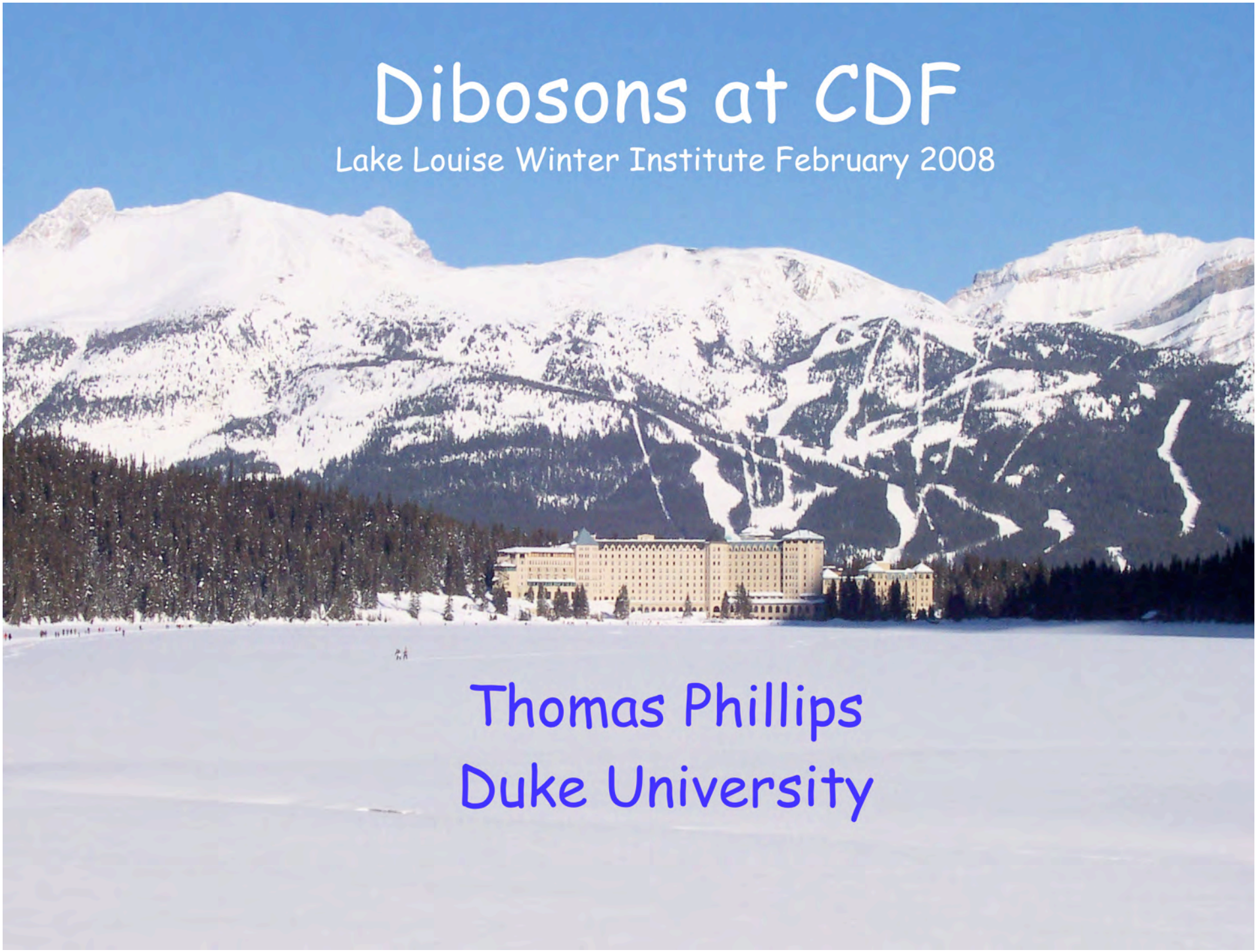
Dibosons at CDF

Lake Louise Winter Institute February 2008

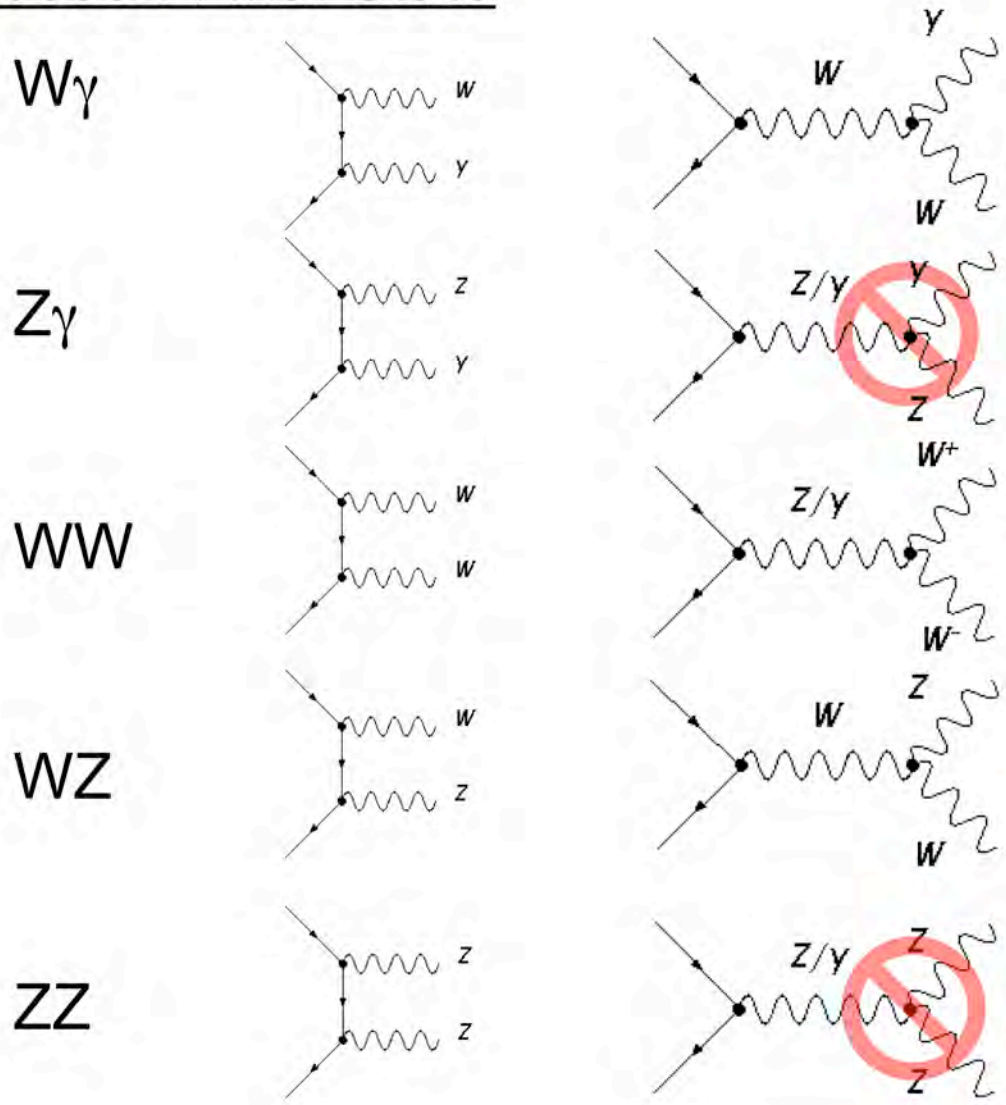


Thomas Phillips

Duke University

Standard Model Dibosons

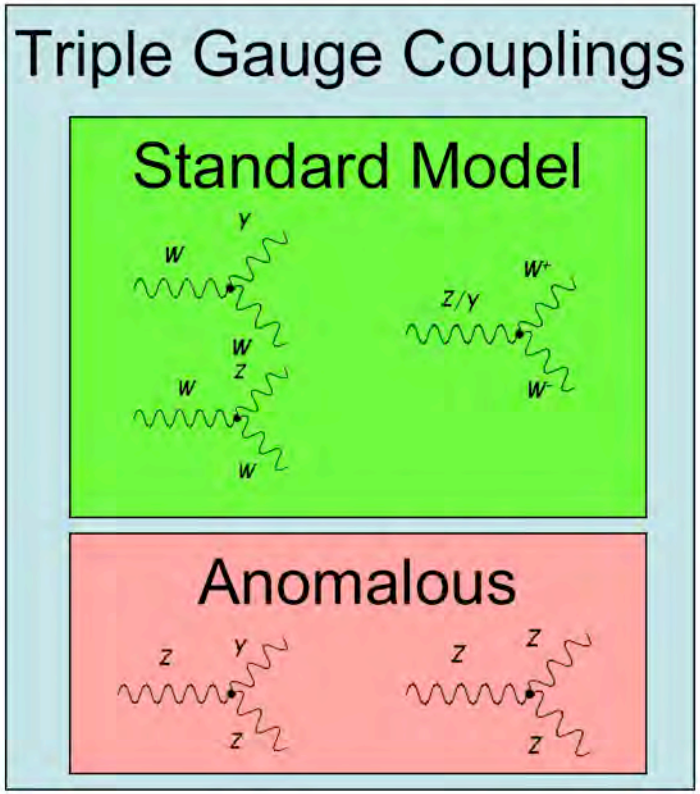
Diboson Final State



SM Tests:

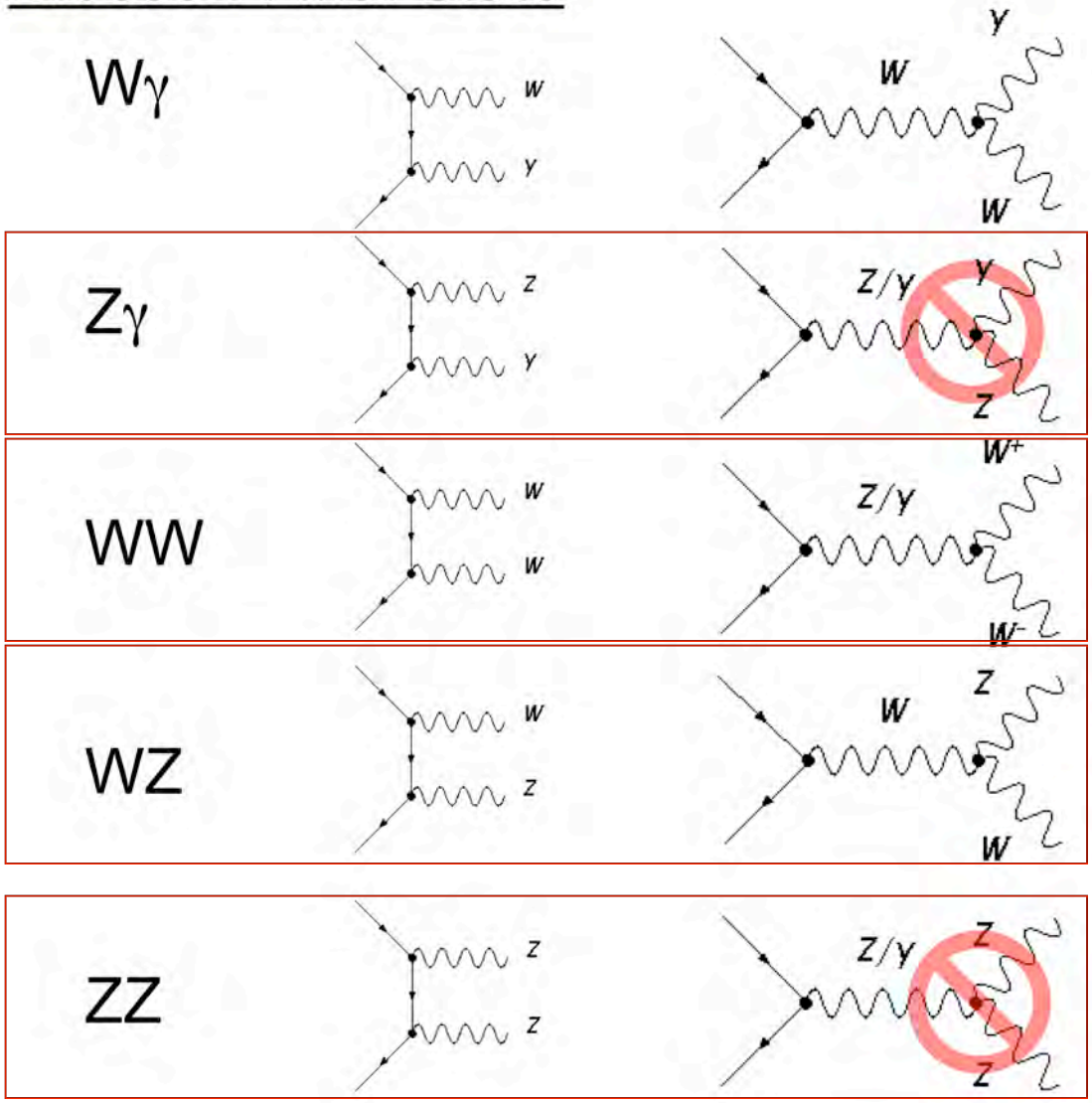
1) Test SM production predictions
2) Look for "anomalous couplings"

Cross sections similar to Higgs



Standard Model Dibosons

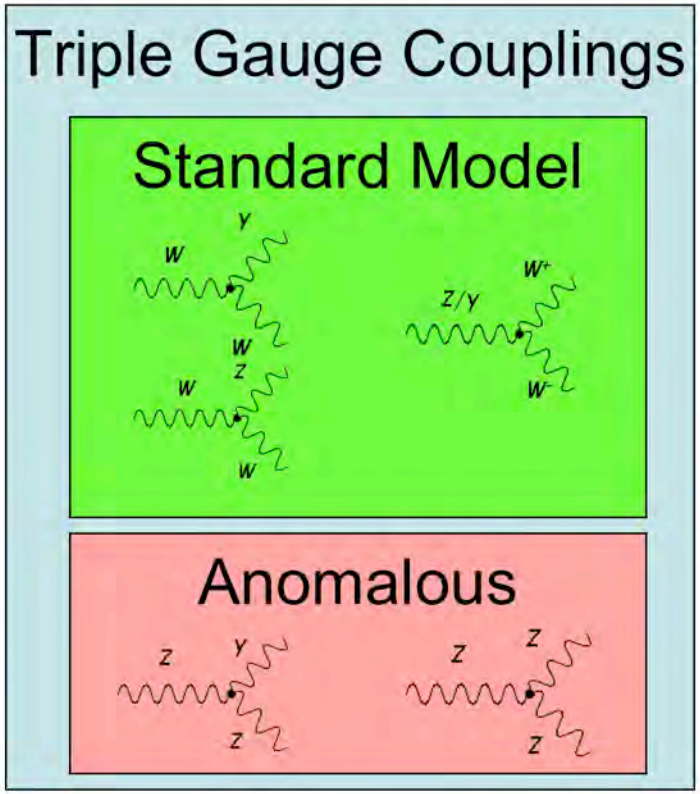
Diboson Final State



SM Tests:

1) Test SM production predictions
2) Look for "anomalous couplings"

Cross sections similar to Higgs

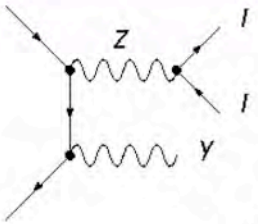


Zγ Production

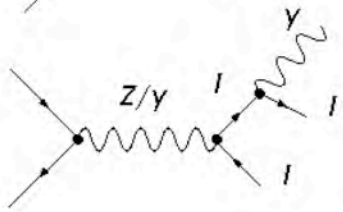
- Search for Z γ with Z->e^+e^- or Z->$\mu^+\mu^-$
- SM Z γ production:
  - ➔Initial-state radiation (ISR)
  - ➔Final-state radiation (FSR)
- No direct Z-γ coupling in Standard Model

Z Selection:
lepton E_T> 20 GeV
1st leg $|\eta|$< 1 2nd leg $|\eta_{track}|$< 1.2 $|\eta_{elec}|$<2.8
M_{ll} > 40 GeV/c^2

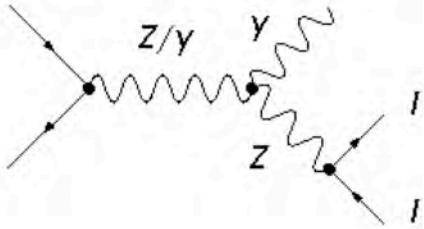
γ Selection:
E_T > 7 GeV
$|\eta_\gamma|$ < 1
$\Delta R_{l\gamma}$> 0.7



ISR (M_{ll}~M_Z)

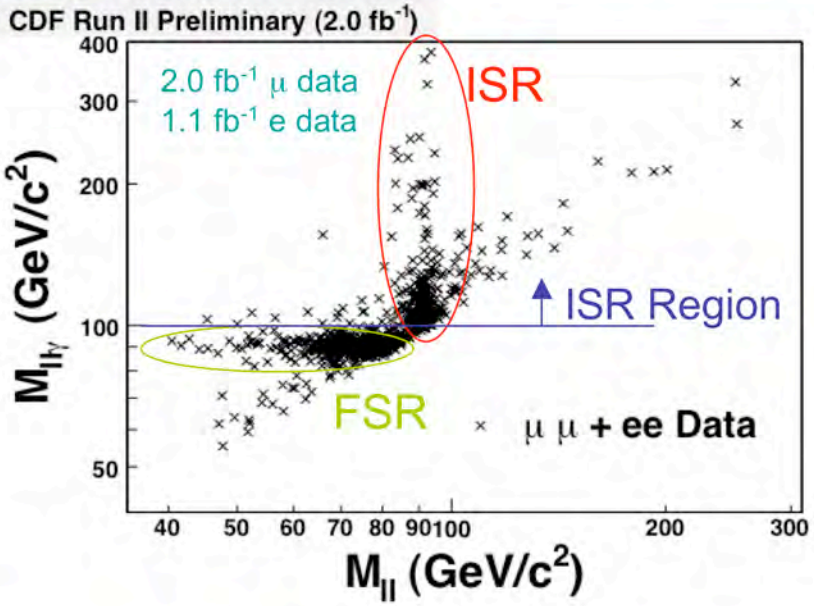


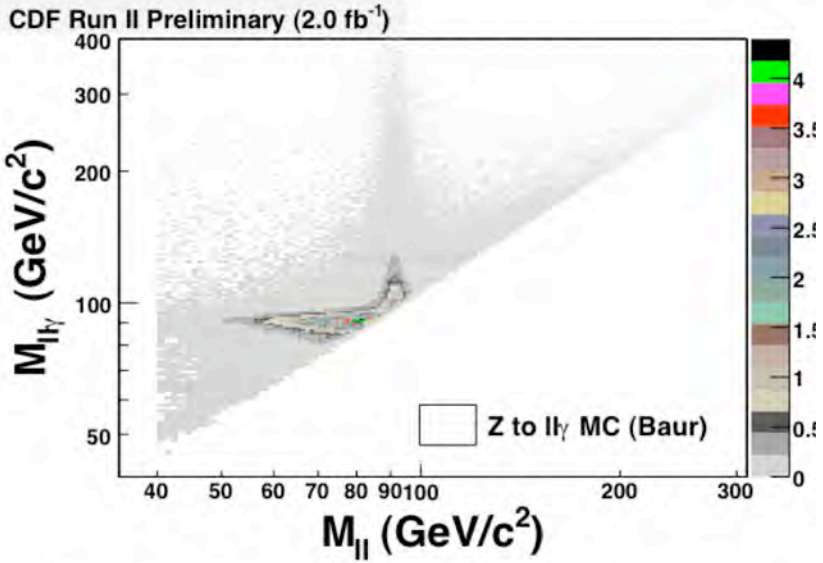
FSR ($M_{ll\gamma}$~M_Z)



Anomalous Coupling (M_{ll}~M_Z)

Zγ Cross Section





Cross section

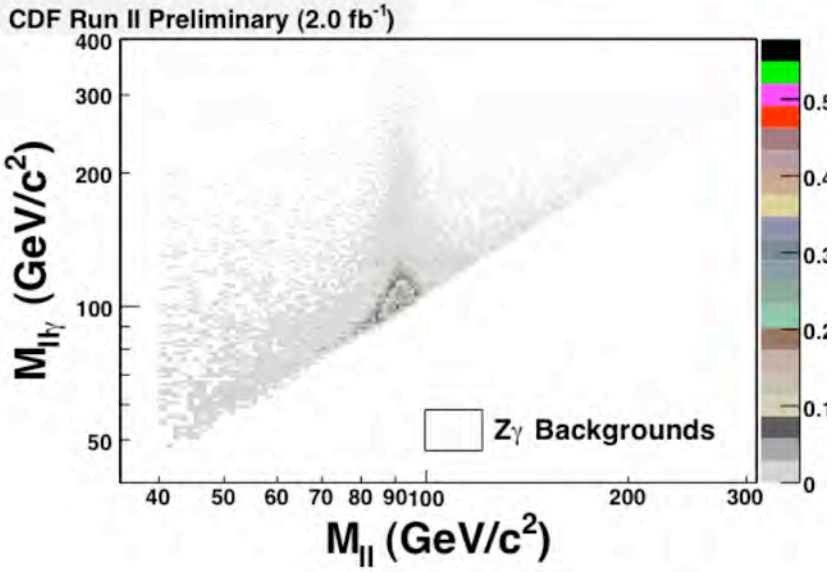
σ_{obs} = 4.6 ±0.2(stat) ±0.2(syst) ±0.3(lum) pb

σ_{NLO} = 4.5 ± 0.3 pb

σ_{obs} (ISR)= 1.20 ±0.10 ±0.17 ±0.07 pb

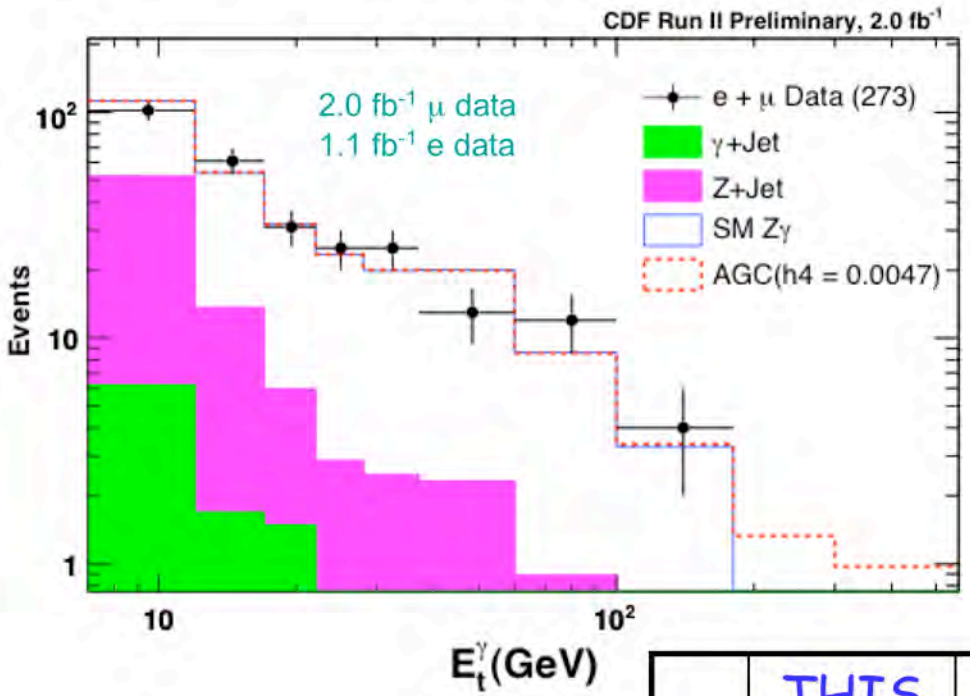
Dominant systematic uncertainties:

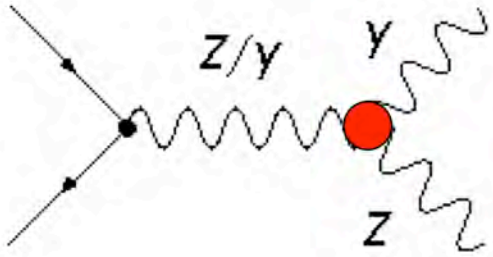
- photon background
- photon MC scale factor
- photon energy scale and conversion rate



Neutral Triple Gauge Couplings

Neutral Triple Gauge Couplings are all 0 at tree level in Standard Model





h_3^Z h_3^γ

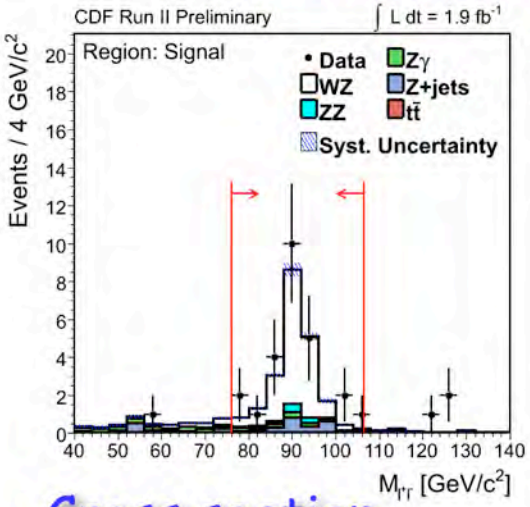
h_4^Z h_4^γ

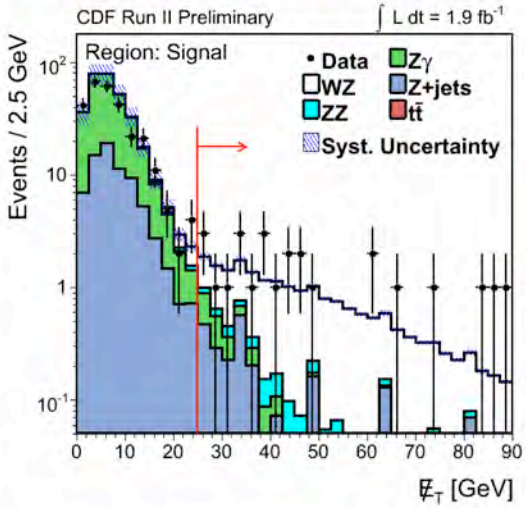
Parameterization from G.J. Gounaris *et al.* PRD 62, 073012.

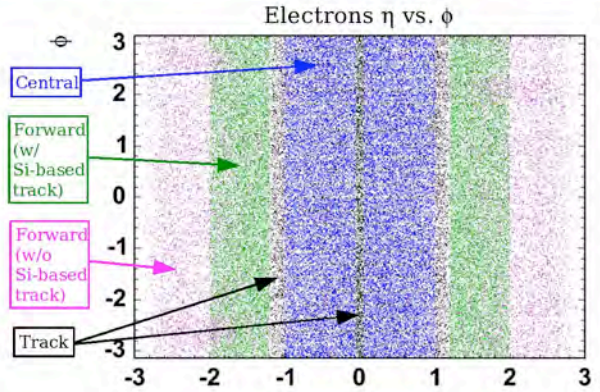
	THIS	CDF RunI	LEP II	DO 1.1fb^{-1}
h_3^Z	**±0.083**	-3.0, 2.9	-0.2, 0.07	-0.083, 0.082
h_4^Z	**±0.0047**	±0.7	-0.05, 0.12	-0.0053, 0.0054
h_3^γ	**±0.084**	±3.1	-0.049,0.008	-0.085, 0.084
h_4^γ	**±0.0047**	±0.8	-0.02, 0.034	-0.0053, 0.0054

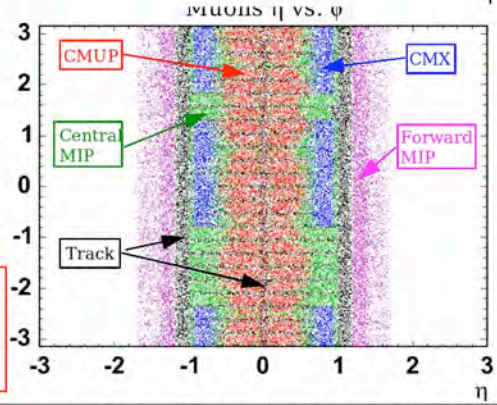
WZ Production Observation

- Search for WZ with leptonic decays for both W and Z
  - ➔small BR, so need large acceptance
  - ➔backgrounds
    - remove as possible with kinematic cuts
    - understand the remainder









This is a 6σ observation

Source	Expected ± Stat ± Syst ± Lumi
Z+jets	$2.45 \pm 0.48 \pm 0.48 \pm 0.00$
ZZ	$1.53 \pm 0.01 \pm 0.16 \pm 0.09$
$Z\gamma$	$1.03 \pm 0.06 \pm 0.35 \pm 0.06$
$t\bar{t}$	$0.17 \pm 0.01 \pm 0.03 \pm 0.01$
WZ	$16.45 \pm 0.03 \pm 1.74 \pm 0.99$
Total	$21.63 \pm 0.48 \pm 2.25 \pm 1.15$
Observed	**25**

Cross section

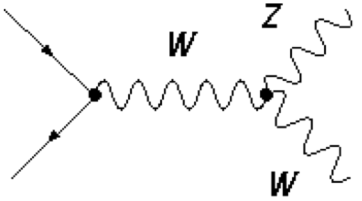
$\sigma = 4.3\ ^{+1.3}_{-1.0}(\text{stat}) \pm 0.2(\text{syst}) \pm 0.3(\text{lum})$ pb

$\sigma_{NLO} = 3.7 \pm 0.3$ pb

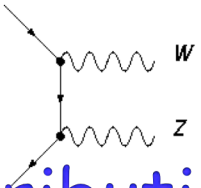
WZ Couplings

- Use Z P_T of WZ events to test WWZ coupling
  - ➔Parameterize WWZ coupling $\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{aTGC}$

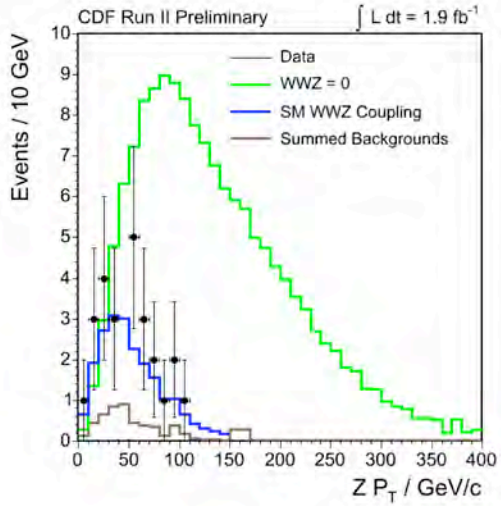
$$\mathcal{L}_{aTGC}/ig_{WWZ} = \Delta g(W^*_{\mu\nu}W^{\mu}Z^{\nu}W_{\mu\nu}W^{*\mu}Z^{\nu}) + \Delta\kappa W^*_{\mu}W_{\nu}Z^{\mu\nu} + \frac{\lambda}{M_W^2}W^*_{\rho\mu}W^{\mu}_{\nu}Z^{\nu\rho}$$

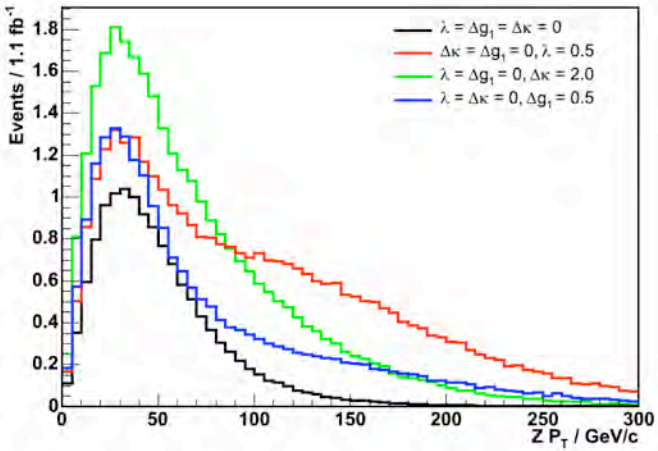


  - ➔$\Delta g = \Delta\kappa = \lambda = 0$ in the Standard Model



- Would see $\mathcal{L}_{SM}$=0 in cross section
- Anomalous coupling limits from Z P_T distribution



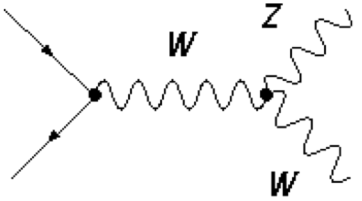


CDF
-0.13< λ <0.14
-0.15<Δg<0.24
-0.82<$\Delta\kappa$<1.27

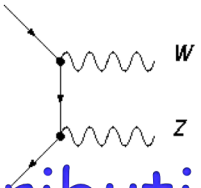
WZ Couplings

- Use Z P_T of WZ events to test WWZ coupling
  - ➔Parameterize WWZ coupling $\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{aTGC}$

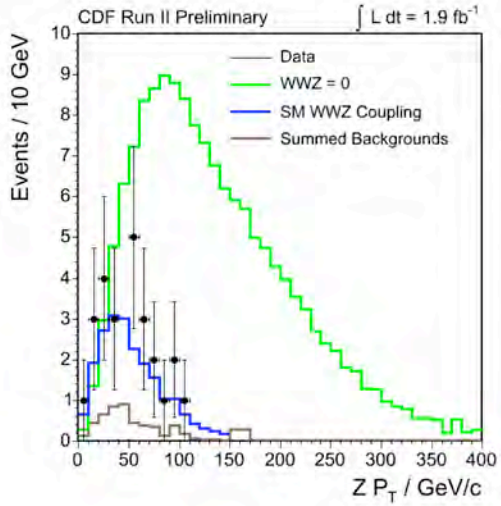
$$\mathcal{L}_{aTGC}/ig_{WWZ} = \Delta g(W^*_{\mu\nu}W^{\mu}Z^{\nu}W_{\mu\nu}W^{*\mu}Z^{\nu}) + \Delta\kappa W^*_{\mu}W_{\nu}Z^{\mu\nu} + \frac{\lambda}{M_W^2}W^*_{\rho\mu}W^{\mu}_{\nu}Z^{\nu\rho}$$

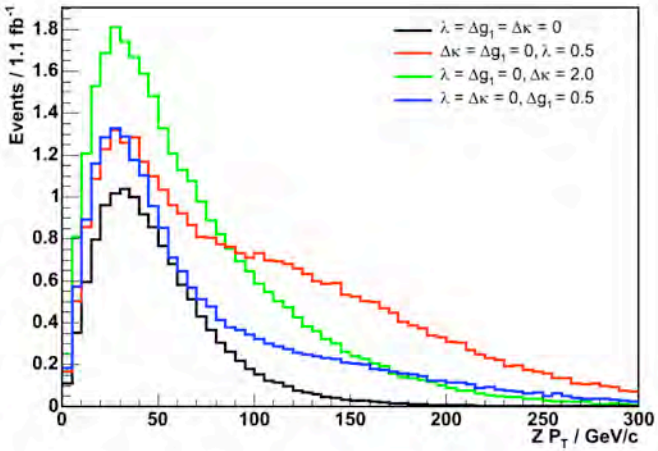


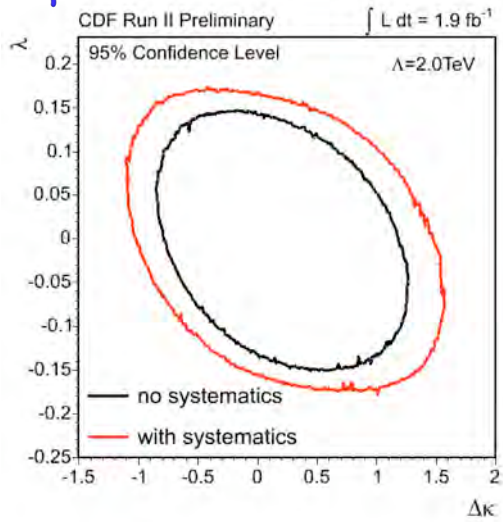
  - ➔$\Delta g = \Delta\kappa = \lambda = 0$ in the Standard Model



- Would see $\mathcal{L}_{SM}$=0 in cross section
- Anomalous coupling limits from Z P_T distribution







WW & WZ -> lν + jets

Search for lν + 2 or more jets

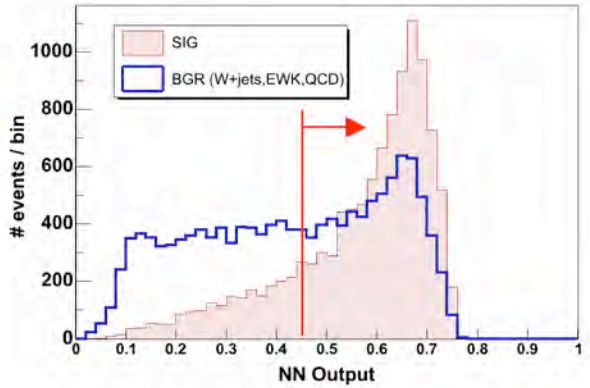
E_T > 20 GeV ME_T > 25 GeV M_T > 30 GeV/c^2

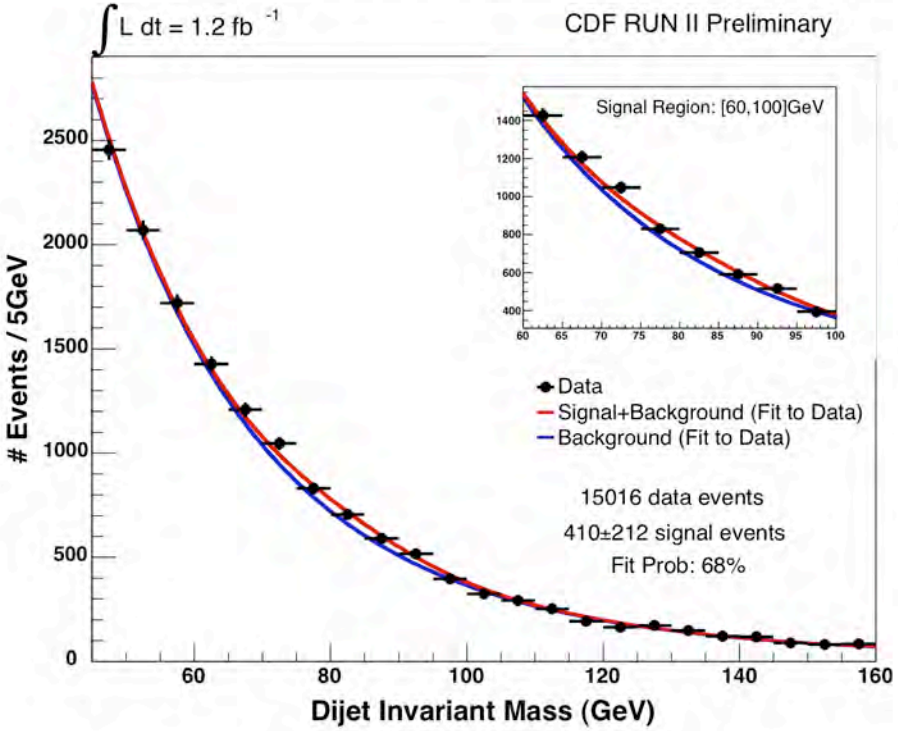
Use neural net to enhance W/Z->2 jets

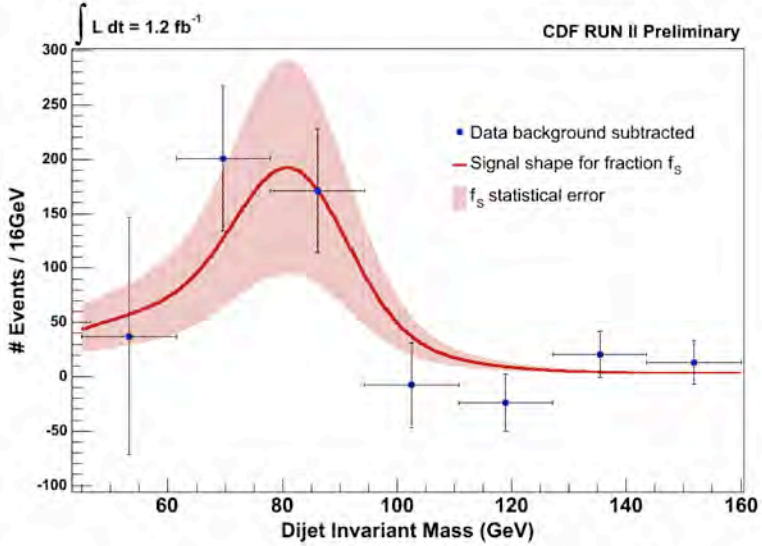
Parameterize and fit for signal & bkg

Theory: $\sigma_{WW} \times Br(W \rightarrow l\nu, W \rightarrow jj) = 1.81$ pb

$\sigma_{WZ} \times Br(W \rightarrow l\nu, Z \rightarrow jj) = 0.28$ pb







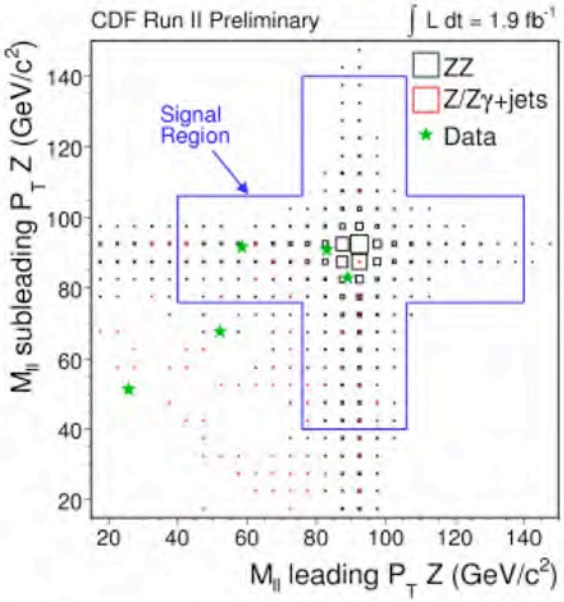
N_{Signal} = 410 ± 212(stat) ± 107(sys)

σ × Br = 1.47 ± 0.77(stat) ± 0.38(sys) pb

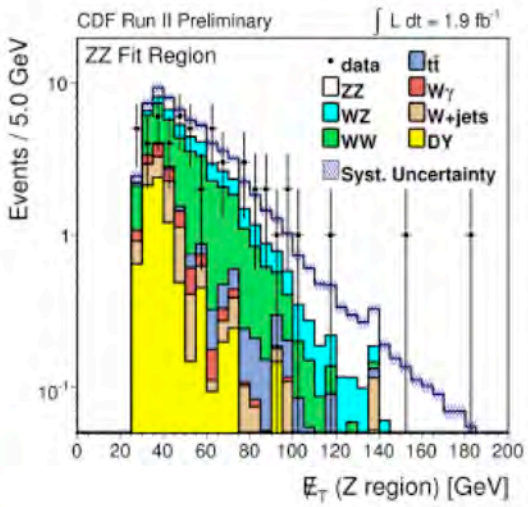
σ × Br < 2.88 pb (95% C.L.)

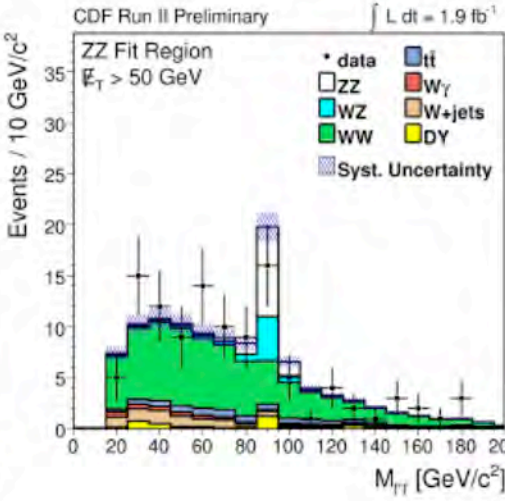
ZZ Production

- $\sigma_{SM}(p\bar{p}\text{->}ZZ) = 1.4\pm0.1$ pb
- Search for 4 leptons or 2 leptons + 2 ν
  - ➔4 leptons (eeee, ee$\mu\mu$, $\mu\mu\mu\mu$)
    - clean, but small branching fraction
    - increase acceptance wherever possible
  - ➔ll$\nu\nu$
    - many backgrounds
      - WW->ll$\nu\nu$
    - use as much kinematic information as possible
      - use matrix elements



3 events in signal box

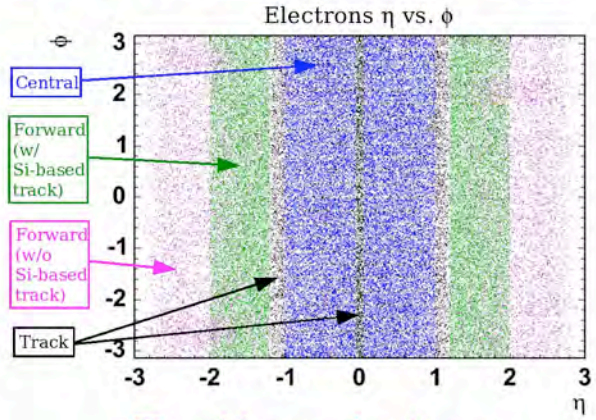




First Measurement of ZZ Cross Section

ZZ->llll

Category	Candidates without a a trackless electron	Candidates with a a trackless electron
ZZ	$1.990 \pm 0.013 \pm 0.210$	$0.278 \pm 0.005 \pm 0.029$
Z+jets/$Z\gamma$+jets	$0.014^{+0.010}_{-0.007} \pm 0.003$	$0.082^{+0.089}_{-0.060} \pm 0.016$
Total	$2.004^{+0.016}_{-0.015} \pm 0.210$	$0.360^{+0.089}_{-0.060} \pm 0.033$
Observed	**2**	**1**



Trackless electrons are forward only

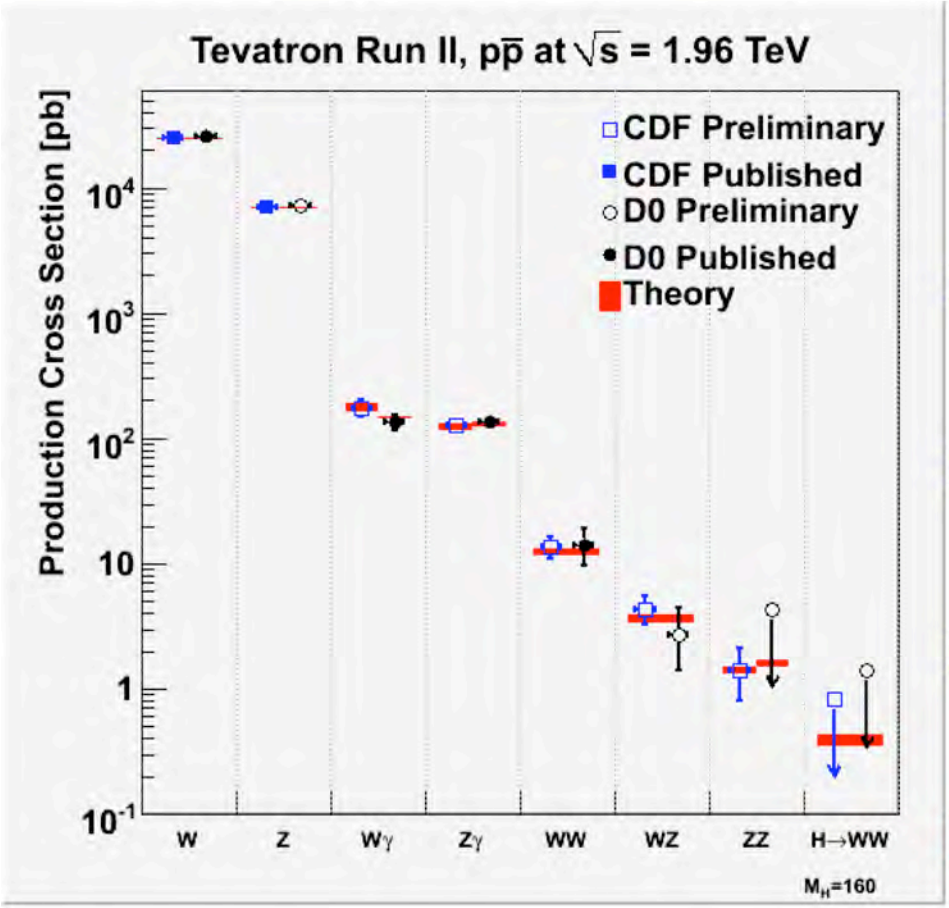
Combined Results:

	$ll\nu\nu$	4 lepton	Combined
P-Value	0.12	1.1×10^{-5}	5.1×10^{-6}
Significance	$1.2\,\sigma$	$4.2\,\sigma$	$4.4\,\sigma$

$1.4^{+0.7}_{-0.6}(stat. + syst.)$ pb (NLO prediction is 1.4 pb)

First measurement of the ZZ cross section at a hadron collider.

Summary



- Zγ cross section
  - σ_{obs} = 4.6 ±0.2(stat) ±0.2(syst) ±0.3(lum) pb
  - (σ_{NLO} = 4.5 ± 0.3 pb)
- Neutral Anomalous Coupling limits
  - $|h_3^Z| < 0.083$ $|h_4^Z| < 0.0047$
  - $|h_3^\gamma| < 0.084$ $|h_4^\gamma| < 0.0047$
- WZ cross section
  - $\sigma = 4.3\ ^{+1.3}_{-1.0}$(stat) ±0.2(syst) ±0.3(lum) pb
  - (σ_{NLO} = 3.7 ± 0.3 pb) hep-ex/0702027
- WWZ Anomalous Coupling limits
  - $-0.13 < \lambda < 0.14$ $-0.15 < \Delta g < 0.24$
  - $-0.82 < \Delta\kappa < 1.27$
- ZZ cross section (4.4 σ ZZ signal)
  - $\sigma = 1.4\ ^{+0.7}_{-0.6}$(stat+syst) pb
  - (σ_{NLO} = 1.4 ± 0.1 pb) hep-ex/0801.4806

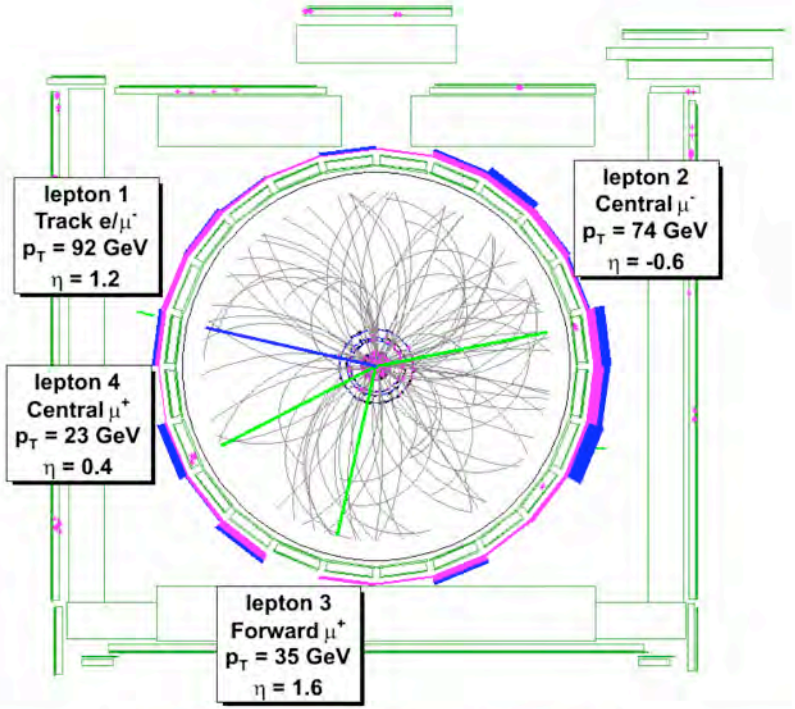
Diboson production is well described by the Standard Model!

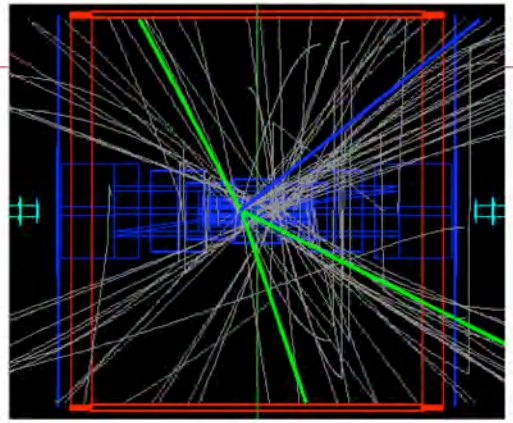
- Now seeing processes with cross sections similar to Higgs!

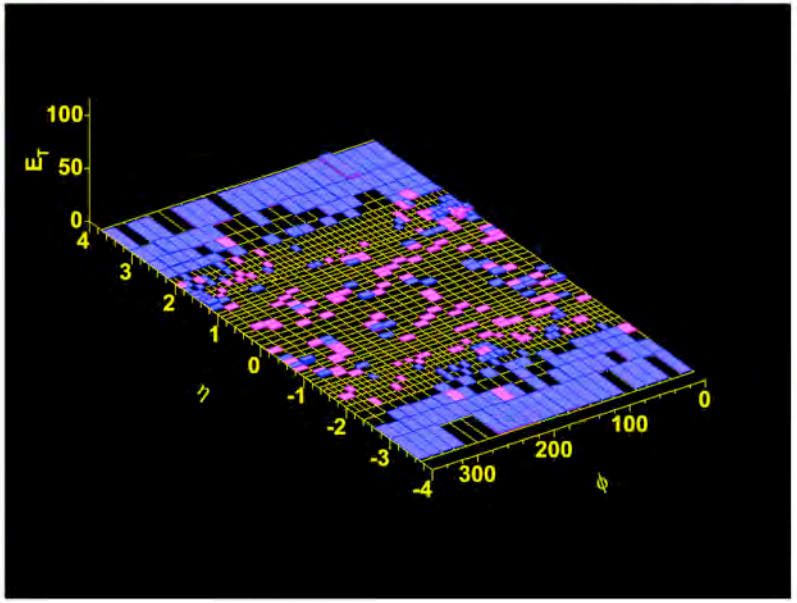
Backup

MY COMPUTER DOESN'T WORK! THE HARD DRIVE CRASHED! WHAT DO I DO?!
DID YOU BACK UP?
WHY? IS IT GONNA BLOW?!
STEINFELD ©96

ZZ to 4 muon candidate





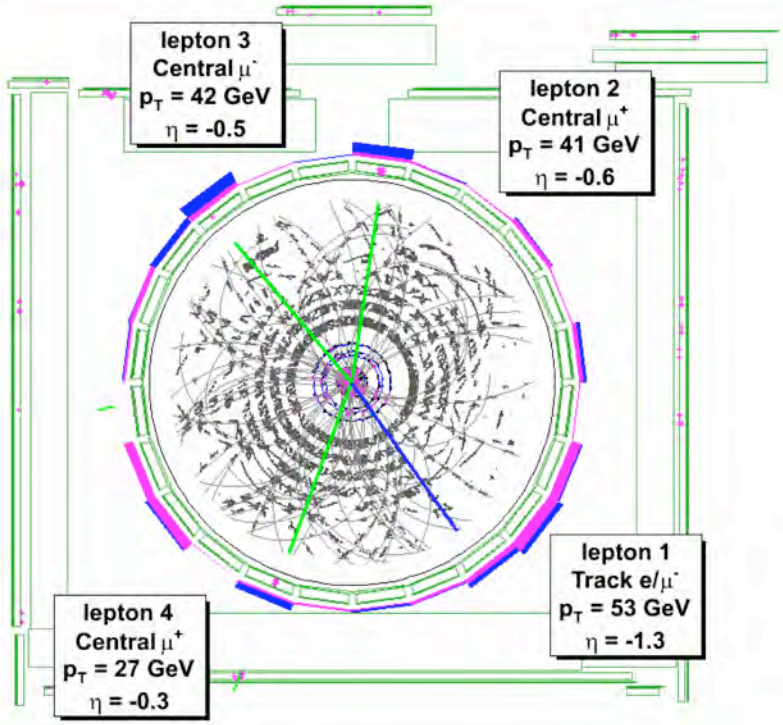


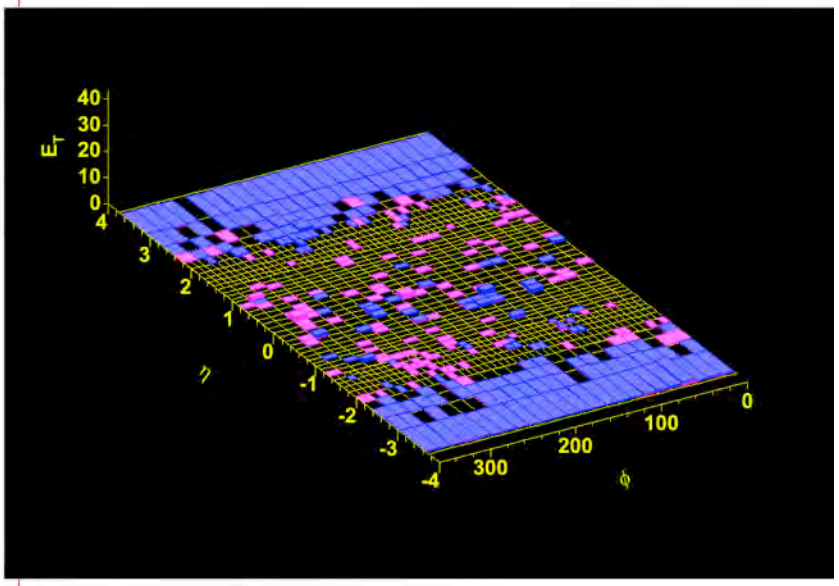
Run=211311 Event=233113

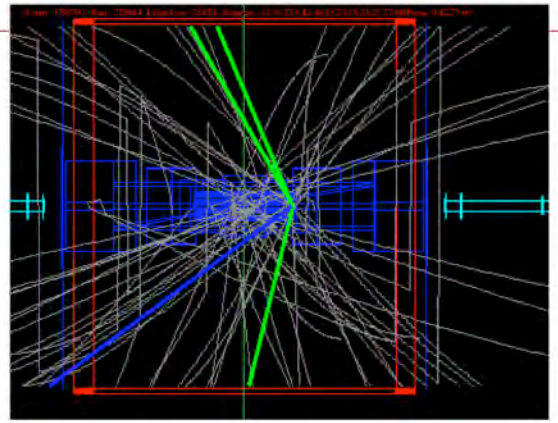
m_{ll1}=90.94 GeV $|\not\!\!E_T|$=9.5 GeV
m_{ll2}=82.20 GeV $N_{jets} = 0$
M_{lll}=311.9 GeV/c^2

Type	p_t	η	ϕ
CrkTrk	92.1	1.2	2.9
CMIOCES	74.2	-0.6	0.2
CMIOPES	33.6	1.6	-1.8
CMUP	22.5	0.4	-2.7

ZZ to 4 muon candidate





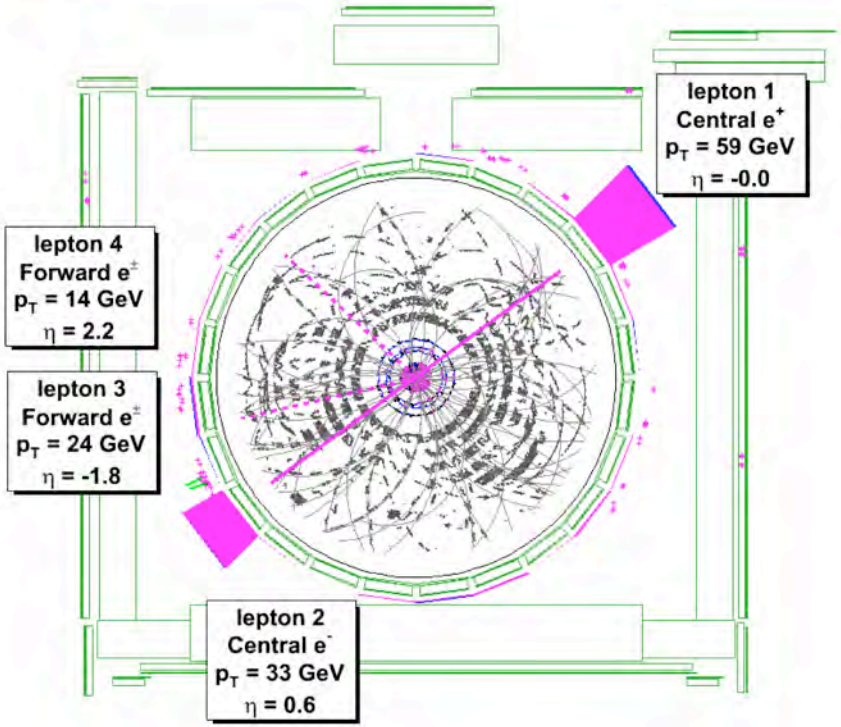


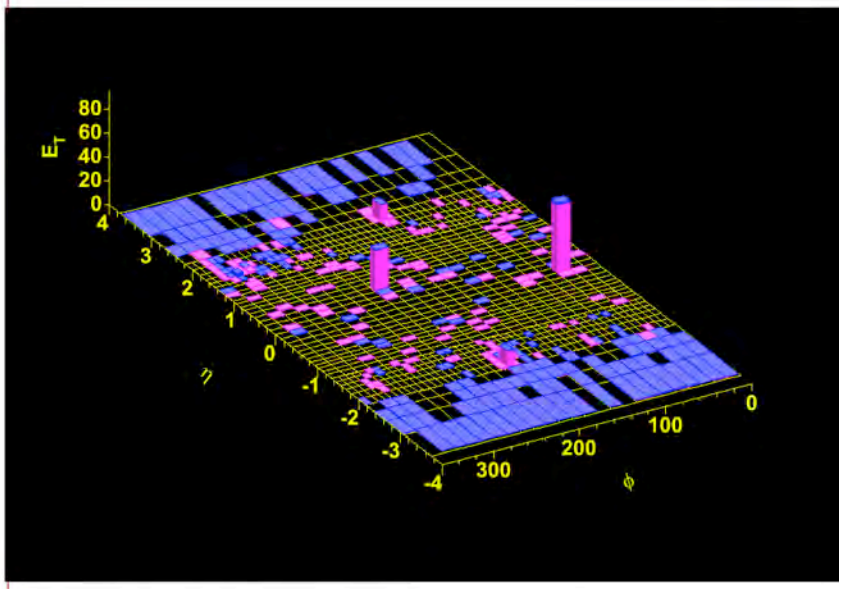
Run=229084 Event=1785583

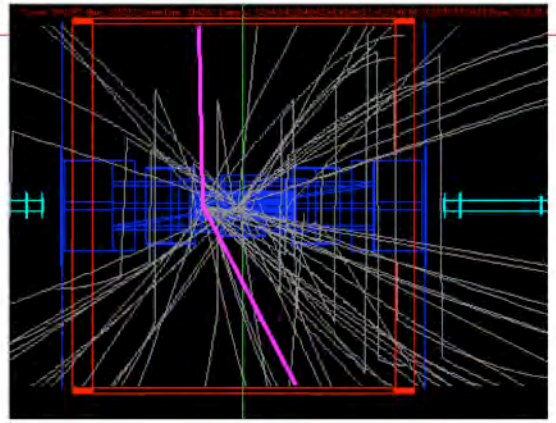
m_{ll1}=91.53 GeV $\quad |\not\!\!E_T|$=0.8 GeV
m_{ll2}=58.94 GeV $\quad N_{jets} = 0$
M_{lll}=174.5 GeV/c^2

Type	p_t	η	ϕ
Track e/μ	52.5	-1.3	-1.0
Central μ	41.2	-0.6	1.4
Central μ	41.5	-0.5	2.3
Central μ	27.3	-0.3	-1.9

ZZ to 4 electron candidate





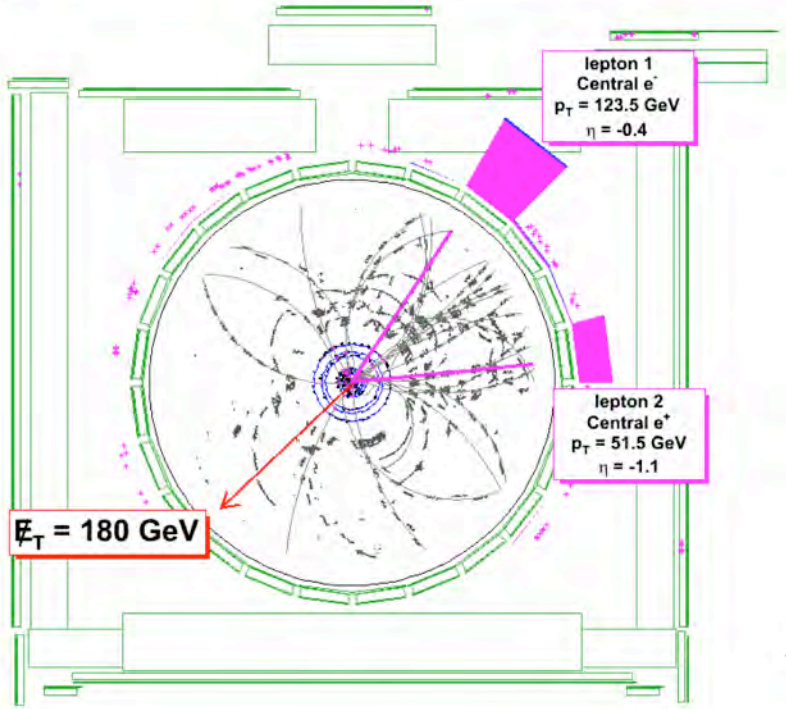


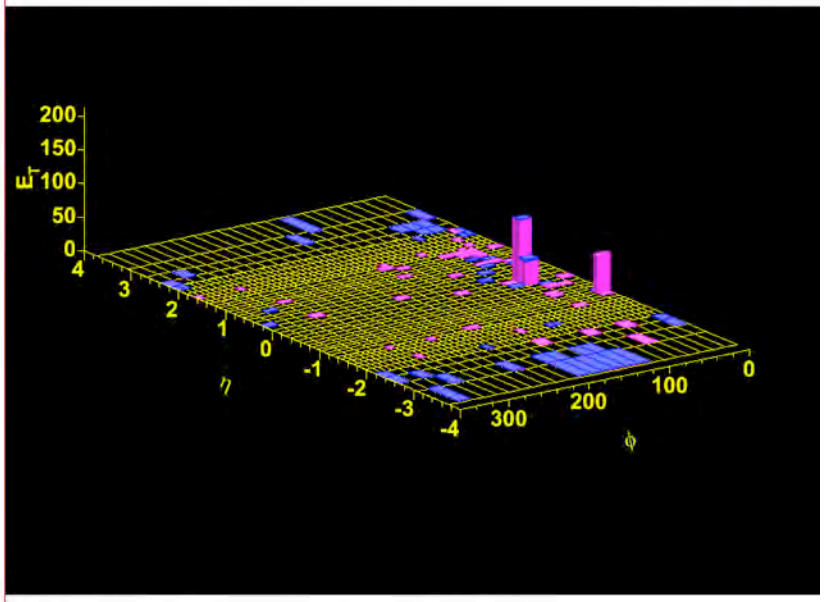
Run=235232 Event=892291

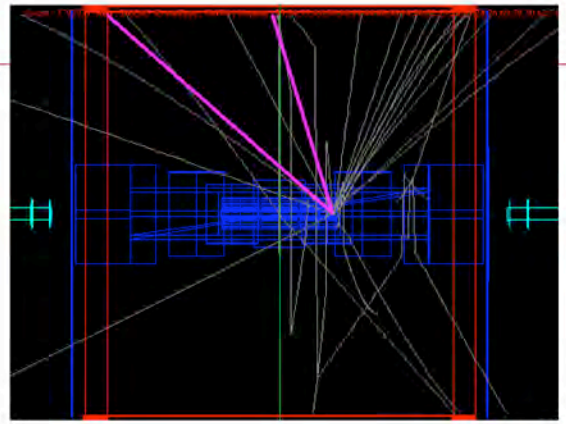
m_{ll1}=89.06 GeV $|\not\!\!E_T|$=2.1 GeV
m_{ll2}=82.82 GeV $N_{jets} = 0$
M_{llll}=230.6 GeV/c^2

Type	p_t	η	ϕ
Central e	59.0	-0.0	0.6
Central e	32.7	0.6	-2.5
Forward e	24.0	-1.8	-2.9
Forward e	14.1	2.2	2.4

ZZ to ee νν candidate





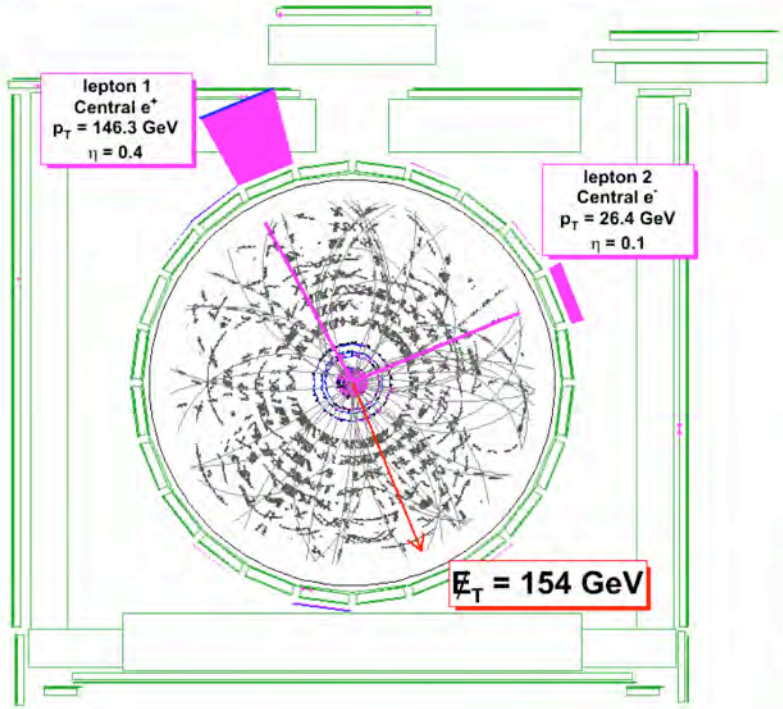


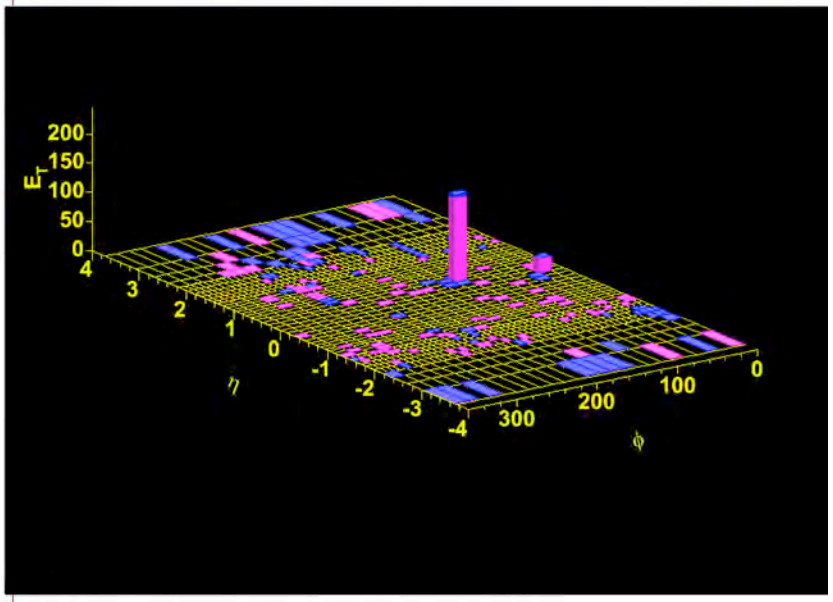
Run=203265 Event=3792931

m_{12}=91.22 GeV $|\not\!\!E_T|$=180.5 GeV

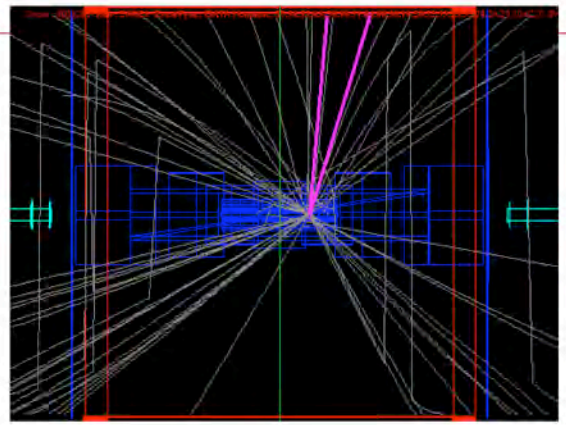
Type	p_t	η	ϕ
Central e	123.5	-0.4	1.0
Central e	51.5	-1.1	0.1

ZZ to ee νν candidate





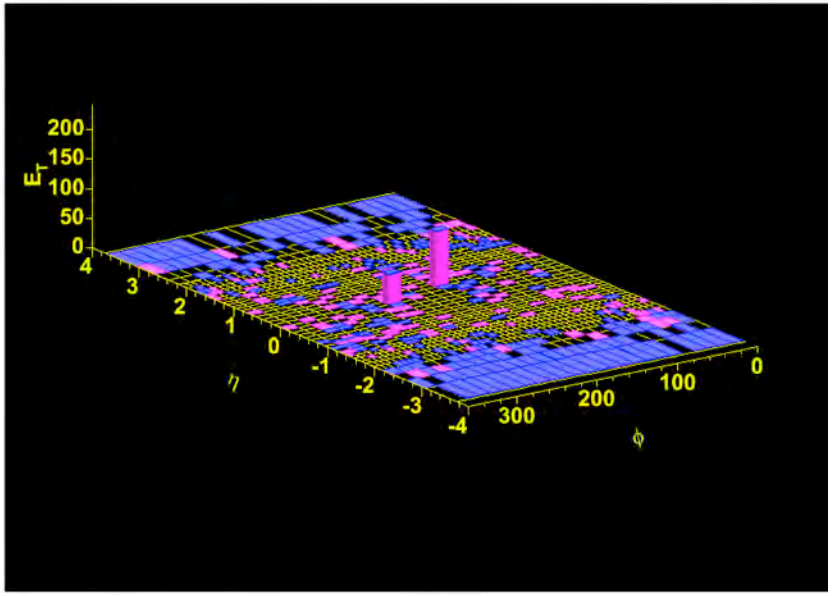
Run=209021 Event=4038281

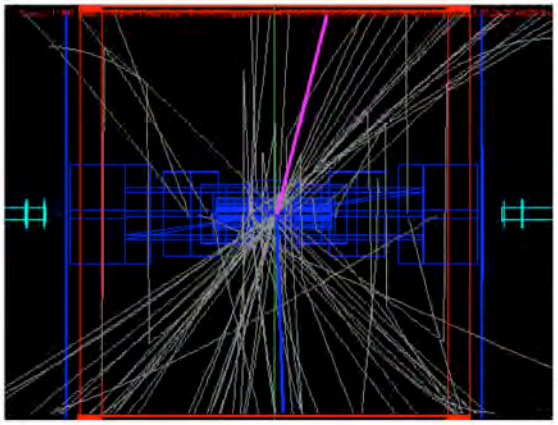


m_{12}=94.24 GeV $|\not\!\!E_T|$=153.8 GeV

Type	p_t	η	ϕ
Central e	146.3	0.4	2.1
Central e	26.4	0.1	0.4

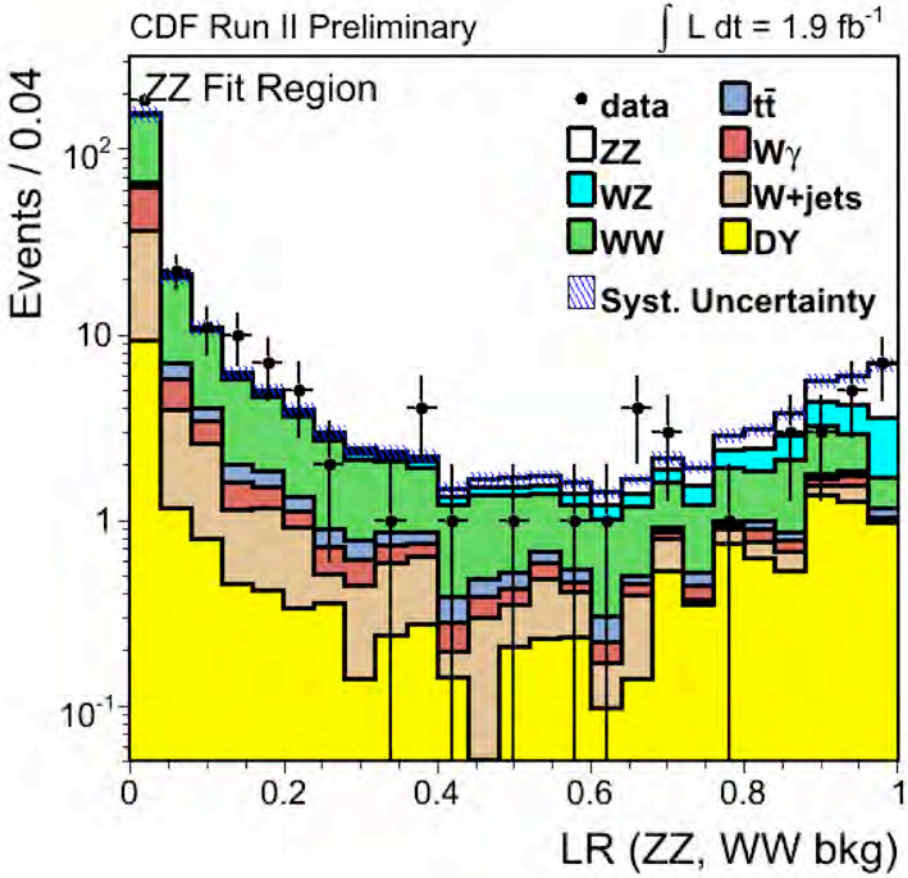
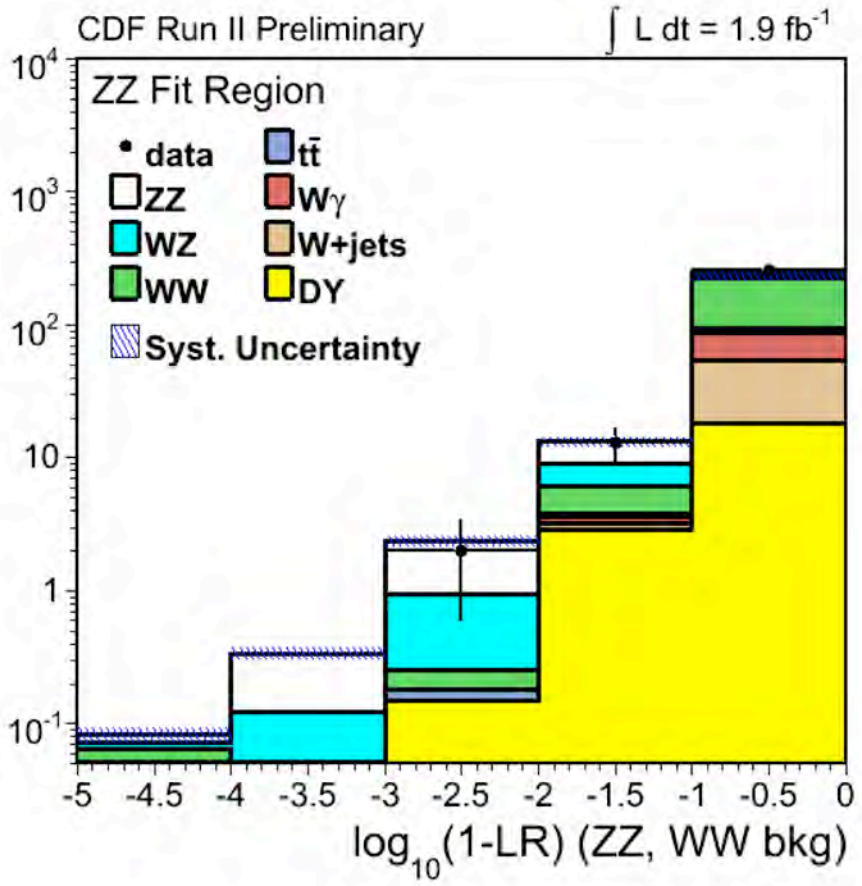
ZZ to ee νν candidate





Run=197288 Event=11891

m_{12}=85.86 GeV $|\not\!\!E_T|$=94.8 GeV

Type	p_t	η	ϕ
Central e	97.0	0.3	2.5
Track e/μ	47.4	0.0	-2.5

llνν Likelihood Ratio