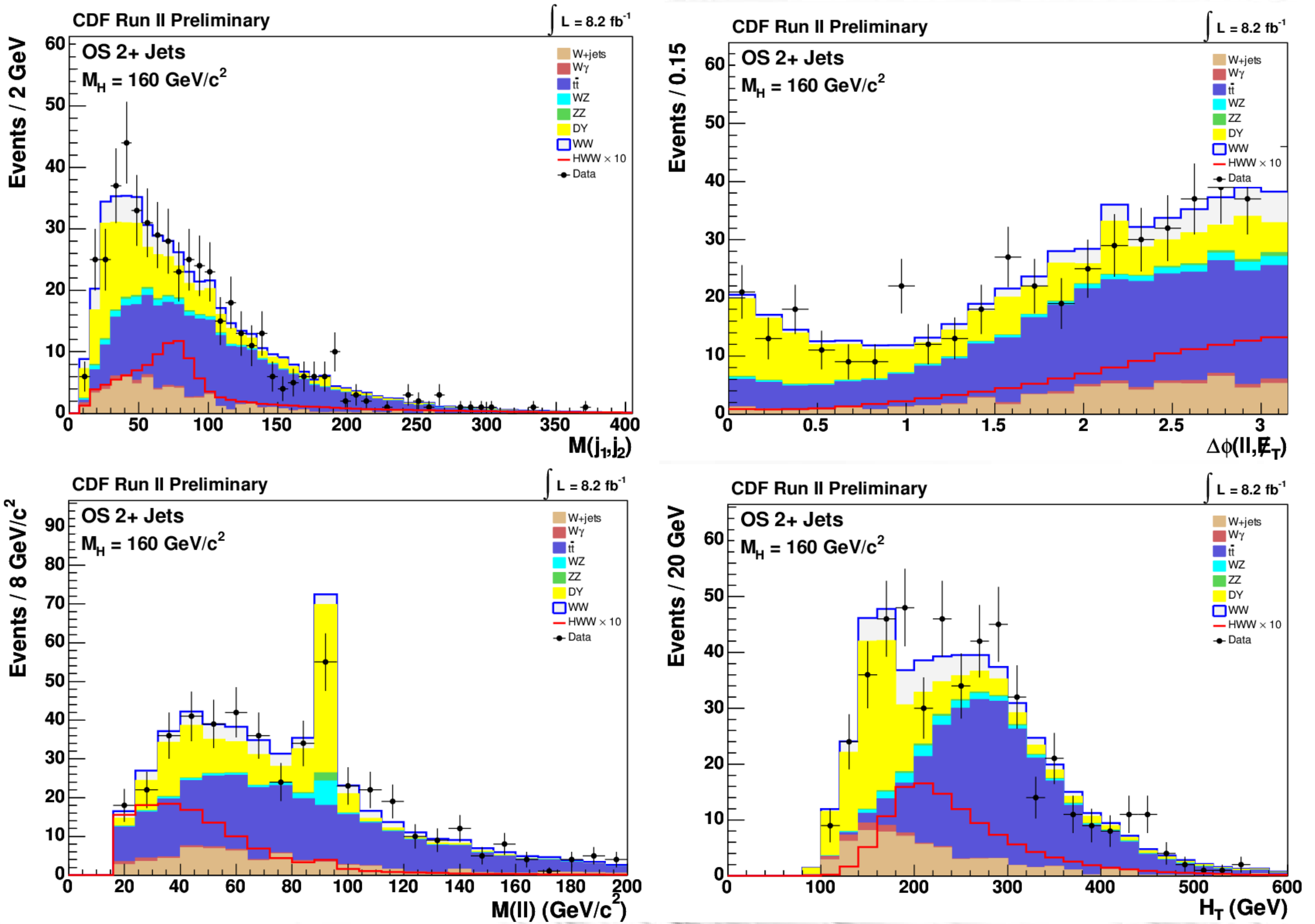
Neural Net Variables

- Signal region
- Uses event selection described above



- ΔR(ll) takes advantage of spin correlation resulting in colinear leptons
- These discriminants are eventually combined with others in a neural net

Neural Net Variables (2)



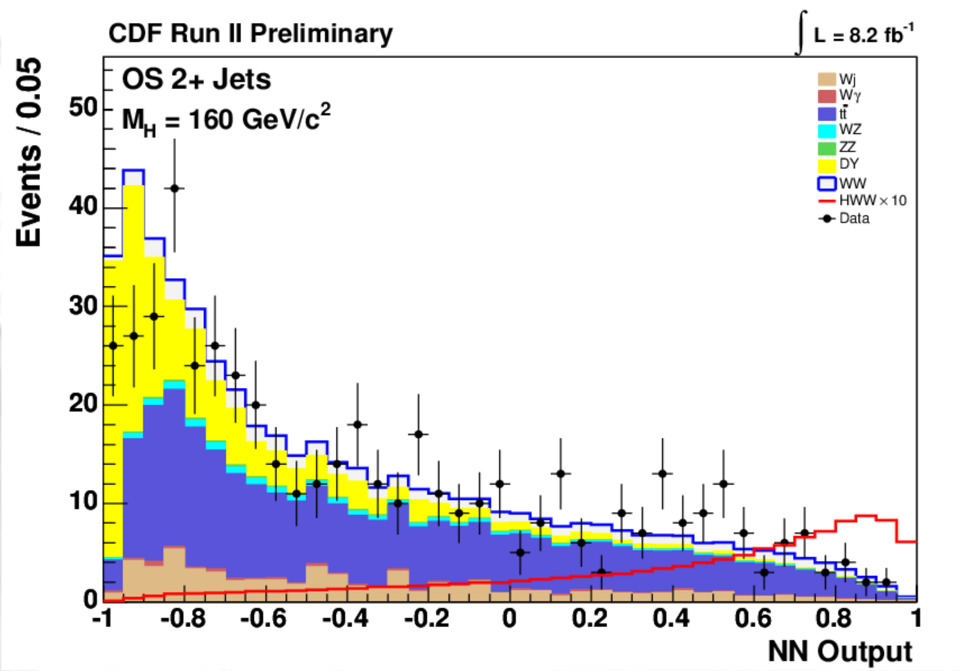
Systematic Uncertainties

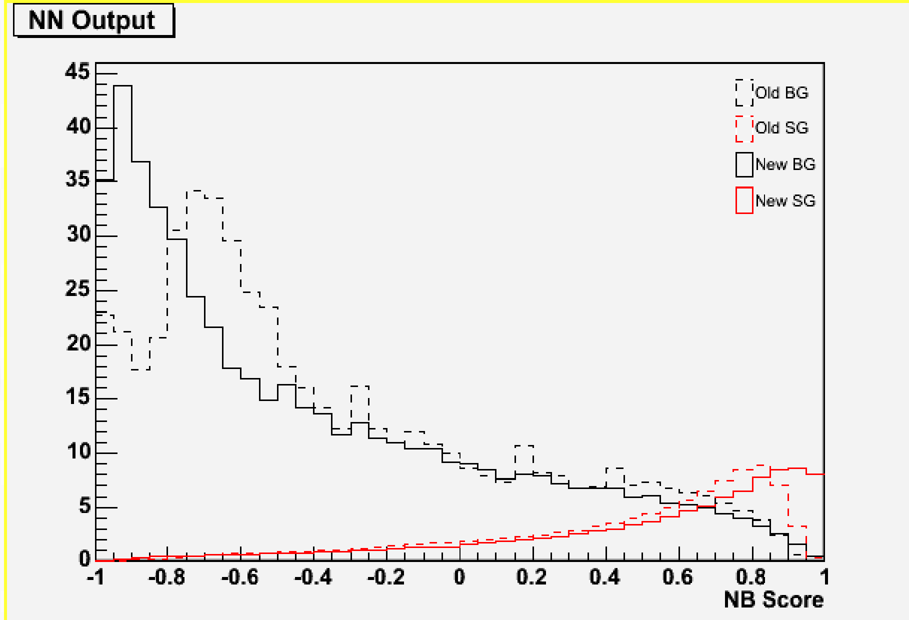
Uncertainty Source	WW	WZ	ZZ	tt	DY	$W\gamma$	W+jet
Cross Section							
Total	*6.0%*	*6.0%*	*6.0%*	10.0%			
Acceptance							
Scale (jets)	-8.2%						
PDF Model (jets)	4.2%						
Higher-order Diagrams		*10.0%*	*10.0%*	10.0%		10.0%	
Jet Energy Scale	*-14.8%*	*-12.9%*	*-12.1%*	*-1.7%*	*-29.2%*	*-22.0%*	
$W\gamma$ Modeling						10.0%	
b-tag Veto				3.2%			
Jet Fake Rates							28.0%
Luminosity	*7.3%*	*7.3%*	*7.3%*	*7.3%*	*7.3%*		

Uncertainty Source	$gg \to H$	WH	ZH	VBF
Cross Section				
Scale	67.5%			
PDF Model	29.7%			
Total		*5.0%*	*5.0%*	10.0%
Acceptance				
Scale (leptons)	3.1%			
Scale (jets)	-6.8%			
PDF Model (leptons)	4.8%			
PDF Model (jets)	-12.3%			
EWK Higher-order Diagrams		*10.0%*	*10.0%*	*10.0%*
Jet Energy Scale	*-17.0%*	*-4.0%*	*-2.3%*	*-4.0%*
Luminosity	*7.3%*	*7.3%*	*7.3%*	*7.3%*

- Because ggH and WW are the main signal and background for combined analysis, they are treated more carefully
- Cross Section: Theoretical uncertainties
- Acceptance: Luminosity, higher order effects, trigger and lepton ID efficiencies

Results: HWW





New Monte Carlo samples and the use of jet kinematics in our discriminant results in an 18% improvement on previous analysis

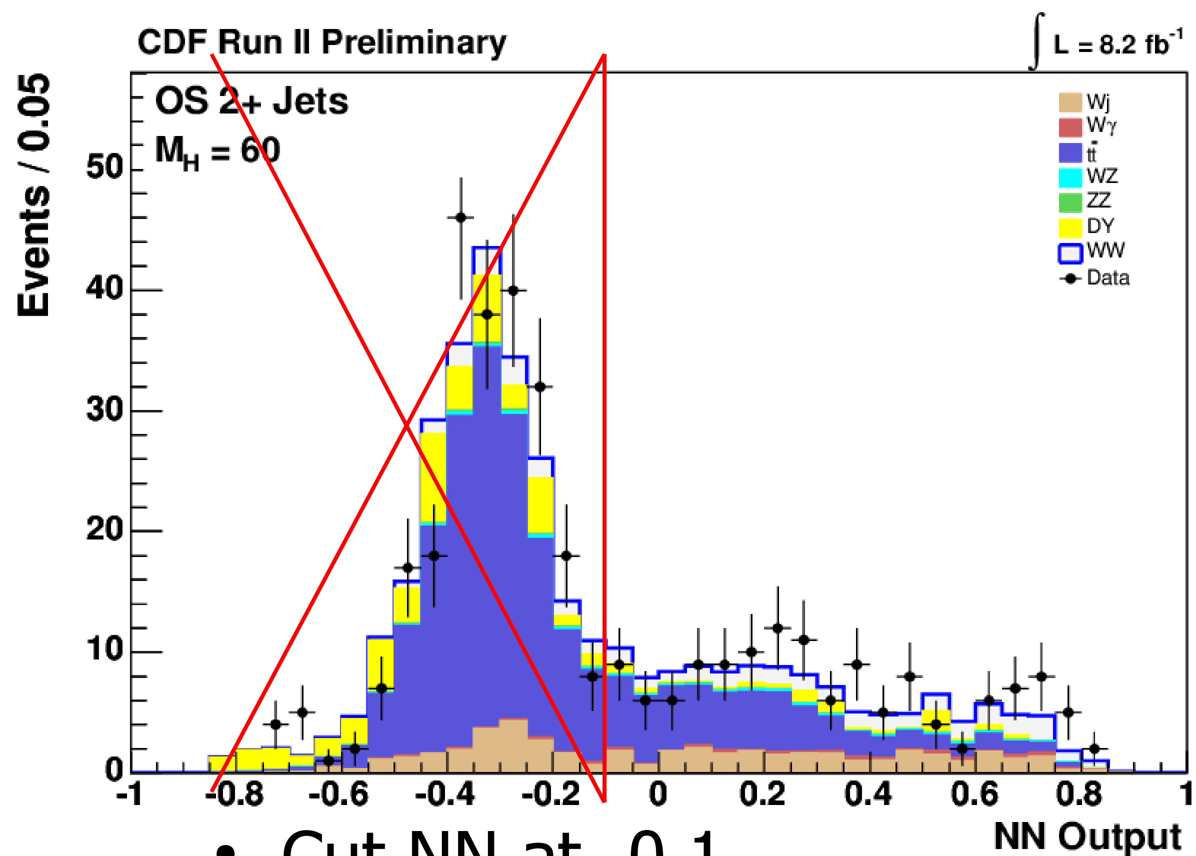
Previous:

-2 Sigma	1.41
-1 Sigma	1.86
Median	2.66
+1 Sigma	3.80
+2 Sigma	5.51

Current:

-2 Sigma	1.17
-1 Sigma	1.56
Median	2.18
+1 Sigma	3.18
+2 Sigma	4.30

Results: WW



W+jets	25.65
Wγ	3.46
ttbar	53.56
WZ	2.96
ZZ	0.83
DY	7.98
Background	94.44
WW	24.07
WW/Total	20.31%

- Cut NN at -0.1
- 24 WW events, 20% WW purity
- Already sufficient for a WW cross section measurement in the 2+jets bin

Conclusions and Next Steps

- Significant improvement to H->WW is possible
- 2.18 times SM cross section is an 18% improvement on previous analysis
- WW cross section measurement is feasible with current WW enhanced region

Future Work:

- Higgs
  - Optimize for low mass
  - Improve top separation using multivariate btagger
  - Extend to 9.97 fb^-1
- WW cross section
  - Improve top separation using multivariate btagger
  - Compare to differential cross section predictions from multiple generators

Backup

Electron Detection and Identification

- Two Categories

	TCE
Region	central
Fiducial	track fiducial to CES
Track p_T	$\geq 10\ (5 if E_T < 20)$
Track $\lvert z_0 \rvert$	≤ 60 cm
# Ax SL (5hits)	≥ 3
# St SL (5hits)	≥ 2
Conversion	$\neq 1$
E_{HAD}/E_{EM}	$\leq 0.055 + 0.00045 * E$
Iso/E_T	≤ 0.1
Lshr	≤ 0.2
E/P	$< 2.5 + 0.015 * E_T$
signed CES ΔX	$-3 \leq q * \Delta X \leq 1.5$ cm
CES $\lvert \Delta Z \rvert$	< 3 cm
Track	Beam constrained

Or a likelihood discriminant using many of the same variables

	PHX/PEM
Region	Plug
Pes2DEta	$1.2 < \lvert\eta\rvert < 2$ (2.8 PEM)
Had/Em	<= 0.05
PEM3x3FitTower	true
$PEM3x3\chi^2$	<= 10
Pes5x9U	>= 0.65
Pes5x9V	>= 0.65
Iso/Et	<= 0.1
ΔR(Pes,PEM)	<= 3.0
PHX only	
Track Match	True
NSiHits	>= 3
Track $\lvert Z0 \rvert$	<= $60cm$
PEM	Not above PHX track requirements

Only use PHX

Stubbed Muons

Four categories of stubbed muons: CMUP, CMU, CMP, CMX

	CMUP/CMX
CMU Fid	x-fid< 0 cm z-fid< 0cm
CMP Fid	x-fid< 0 cm z-fid<-3cm
CMX Fid	x-fid< 0 cm z-fid<-3cm
E_{em}	$<= 2 + max(0, (p - 100) * 0.0115)$
E_{had}	$<= 6 + max(0, (p - 100) * 0.028)$
Iso/Pt	$<= 0.1$
NAxL(5 hits)	$>= 3$
NStL(5 hits)	$>= 2$
Track $\|Z_0\|$	$<= 60cm$
Track $\|D_0\|$	$<= 0.2cm$ (0.02cm if NSiHit> 0)
χ^2/dof	$<= 4$ (3 if run <= 186598)
$\|\Delta X_{CMU}\|$	$<= 7cm$
$\|\Delta X_{CMP}\|$	$<= 5cm$
$\|\Delta X_{CMX}\|$	$<= 6cm$
ρ_{exit}	> 140 cm if CMX
CMP veto	No Bluebeam in CMP for run < 154449
CMX veto	No CMX for run < 150144, No Miniskirt, No Keystone
Arches	Arches only for all run range
	Arches removing wedge 14 on West Side for run > 190697
Tracks	BcTrk (Larry's Correction if Data)

A CMP(CMU) muon should not be fiducial to the CMU(CMP or CMX)

Stubbless Muons

Minimum ionizing track pointing to CES/PES

	CMIOCES/CMIOPES
E_{em}	$<= 2 + max(0, (p - 100) * 0.0115)$
E_{had}	$<= 6 + max(0, (p - 100) * 0.028)$
Iso/Pt	$<= 0.1$
Uniqueness	Not a CMUP or CMX muon
Track $\|Z_0\|$	$<= 60cm$
Track $\|D_0\|$	$<= 0.2cm$ (0.02cm if NSiHit> 0)
$E_{em} + E_{had}$	$> 0.1GeV$
Central	Track CES Fiducial
NAxL(5 hits)	$>= 3$
NStL(5 hits)	$>= 3$
χ^2/dof	$<= 3$
	BcTrk (Larry Correction if Data)
Forward	Track PES Fiducial
Cot Hit Fraction	> 0.6
	No beam constriant on IO tracks

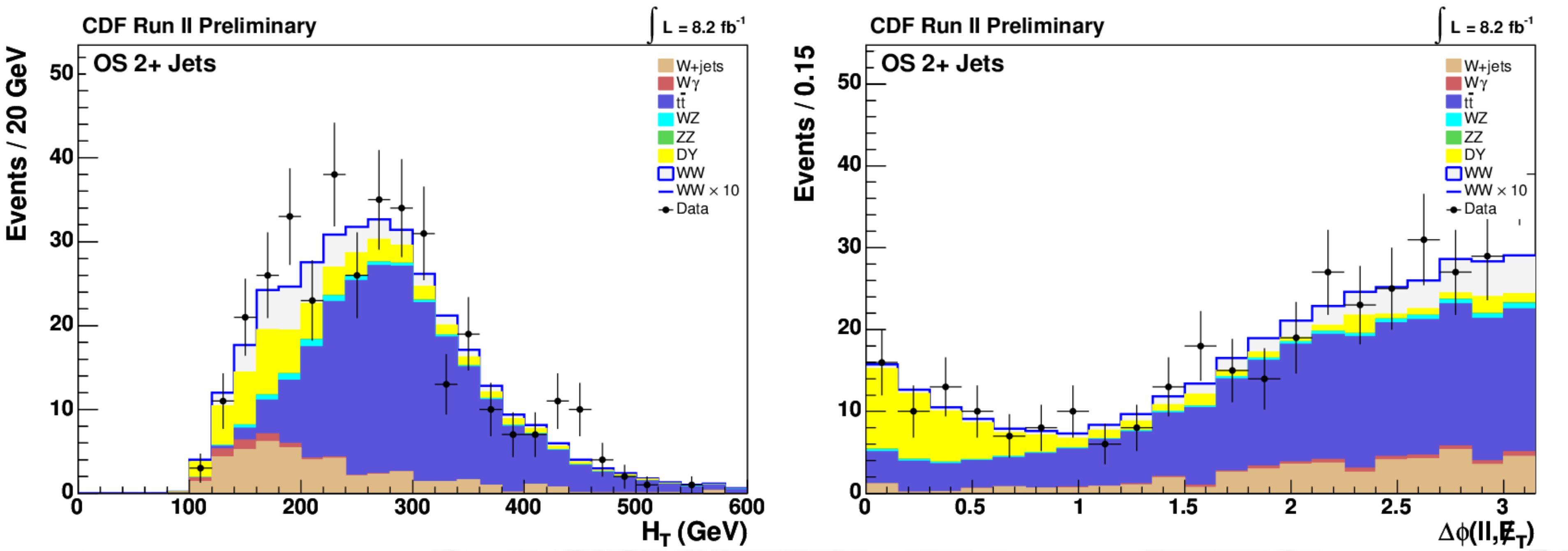
Other Leptons

- CMXMsKs: Same as CMX muon, but in the Miniskirt or Keystone detectors
  - $75^\circ < \Phi < 105^\circ$ (for $|\eta| <$? (Note says 0)), $225^\circ < \Phi < 315^\circ$
- BMU: Same as CMIOPES muon, but with a stub in one of the IMU detectors
- CrkTrk: Similar to CMIOCES, but no minimum ionizing calorimeter or CES fiduciality requirements

	CrkTrk
Iso/Pt	$<= 0.1$ using CDF Muon *or*
	$<= 0.1$ using nearest CDF EMObj with $\Delta R < 0.05$
Track $\|Z_0\|$	$<= 60cm$
Track $\|D_0\|$	$<= 0.2cm$ (0.02cm if NSiHit$>$ 0)
χ^2/dof	$<= 3$
NAxL(5 hits)	$>= 3$
NStL(5 hits)	$>= 3$
Uniqueness	Not a CMUP or CMX muon
Is in Crack	Not Track CES or PES Fiducial
Conversion	$! = 1$
	BcTrk (Larry Correction if Data)

WW Neural Net Variables

- Using the WW enhanced region discussed above
- Presenting neural net variables with correlation > 1%



WW Neural Net Variables (2)