First Observation of WZ Production and Search for ZZ at CDF

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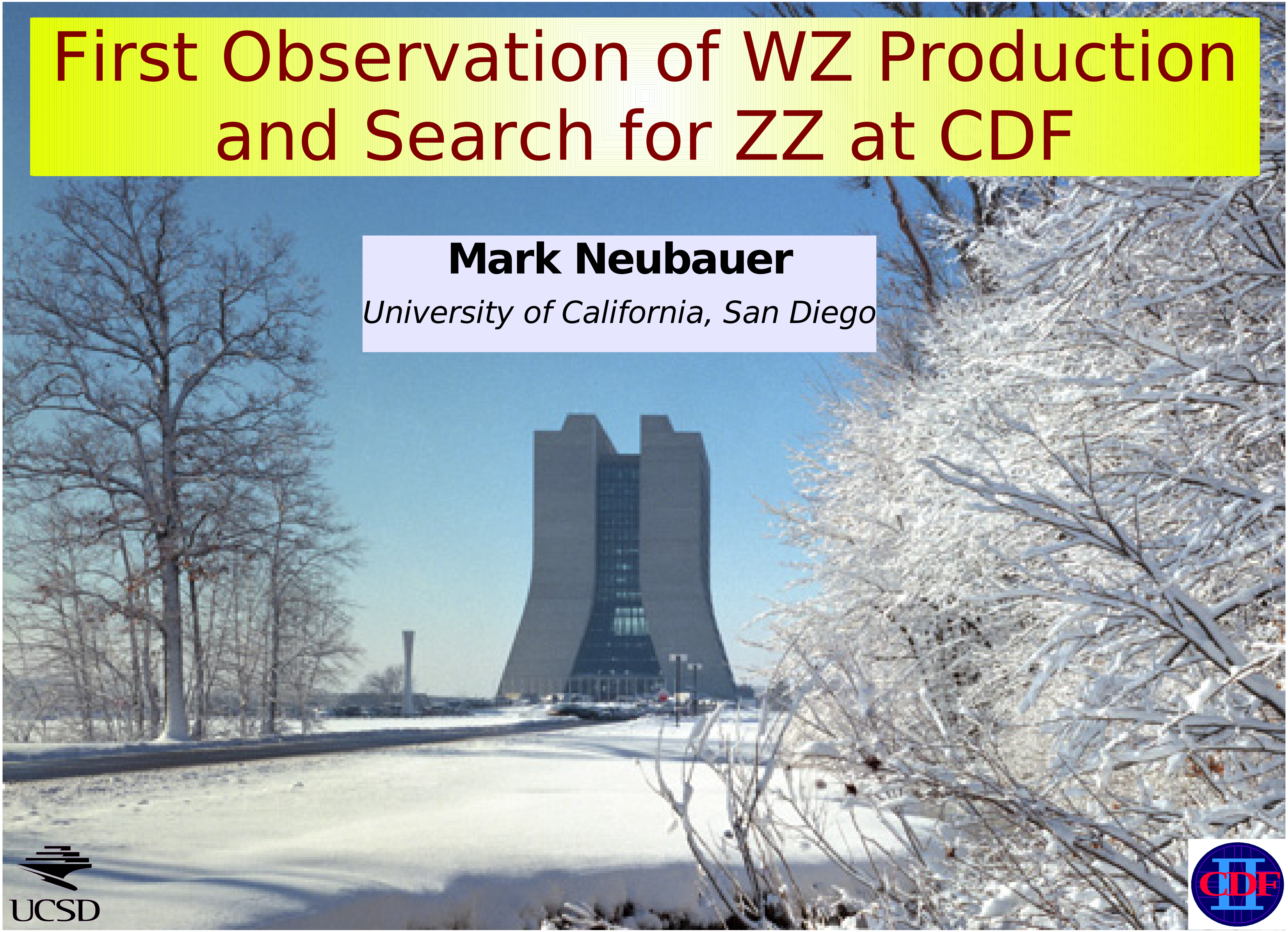


UCSD

Some Open Questions in the SM

The Standard Model (SM) has been very successful at describing the known particles and their interactions (except gravity) under extraordinary experimental scrutiny

A cornerstone of the SM is electroweak symmetry breaking (EWSB)

- $SU(2)_L \otimes U(1)_Y$ is a spontaneous broken symmetry
- generates masses of the weak gauge bosons ($W^\pm$, Z^0) and the fermions
- predicts the existence of a scalar particle: the Higgs boson

However, the SM is an effective theory describing physics at the electroweak scale and is incomplete:

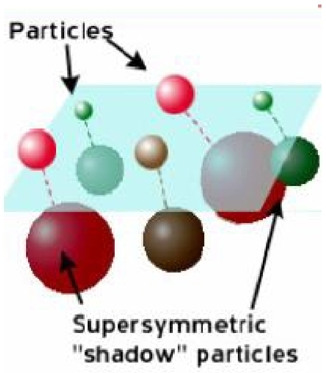
- Neutrino masses
- Gauge coupling unification
- Dark matter
- Higgs mass (m_H) unstable against radiative corrections (hierarchy problem)

New physics could come in many different forms

- Supersymmetry (SUSY), Technicolor, New heavy gauge bosons (W', Z', ..), Extra dimensions, ... , ?

More experimental input needed to show us the way...

Supersymmetry

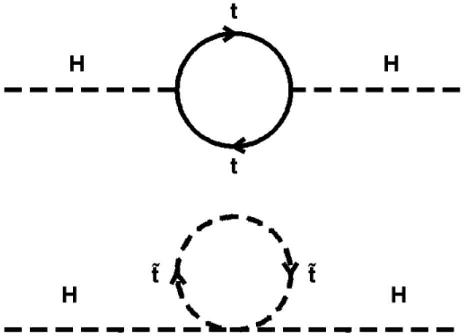


Symmetries play a central role in physics

New spin-based symmetry:
- SM fermion (boson) ⇔ Sparticle boson (fermion)

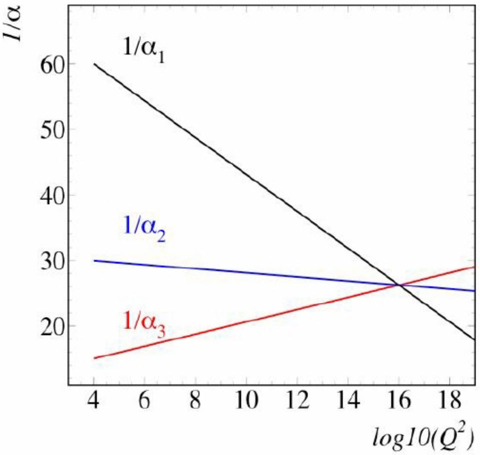
Enlarged Higgs sector (2 doublets → 5 physical states)

	$[u,d,c,s,t,b]_{L,R}$	$[e,\mu,\tau]$	$[\nu_{e,\mu,\tau}]$	Spin $\frac{1}{2}$
MSSM	$[\tilde{u},\tilde{d},\tilde{c},\tilde{s},\tilde{t},\tilde{b}]_{L,R}$	$[\tilde{e},\tilde{\mu},\tilde{\tau}]$	$[\tilde{\nu}_{e,\mu,\tau}]$	Spin 0
	g	$W^{\pm}, H^{\pm}$	$\gamma, Z, H_1^0 H_2^0$	Spin1/Spin 0
	$\tilde{g}$	$\tilde{\chi}^{\pm}_{1,2}$	$\tilde{\chi}^{0}_{1,2,3,4}$	Spin $\frac{1}{2}$



SUSY provides

- solution to heirarchy problem
- gauge unification
- natural dark matter candidate: LSP (typically lightest χ)
  - LSP is stable if R-parity (≡ (-)$^{(3B-L+2S)}$) is conserved



Superpartners not yet observed → SUSY is a broken symmetry

- numerous breaking mechanisms (e.g. mSUGRA, GMSB)

The Higgs Boson

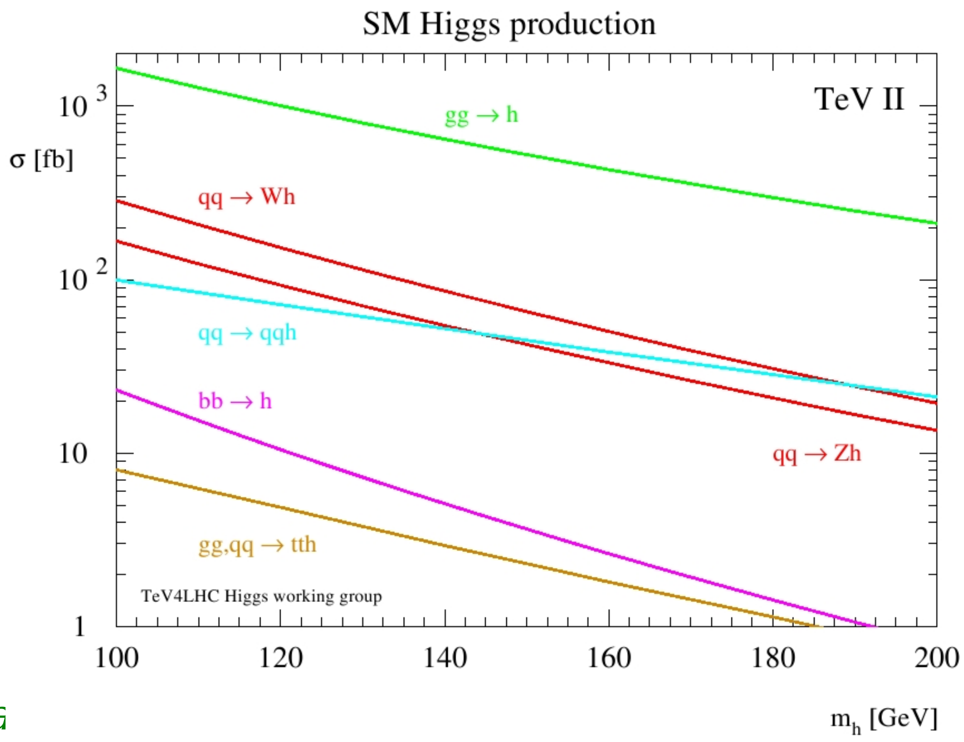
- m_H is a free parameter in SM
- LEP direct search: $m_H > 114.4$ GeV (95% C.L)
- Constraints from fits to EW data (http::/www.cern.ch/LEPEWWG):
  - Best fit: $m_H = 85^{+39}_{-28}$ GeV
  - 95% C.L.: $m_H < 166$ GeV
- EW fit + direct search: $114.4 < m_H < 199$ GeV

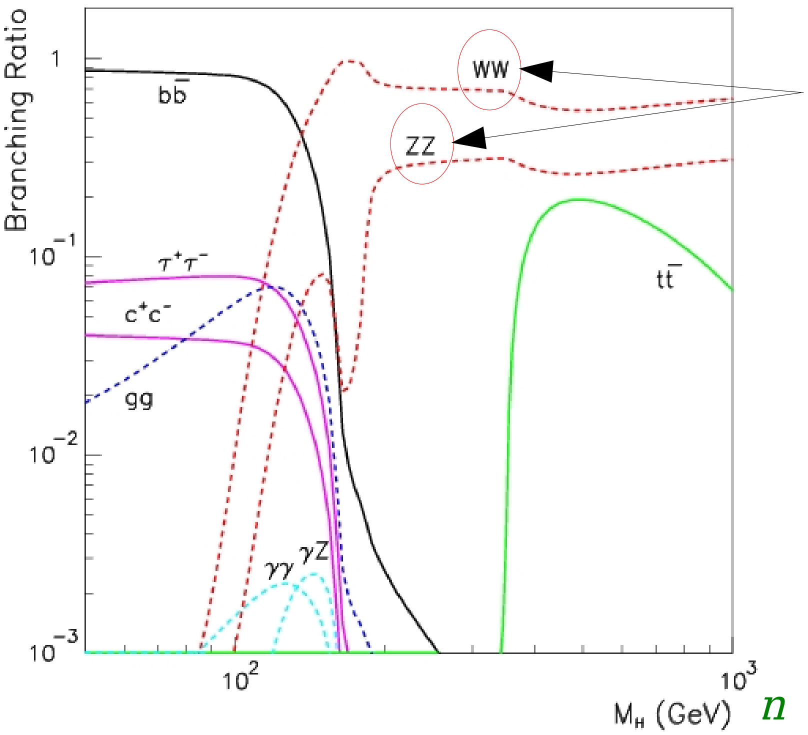
latest CDF W mass result changes best fit to:

$m_H = 80^{+36}_{-26}$ GeV

Intensive search for Higgs underway at Tevatron

- Strategy / Sensitivity depends upon m_H





Heavy
Diboson
Final
States

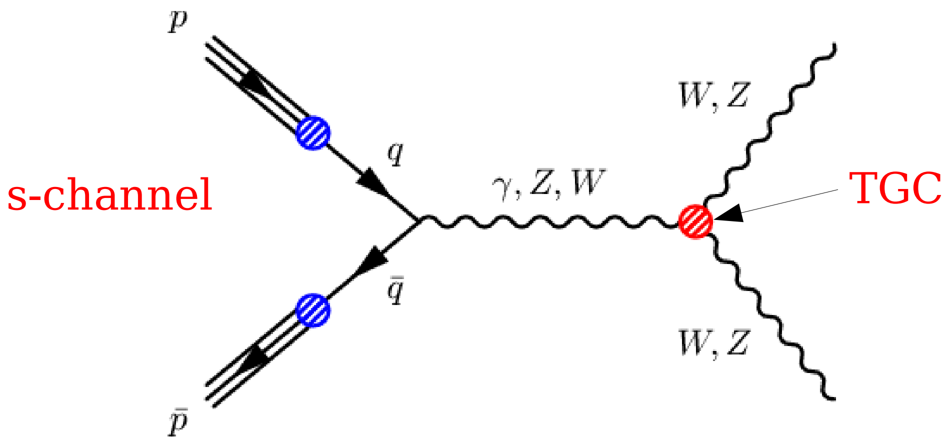
Diboson Physics

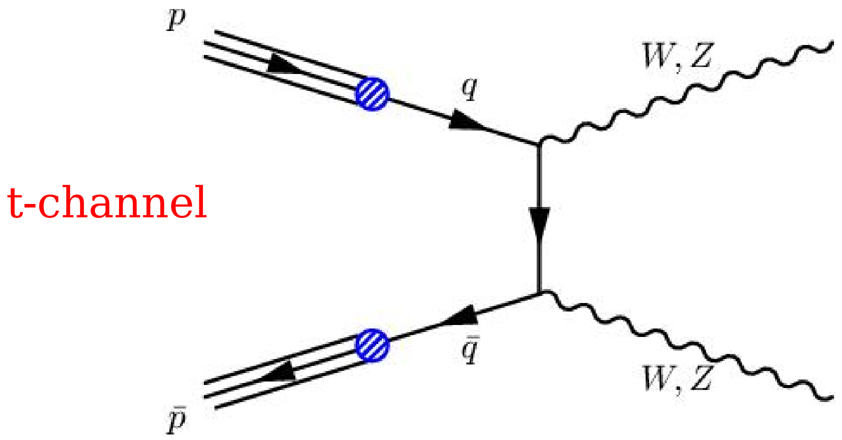
The gauge bosons of the electroweak interaction (W, Z, γ) are readily produced in high energy p$\bar{\text{p}}$ collisions

Boson pair production is far more rare and probes gauge boson self-interactions

→ consequence of non-Albelian nature of $SU(2)_L \otimes U(1)_Y$

→ sensitive to new physics in trilinear gauge couplings (TGC)


s-channel


t-channel

Tevatron (p$\bar{\text{p}}$) complementary to LEP (e^+e^-)

- Sensitive to different TGC combinations
- Tevatron explores higher $\hat{s}$ than LEP

$$q\bar{q}' \rightarrow W^{(*)} \rightarrow W\gamma : WW\gamma \text{ only}$$

$$q\bar{q}' \rightarrow W^{(*)} \rightarrow WZ : WWZ \text{ only}$$

$$q\bar{q} \rightarrow Z/\gamma^{(*)} \rightarrow WW : WW\gamma, WWZ$$

$$q\bar{q} \rightarrow Z/\gamma^{(*)} \rightarrow Z\gamma : ZZ\gamma, Z\gamma\gamma$$

$$q\bar{q} \rightarrow Z/\gamma^{(*)} \rightarrow ZZ : ZZ\gamma, ZZZ$$

Absent in SM

WWγ and WWZ Anomalous Couplings

Parameterize new physics in terms of coupling parameters in an effective Lagrangian

$$L_{WWV}/g_{WWV} = i\boxed{g_1^V}(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\boxed{\kappa_V}W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\boxed{\lambda_V}}{M_W^2}W^\dagger_{\lambda\mu}W^\mu_\nu V^{\nu\lambda}$$

$V \equiv Z, \gamma$

Phys.Rev.**D48** 2182 (HISZ)

5 C and P conserving coupling parameters ($g_1^\gamma = 1$ by EM gauge invariance)

SM at tree level: $g_1^Z = k_Z = k_\gamma = 1, \quad \lambda_Z = \lambda_\gamma = 0$

$\Delta\kappa_Z = \Delta\kappa_\gamma = 0 \ (\Delta\kappa \equiv \kappa - 1) \qquad \Delta g_1^Z = 0 \ (\Delta g_1^Z \equiv g_1^Z - 1)$

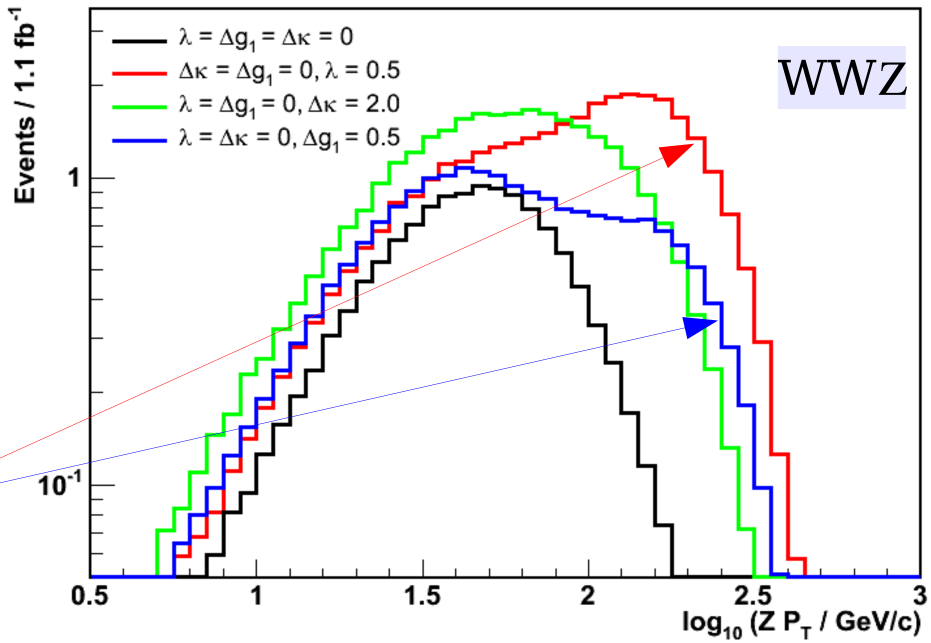
Form factor anzatz to avoid unitarity violation at large $\hat{s}$:

$$\alpha \Rightarrow \alpha(\hat{s}) = \frac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$$

$\sqrt{\hat{s}}$ = CM energy of subprocess

Λ = scale of NP ~1 to 2 TeV

Anomalous couplings can enhance cross-section at high gauge boson P_T



Motivation: Demonstrate Sensitivity

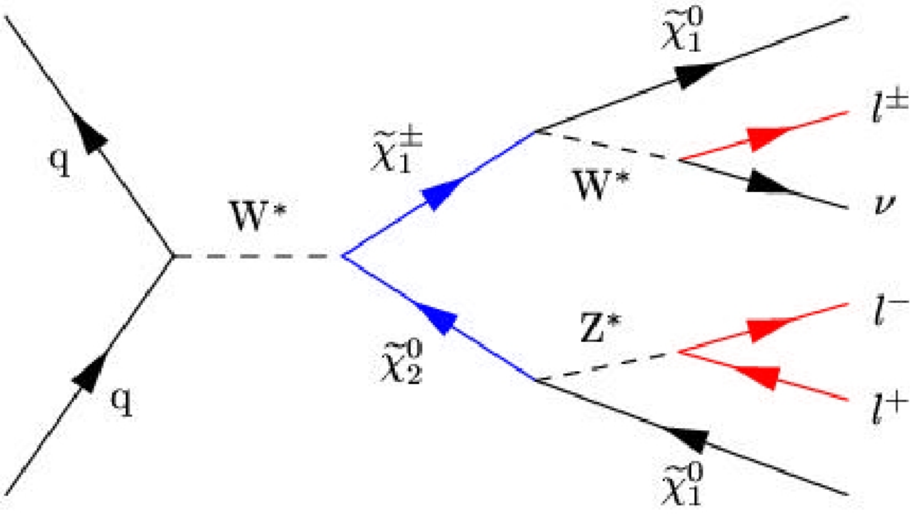
Finding multilepton signals with very small σ × Br (e.g. Higgs, SUSY)

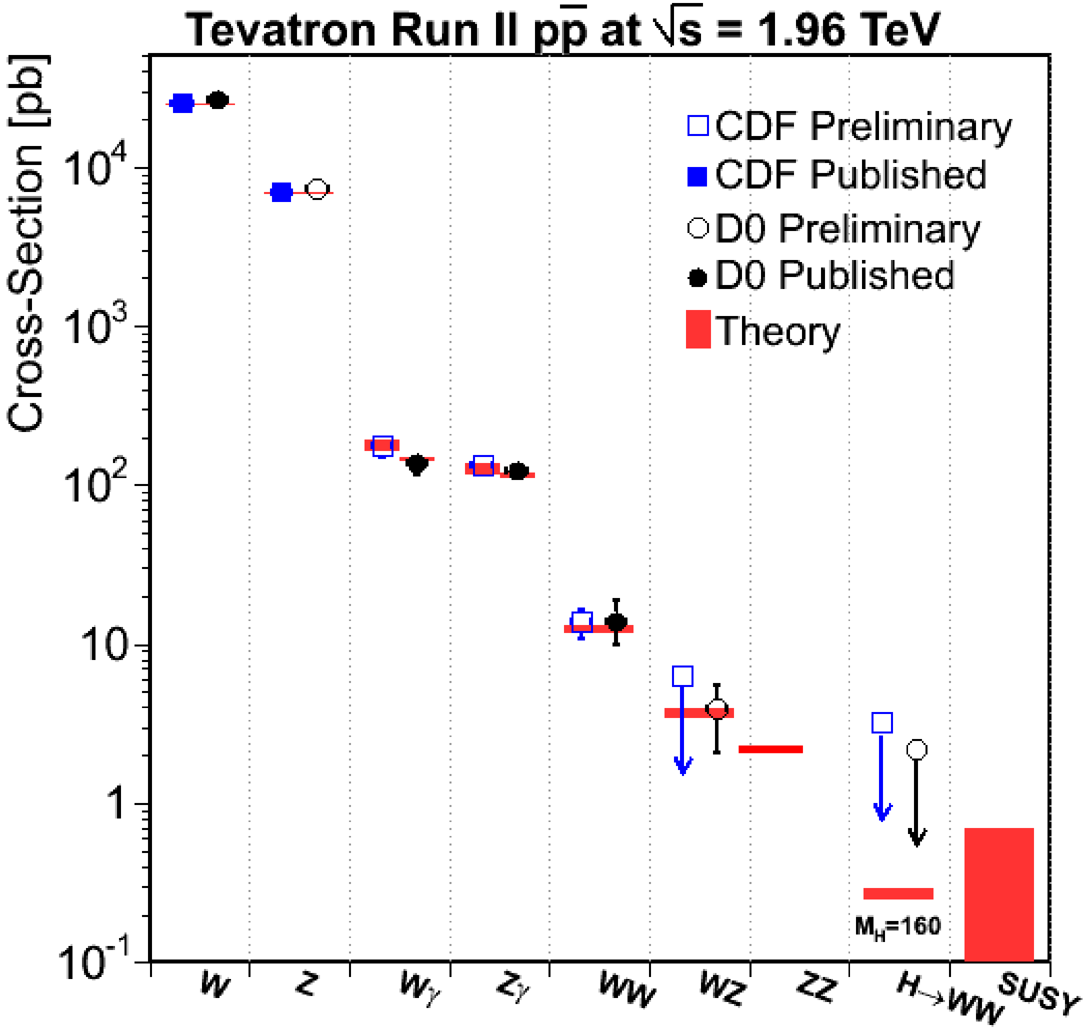
→ Search for WZ in 3 leptons + Missing Transverse Energy ($\not\!\!E_T$)

→ Search for ZZ in 4 leptons

3 leptons + $\not\!\!E_T$ final state common to:

- WZ
- WH → WWW
- "SUSY Golden Mode"

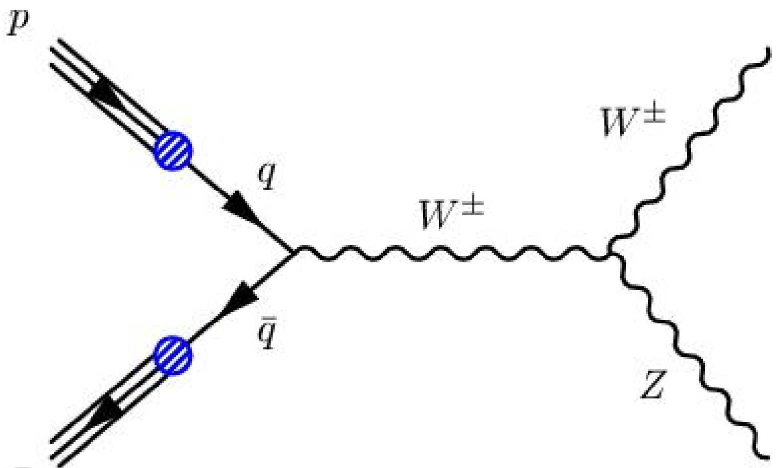




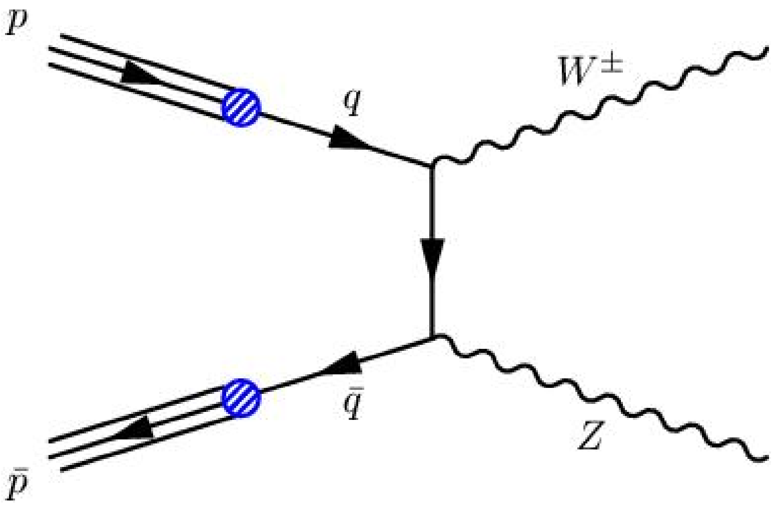
WZ: SM Mirror of SUSY Golden Mode

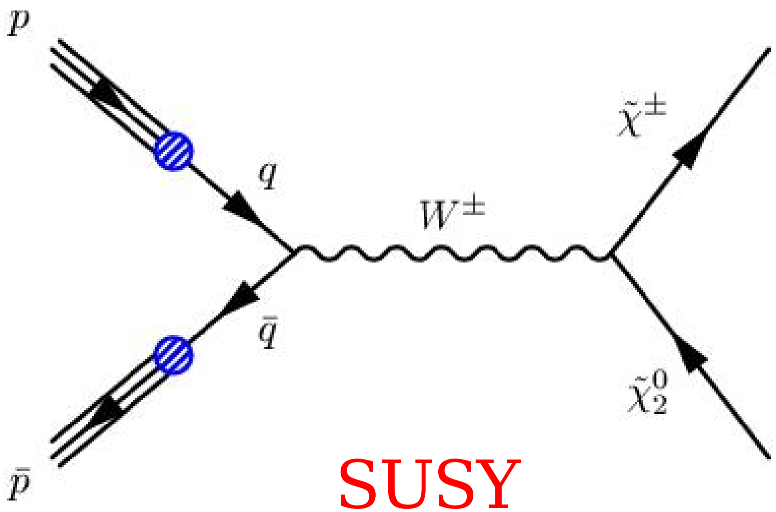
$p\bar{p} \rightarrow W^{\pm}Z^{0} \rightarrow \ell^{\pm}\ell^{+}\ell^{-} + \cancel{E}_{T}$

$p\bar{p} \rightarrow \chi_{1}^{\pm}\chi_{2}^{0} \rightarrow \ell^{\pm}\ell^{+}\ell^{-} + \cancel{E}_{T}$

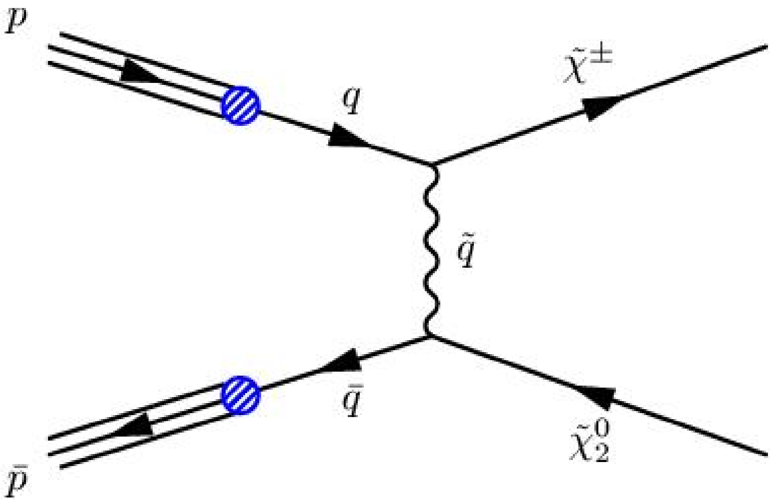


SM WZ





SUSY



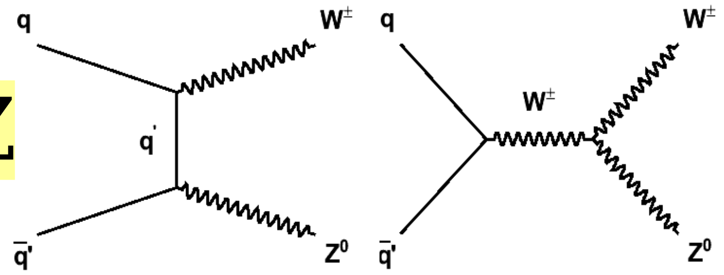
Physics Motivation Summary

- Study trilinear gauge couplings
- Demonstrate sensitivity to rare multilepton (3 or more leptons) signals (e.g. SUSY trileptons, WH)
- Important background for many high p_T analyses ($H \to WW^*$, ZH/WH, SUSY, tt, ...)
- Could have contributions from SUSY, Technicolor, W', ... , or maybe something completely unexpected?

WZ/ZZ Production in the Standard Model

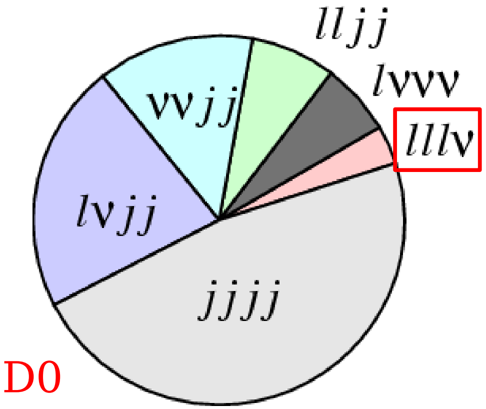
WZ

Involves a single SM triple gauge coupling:



- Not available @ LEP
- Measure WWZ coupling independent of WWγ
- Yet to be observed (>5σ)

First evidence (3.3σ) from D0



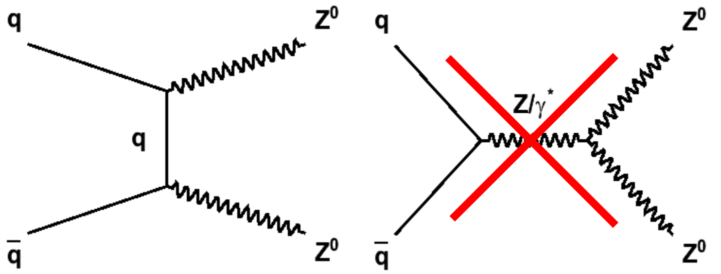
NLO cross section: 3.7 ± 0.1 pb

Campbell,Ellis, Phys.Rev. D60 (1999) 113006

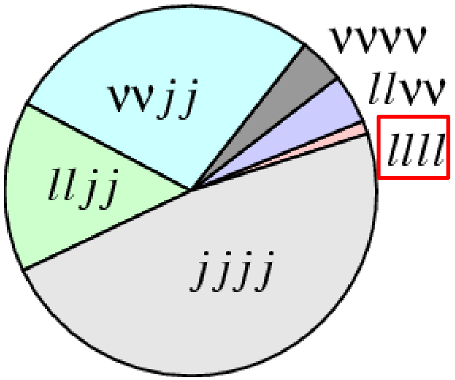
BR(WZ → 3 e,μ) = 1.8%

ZZ

Triple neutral gauge couplings absent in SM:



- Search for ZZγ or ZZZ coupling (=0 in SM)
- SM ZZ production not yet observed in $p\bar{p}$



NLO cross section: 1.4 ± 0.1 pb

Campbell,Ellis, Phys.Rev. D60 (1999) 113006

BR(ZZ → 4 e,μ) = 0.5%

Previous WZ Search

Using $\int L\, dt$ = 0.8 fb^{-1}

$W^\pm Z^0 \to \ell^\pm \ell^+ \ell^- \nu$ selection:

- 3 leptons (e,μ) with Pt > 20,10,10 GeV/c
- Z^0 region: $76 < M(\ell^+\ell^-) < 106$ GeV/c^2
- $\not{E}_T > 25$ GeV

Observe 2 events (eee) with an expected background of 0.9 ± 0.2 and WZ signal of 3.7 ± 0.3

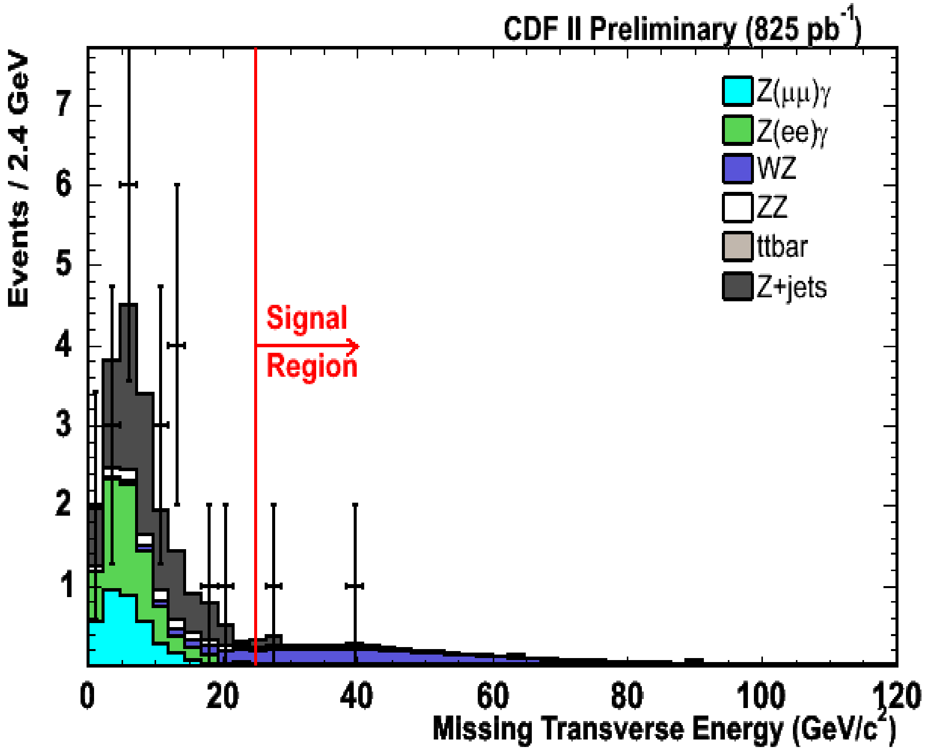
σ(WZ) < 6.34 pb (95% C.L.)

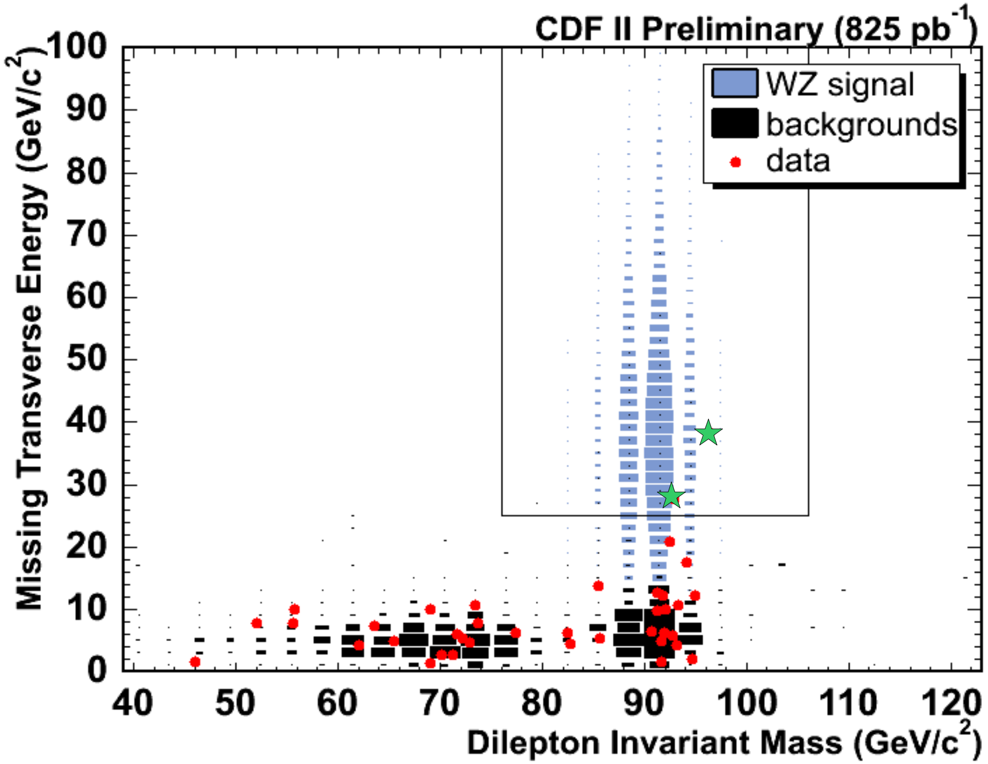
Signal:

WZ: 3.72 ± 0.02 (stat.) ± 0.15 (syst.)

Backgrounds:

ZZ: 0.50 ± 0.01 (stat.) ± 0.05 (syst.)
Zγ: 0.03 ± 0.01 (stat.) ± 0.01 (syst.)
$t\bar{t}$: 0.05 ± 0.01 (stat.) ± 0.01 (syst.)
Z+jets: 0.34 ± 0.07 (stat.) $^{+0.15}_{-0.09}$ (syst.)
Total: 0.92 ± 0.07 (stat.) $^{+0.16}_{-0.10}$ (syst.)





WZ First Evidence

D0: $\int L\, dt$ = ~0.8 fb^{-1}

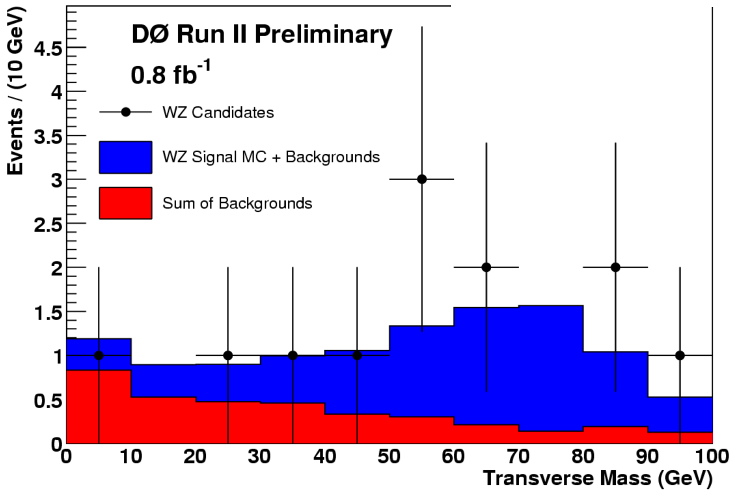
Observe 12 events with expected background of 3.6 ± 0.2 and signal of 7.5 ± 1.2

WZ Candidate Transverse Mass

$$m_T c^2 = \sqrt{E_T \not{E}_T (1 - \cos\Delta\phi)}$$

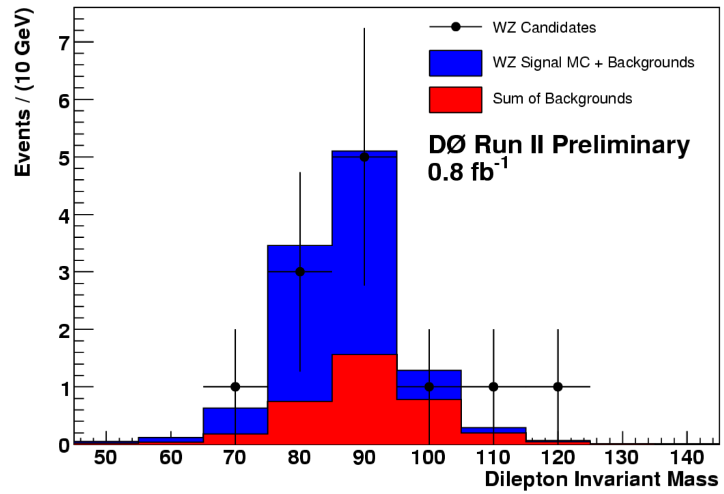
3.3σ evidence

$$\boxed{\sigma = 4.0^{+1.9}_{-1.5}\,(\text{stat+syst})\ \text{pb}}$$

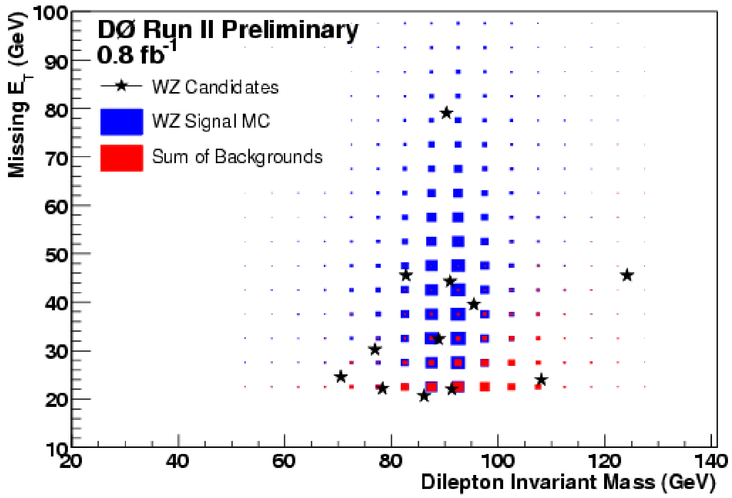


Decay Channel	Number of Candidates	Overall Efficiency	Expected Signal	Estimated Background
eee	2	0.158±0.012	1.81±0.18	0.960±0.069
$ee\mu$	1	0.167±0.029	1.88±0.52	0.485±0.053
$\mu\mu e$	7	0.175±0.043	1.77±0.66	0.963±0.080
$\mu\mu\mu$	2	0.205±0.033	2.04±0.54	1.203±0.143
Total	12	-	7.5±1.36	3.61±0.20

WZ Candidate Dilepton Invariant Mass

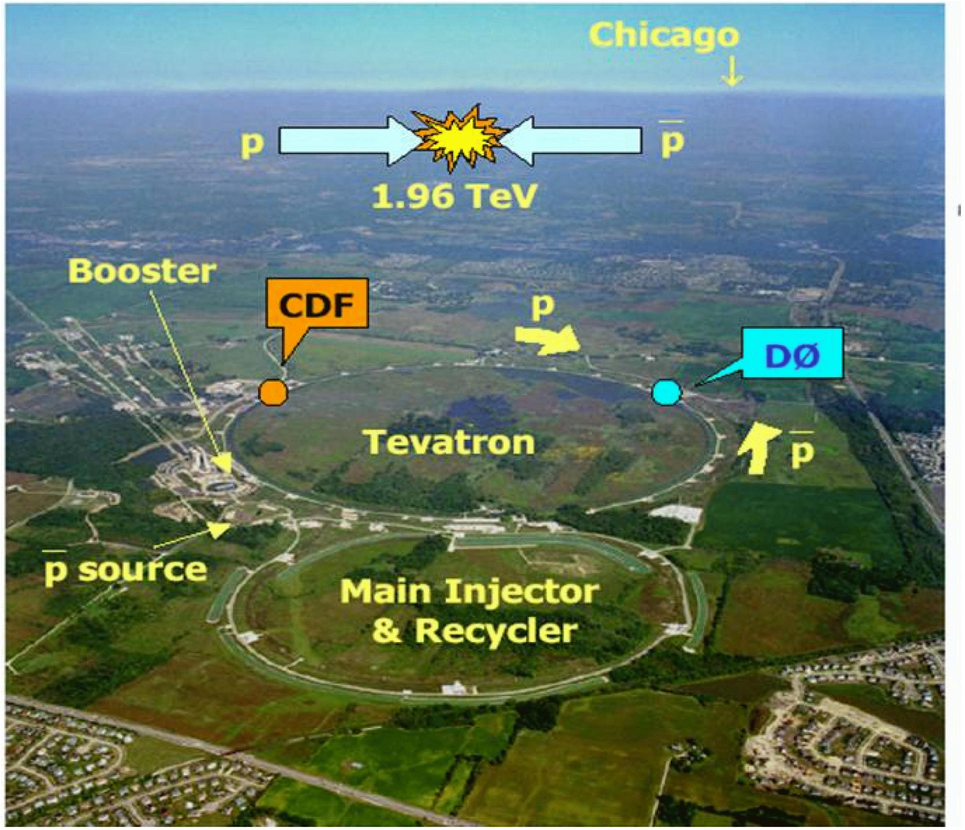


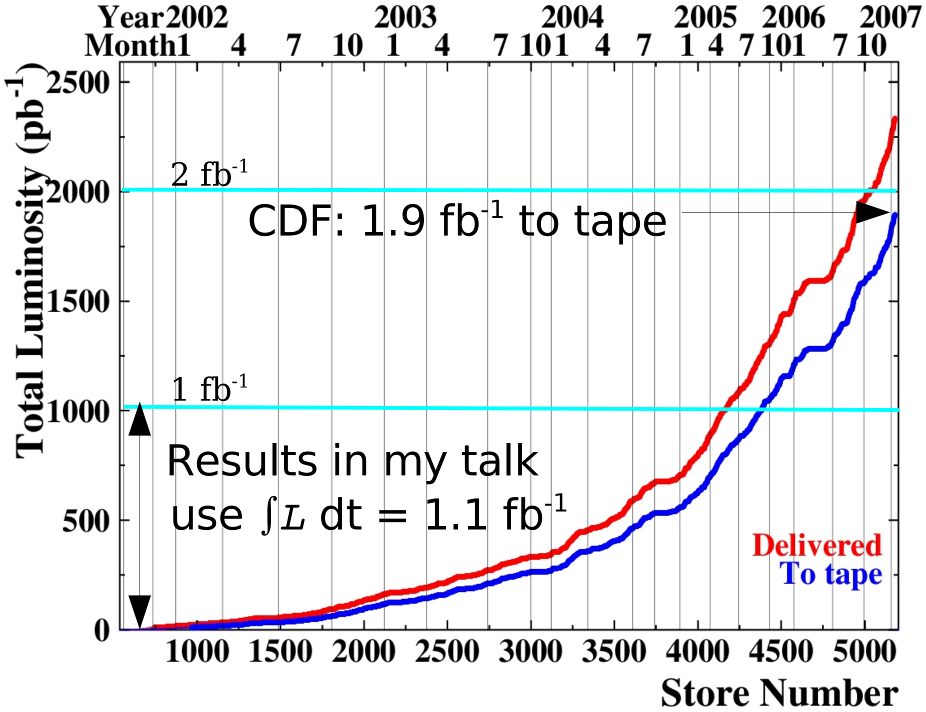
WZ Candidate Mass vs. Missing E$_T$



The Fermilab Tevatron

World's highest energy particle collider
until turn-on of LHC @ CERN





CDF: 1.9 fb^{-1} to tape

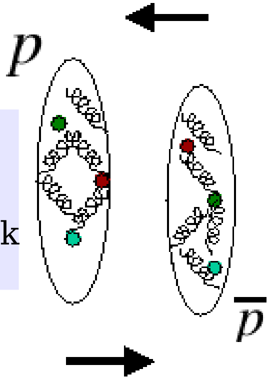
Results in my talk use $\int L\, dt = 1.1\ fb^{-1}$

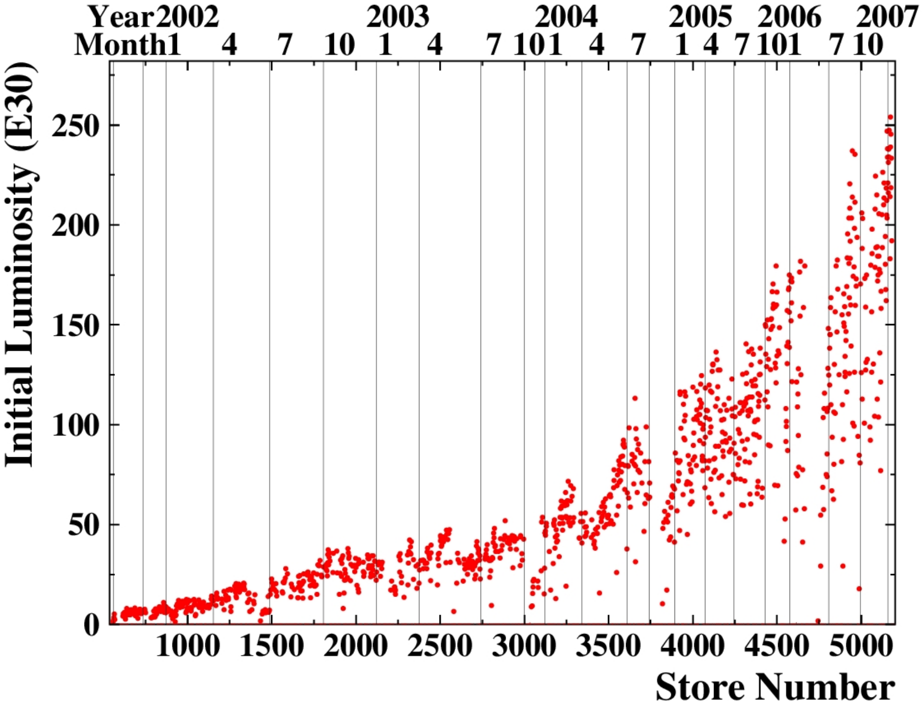
Run II Started 2001:

- $\sqrt{s}$=1.96 TeV
- record luminosity:
  $L_{inst} = 237 \times 10^{30}\ cm^{-2}s^{-1}$
- $\int L\, dt$ = ~2 fb^{-1}
  → 4 – 8 fb^{-1} expected by 2009

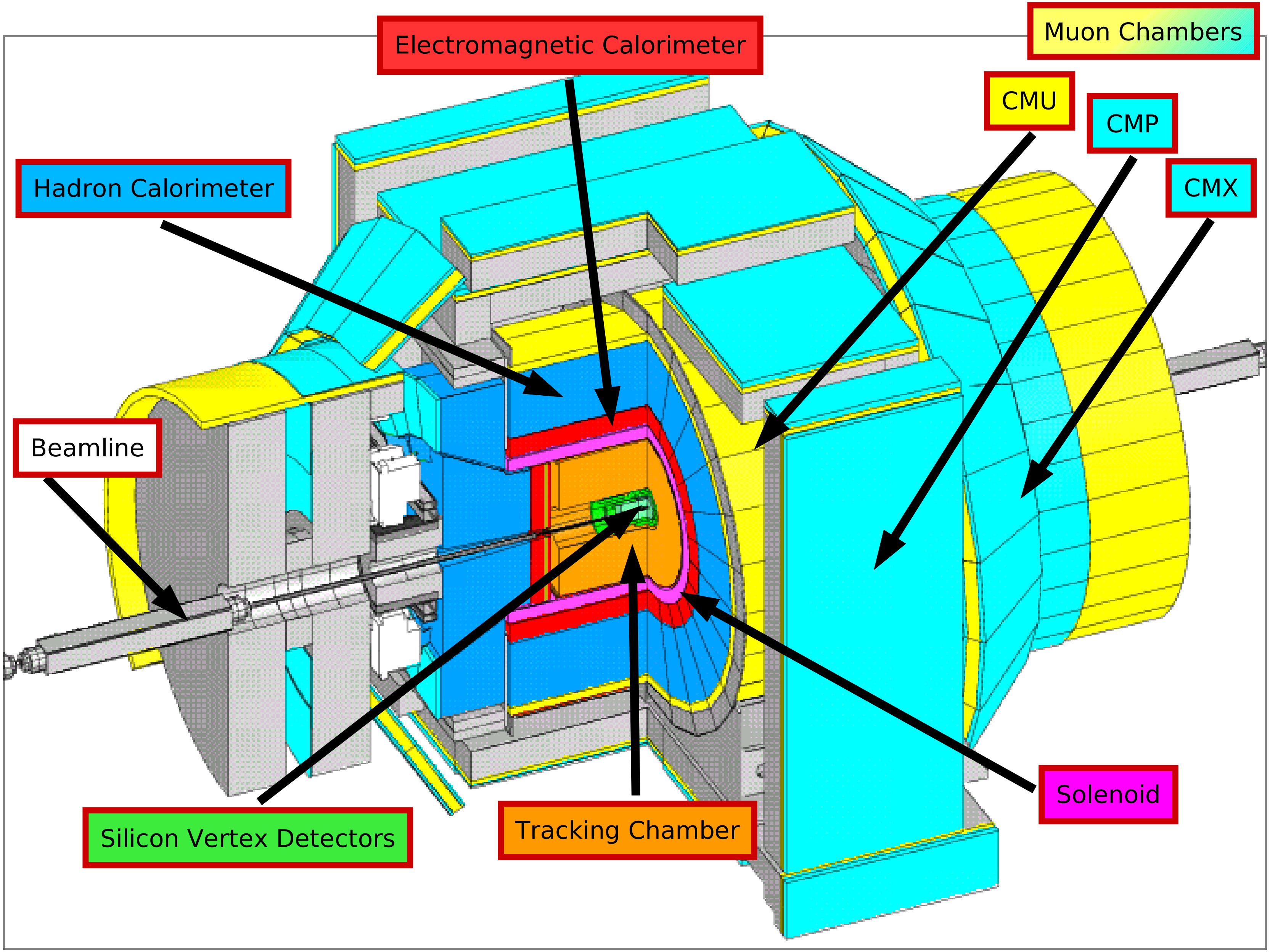
Collisions:

- gluon-gluon
- quark-antiquark
- gluon-quark





The CDF II Detector



Tracking

- Central drift chamber
  - Track acceptance:
    100% of layers $|\eta| < 1$
    0% by $|\eta| < 2$
- Silicon coverage out to $|\eta| < 2$ for large $|\eta|$ tracking

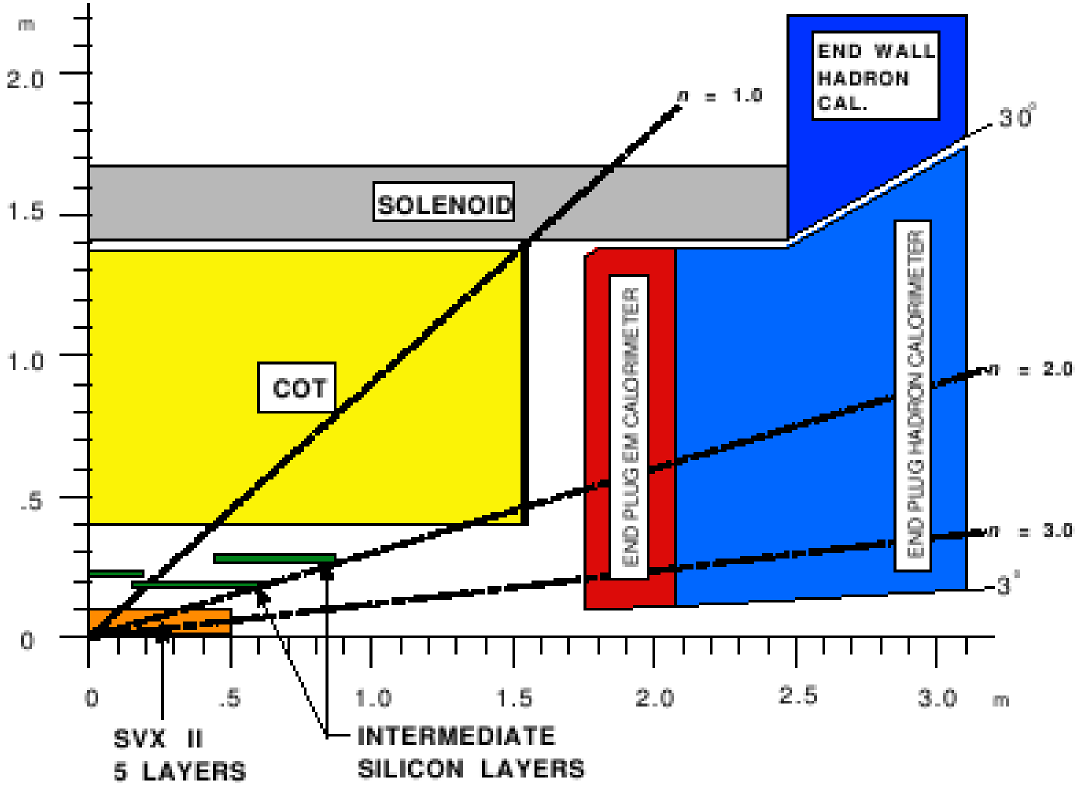
Calorimetry

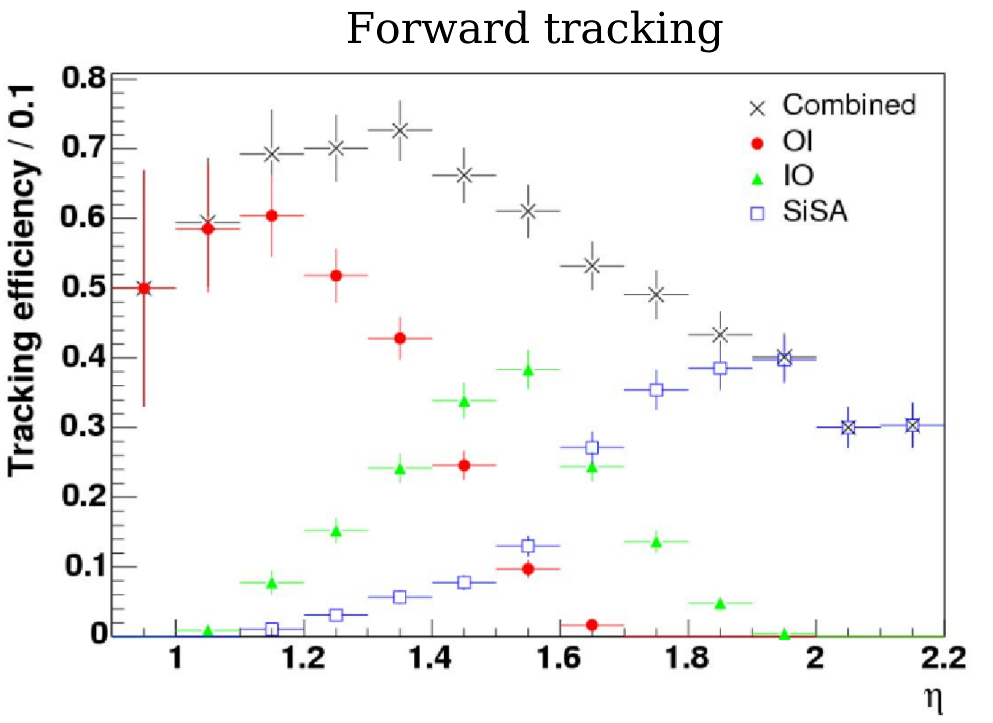
- Segmented sampling EM/Had calorimeters
- Shower maximum detectors
  - shape measurement
  - central (gas)
  - forward (scintillator)

Muon Detection

- CMU/CMP (Central) ($|\eta| < 0.6$)
- CMX (Extended) ($0.6 < |\eta| < 1.2$)
- BMU (Forward) ($1.2 < |\eta| < 1.5$)

Integrated Tracking System





- Central |η| < 1 tracking: efficiency ~100% (Outside-In=OI)
- Silicon-seeded tracks (Inside-Out=IO)
  - ➔ increase high |η| tracking efficiency
- Silicon-only tracking for very forward tracks (Silicon-standalone=SISA)
- Forward electrons use plug shower seeded tracking

Lepton Selection (Winter 2006 Analysis)

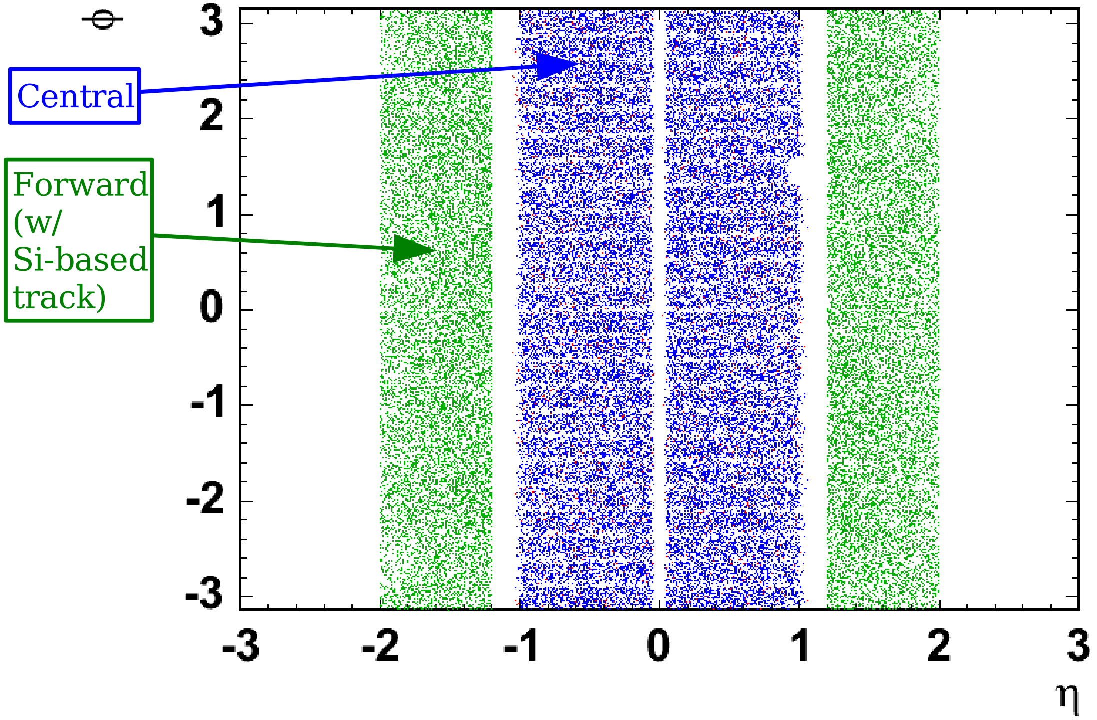
Electrons

- Central calorimeter fiducial
- Forward calorimeter fiducial
  - With Si-based track

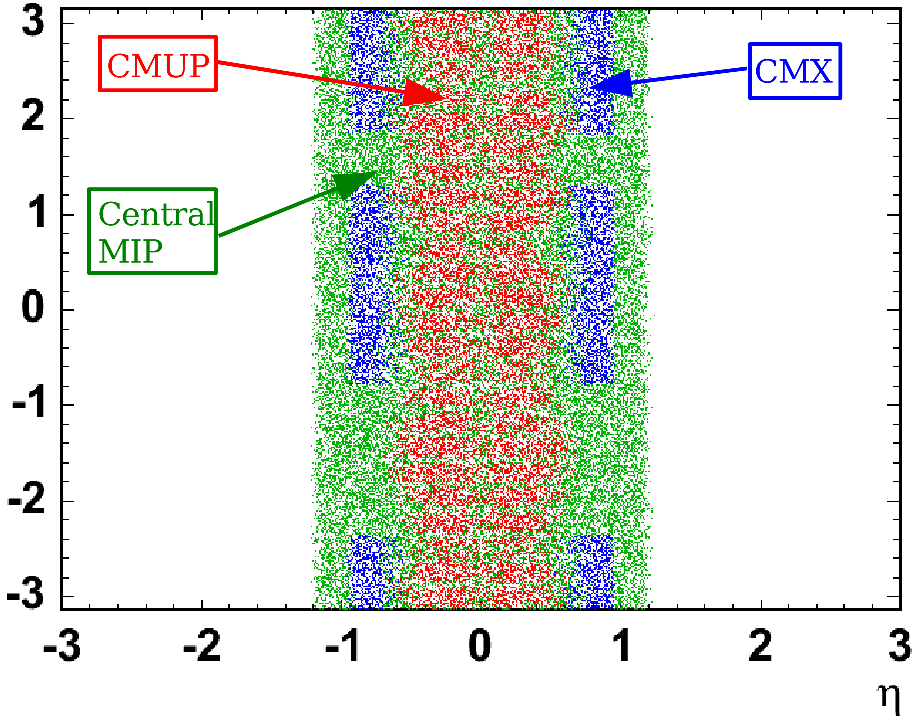
Muons

- CMU+CMP (CMUP) stubs
- CMX stub
- Minimum Ionizing Particle (MIP)

Electrons η vs. φ



Muons η vs. φ



All leptons required to be calorimeter isolated: minimal transverse energy around lepton

Lepton Selection (Current Analysis)

In final states with 3 or more leptons (WZ and ZZ), lepton acceptance is key

- Try to use every track and electromagnetic shower found
- Exploit as much of the available information as possible for each candidate

Electrons

- Central calorimeter fiducial
- Forward calorimeter fiducial
  - With or w/o Si-based track

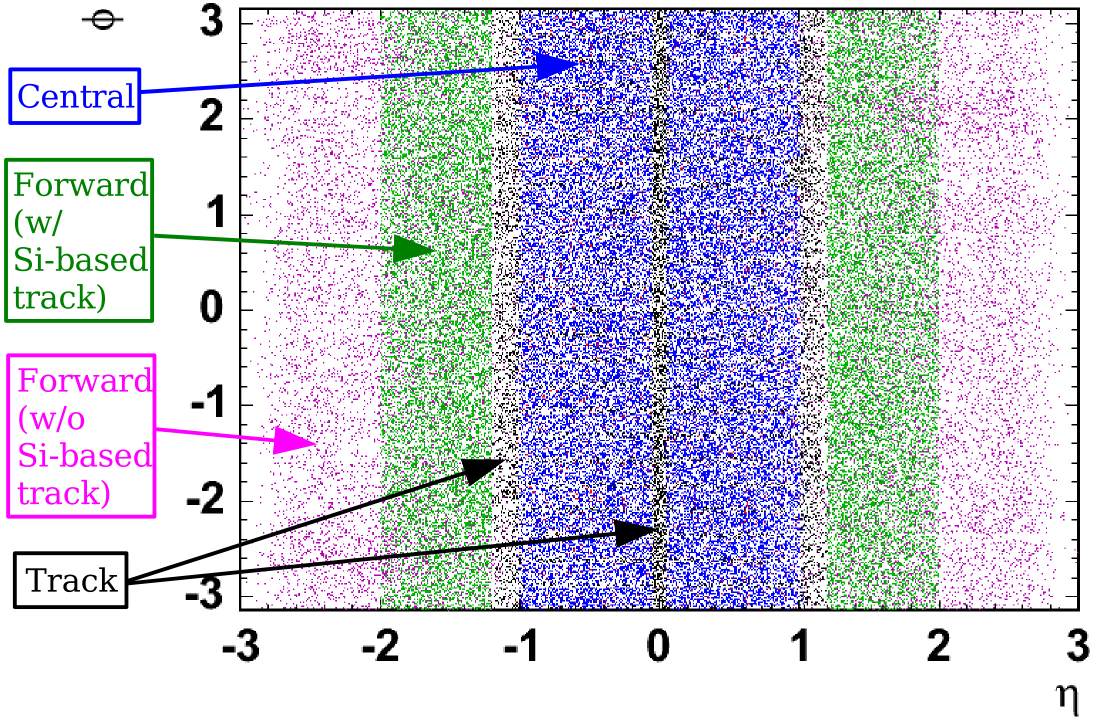
Muons

- CMU+CMP (CMUP) stubs
- CMX stub
- Minimum Ionizing Particle (MIP)

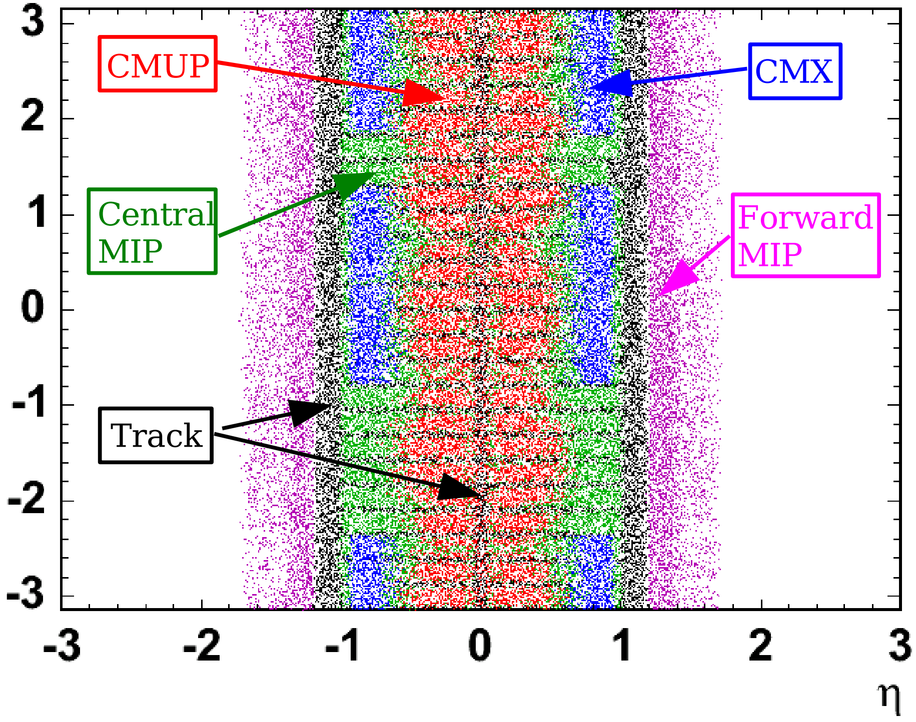
Tracks

- Fill in regions not fiducial to a calorimeter (shower max)
- Considered flavor neutral (e or μ)

Electrons η vs. φ



Muons η vs. φ



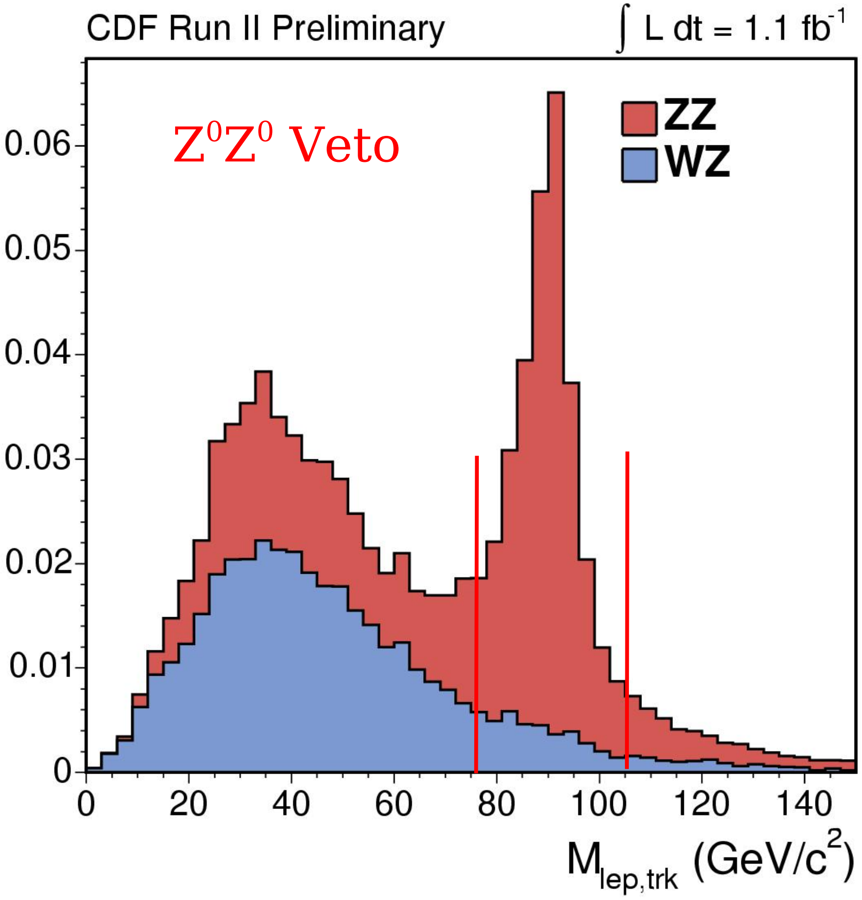
All leptons required to be calorimeter isolated: minimal transverse energy around lepton

WZ Candidate Selection

$W^{\pm}Z^{0} \rightarrow \ell^{\pm}\ell^{-}\ell^{+}\nu$ Candidate Selection:

- Triggers:
  - Central $e^{\pm}$,
  - Central $\mu^{\pm}$ (CMUP, CMX)
  - Forward $e^{\pm}$ + large $\not{E}_T$
- Trilepton identification
  - 3 reconstructed leptons with $E_T >$ 20,10,10 GeV
- Z^0 mass region:
  - $\geq$1 opposite-charge, same-flavor lepton pair in (76, 106) GeV/c^2

    → Indicates leptonic decay of Z^0 boson
- Z^0Z^0 Veto:
  - Invariant mass of non-Z^0 ("W") lepton + additional high p_T track (> 8 GeV/c) not inside Z^0 mass region (76,106) GeV/c^2

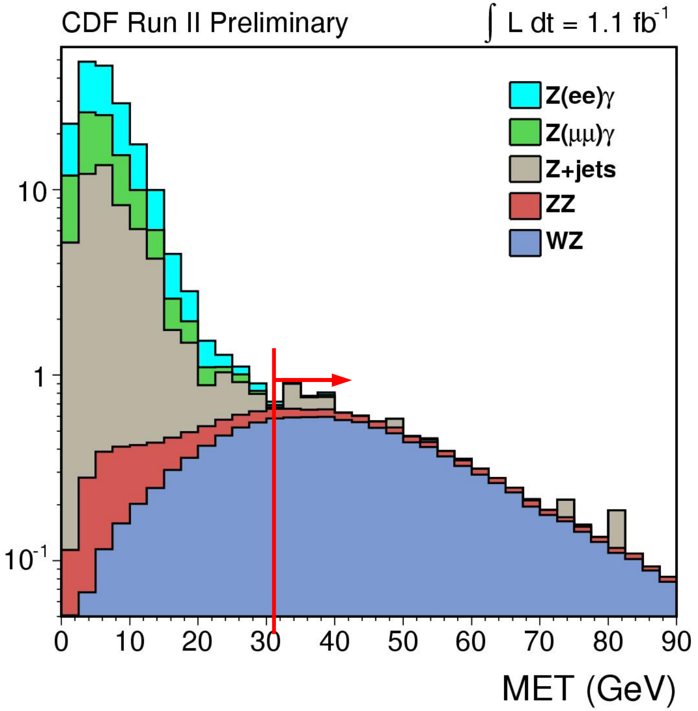


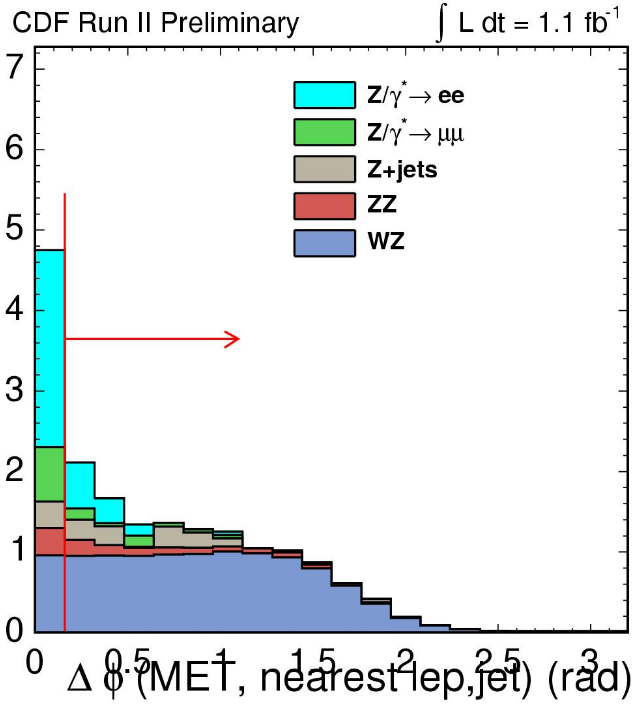
WZ Candidate Selection (cont)

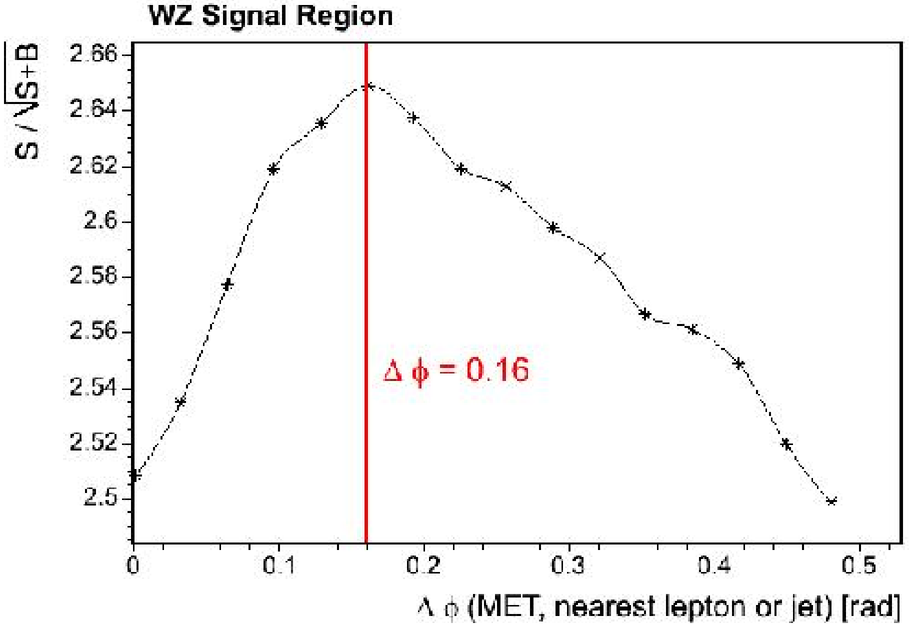
$W^{\pm}Z^{0} \to \ell^{\pm}\ell^{-}\ell^{+}\nu$ Selection (cont):

- Missing Transerve Energy ($\not{E}_T$):
  - $\not{E}_T > 25$ GeV

    → Indicates unobserved neutrino from leptonic decay of $W^{\pm}$ boson
- $\not{E}_T$ Quality:
  - $\Delta\phi(E_T$, nearest lepton or jet$) > 9^{\circ}$







Optimized using independent background samples

Signal and Background Modeling

Expected backgrounds from Zγ, ZZ, Z+jets, $t\bar{t}$

Geometric and kinematic acceptance for WZ, ZZ, Zg, $t\bar{t}$ using Monte Carlo calculations and GEANT-based simulation of the CDF II detector

Use CTEQ5L parton distribution functions (PDFs) to model momentum distribution of initial-state partons

- Zγ: U. Baur's ME generator + Pythia + GEANT
- WZ, ZZ, $t\bar{t}$: Pythia + GEANT

Z+jets determined from data

- Measure P_{fake}(lepton-like jet → lepton) in inclusive multi-jet data after small MC-based correction for leptonic W,Z decays
- Scale dilepton + lepton-like jet(s) events in data by P_{fake}

WZ Control / Signal Regions

$W^{\pm}Z^{0} \rightarrow \ell^{\pm}\ell^{+}\ell^{-} + \not\!\!E_T$ Signal Region

- Z^0 mass region ($76 < M_{\ell+\ell-} < 106$)
- $\not\!\!E_T > 25$ GeV

Dilepton (Drell-Yan) Region:

Tests efficiency and acceptance calculations

- Z^0 mass region ($76 < M_{\ell+\ell-} < 106$)
- Invert $\not\!\!E_T$ cut

Trilepton Control regions

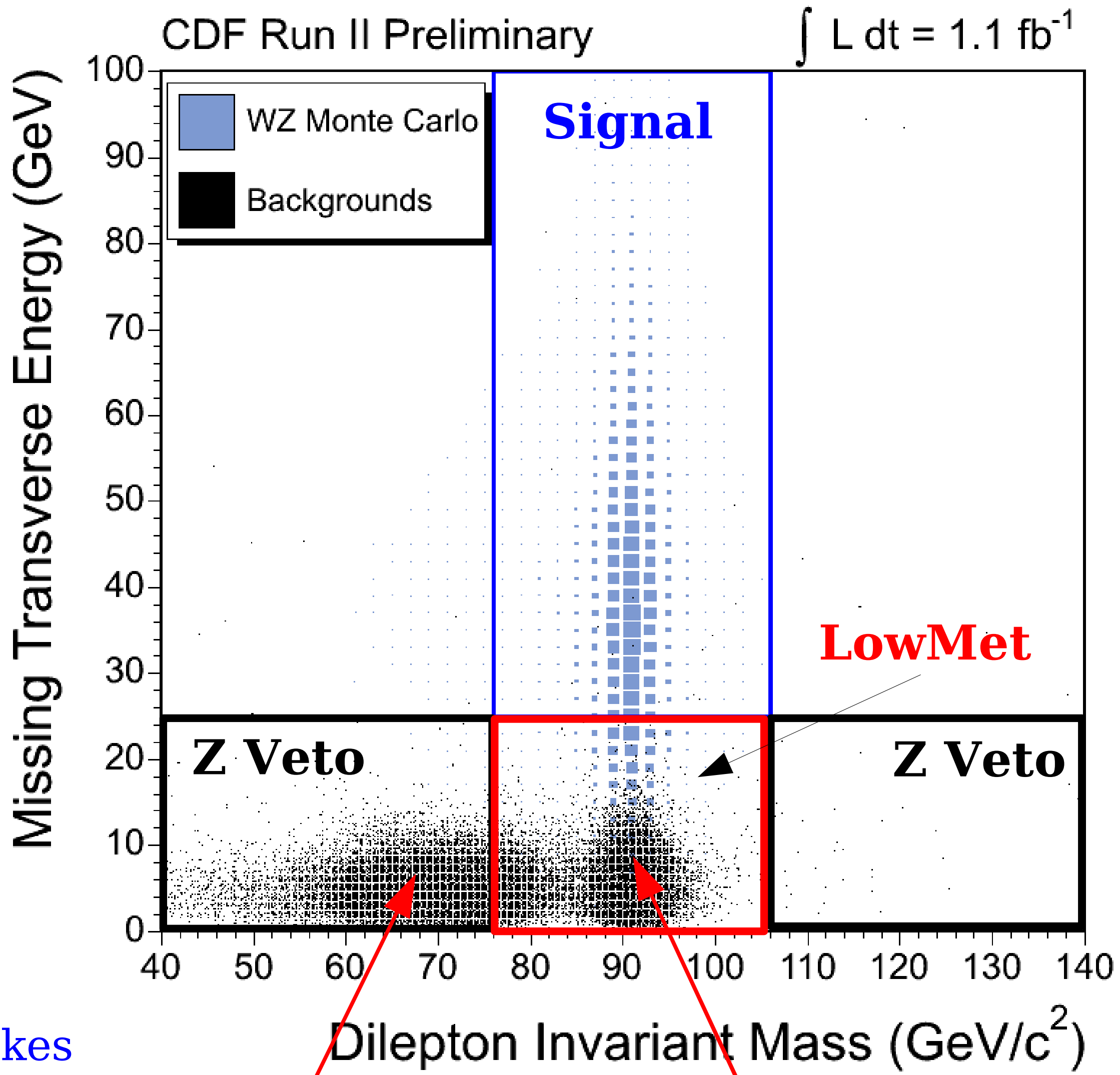
Tests background modeling

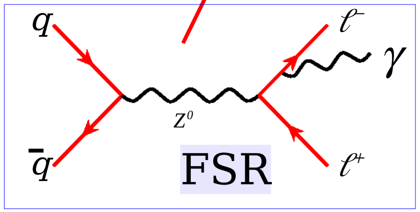
Low MET Region: ← Zγ ISR, Z+jet fakes

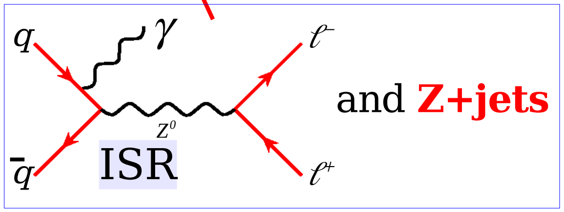
- Invert $\not\!\!E_T$ cut

Z Veto Region: ← Zγ FSR dominated

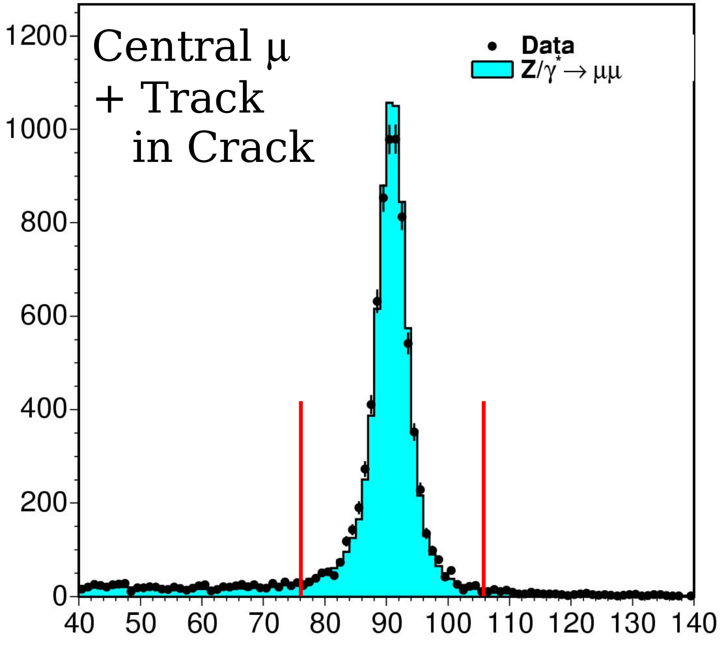
- Invert Z^0 mass cut
- Invert $\not\!\!E_T$ cut

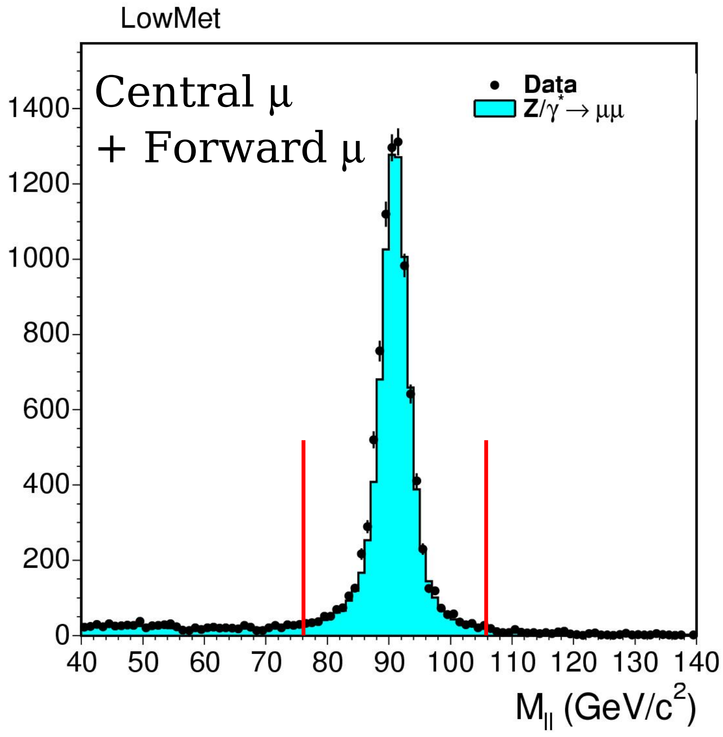


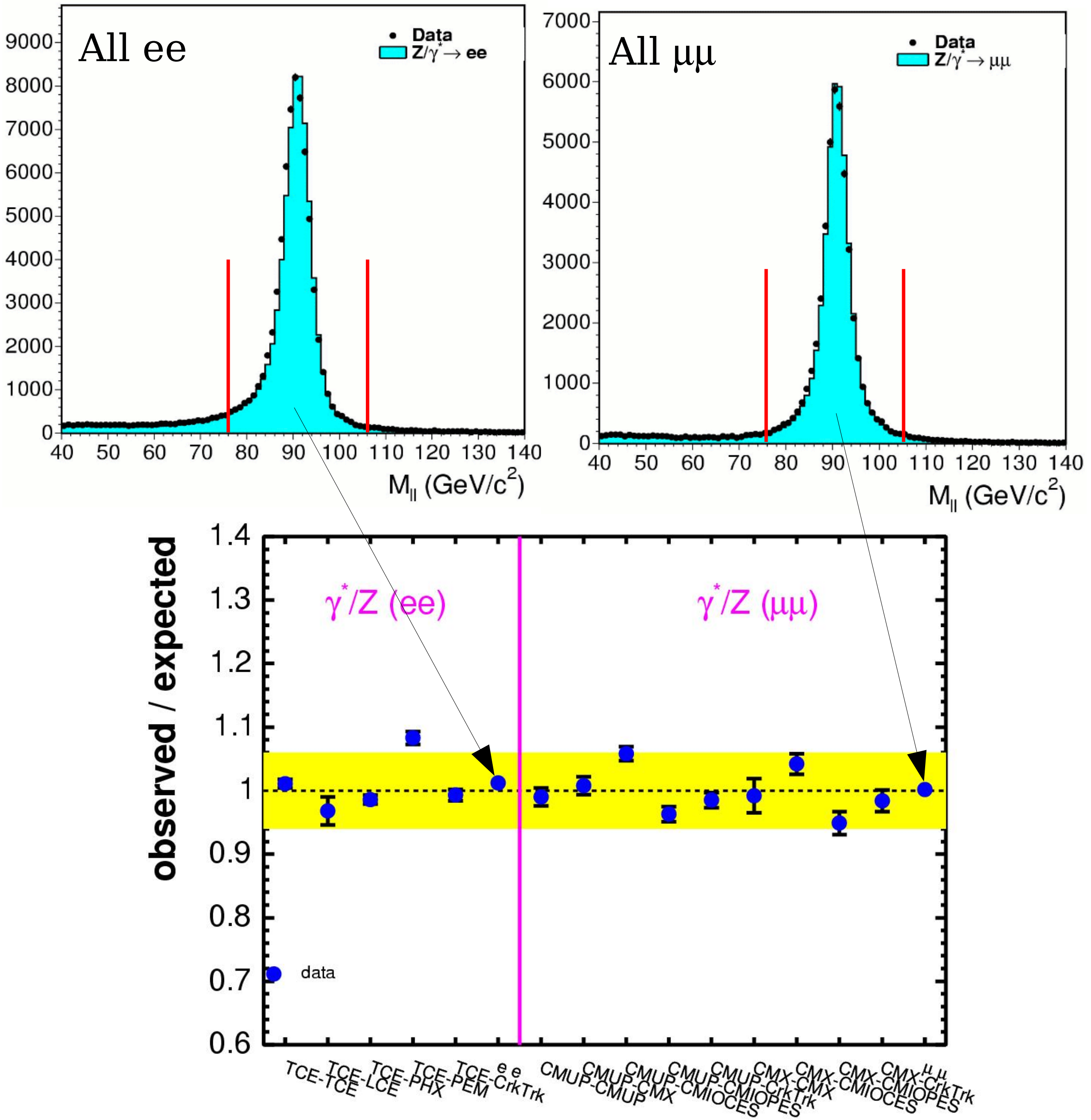




Dilepton (Drell-Yan) Control Region

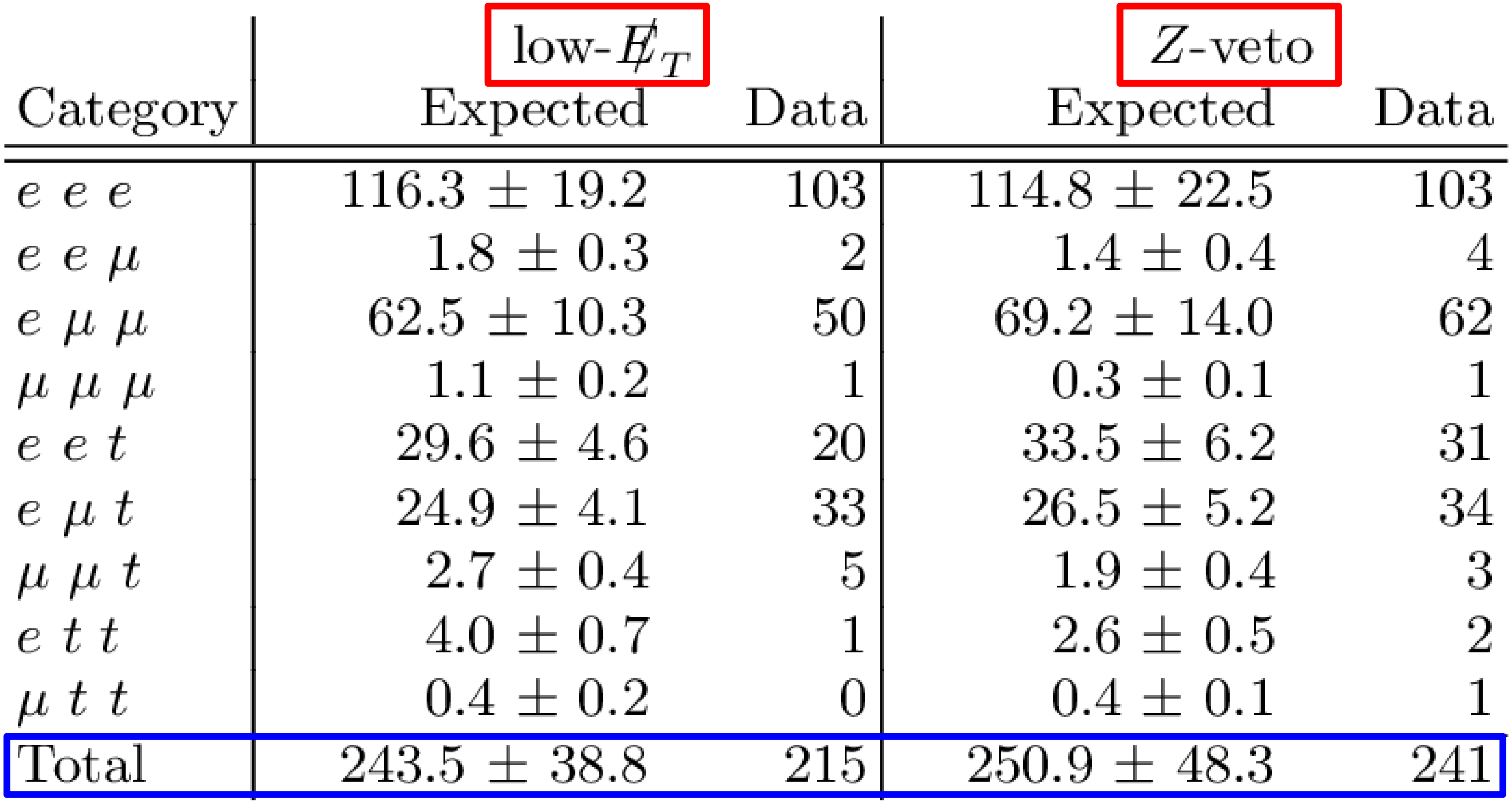






All of our triggerable dilepton pairs

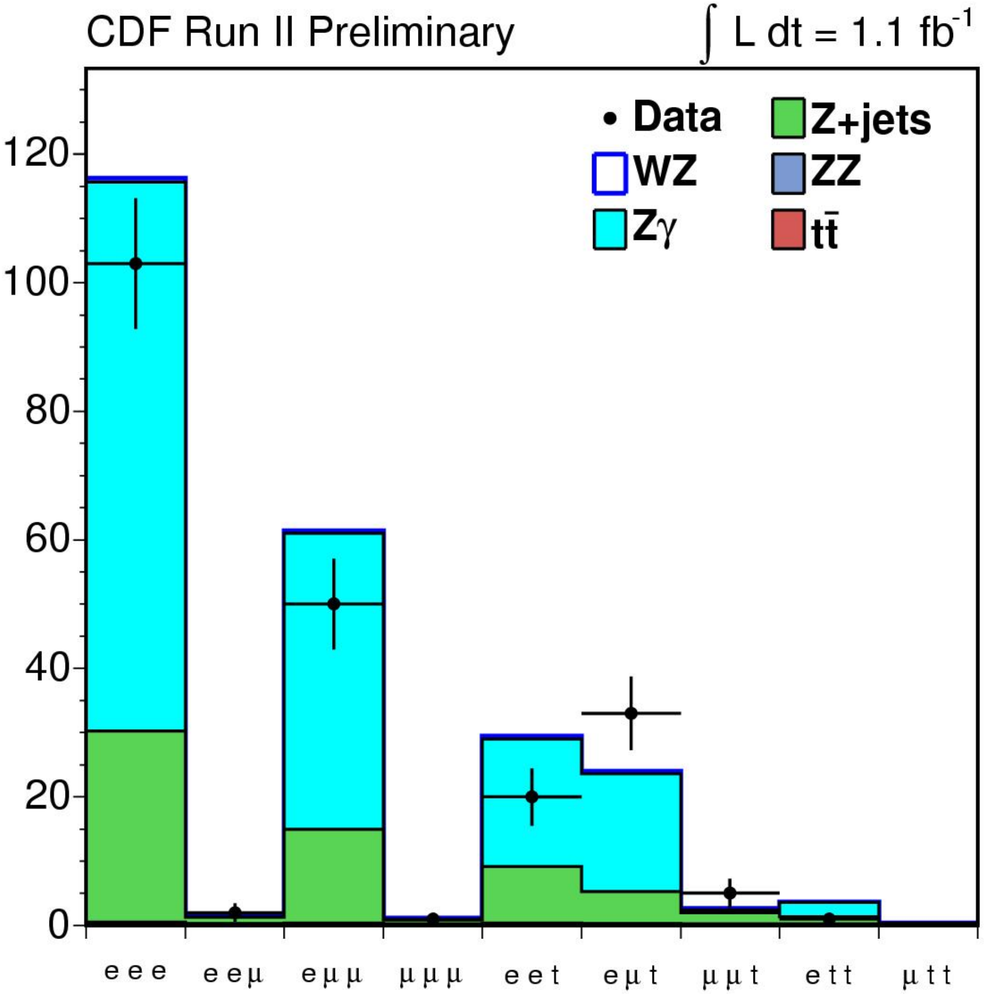
Trilepton Control Region Results



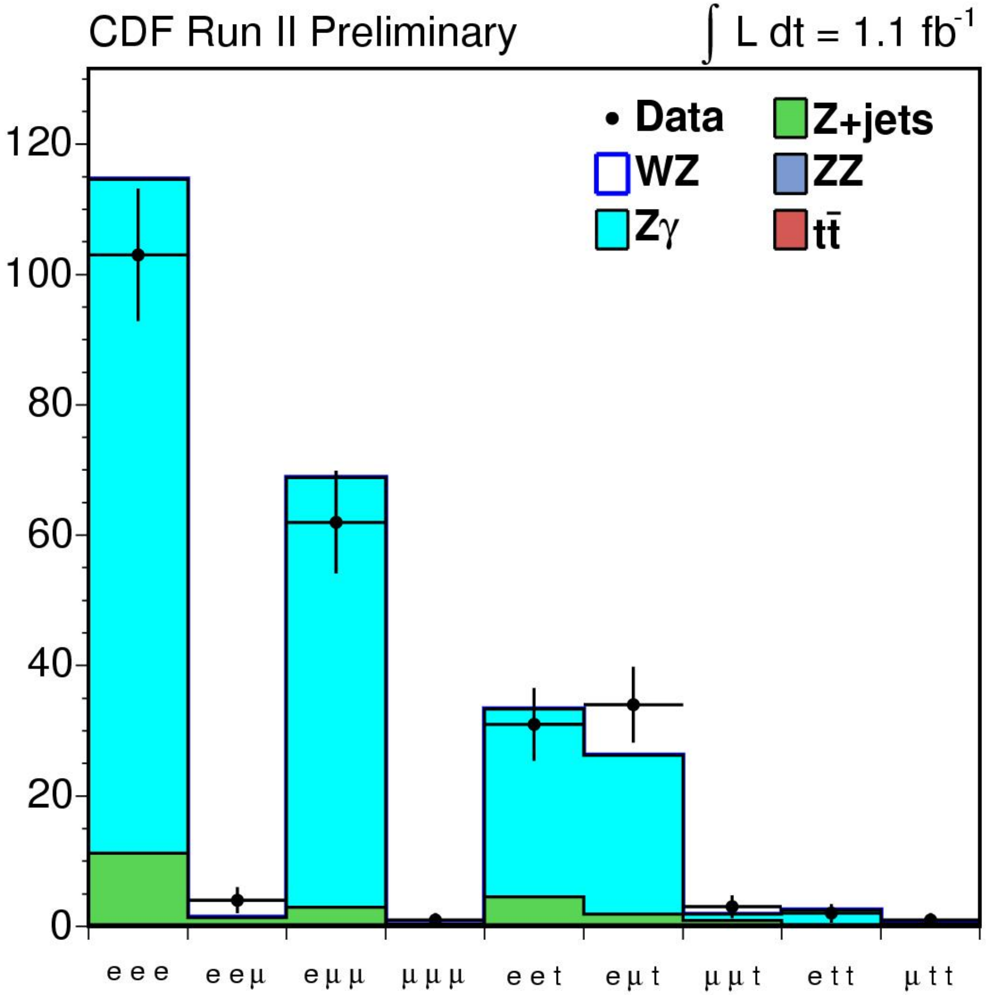
Category	low-$\not{E}_T$ Expected	Data	Z-veto Expected	Data
$e\ e\ e$	116.3 ± 19.2	103	114.8 ± 22.5	103
$e\ e\ \mu$	1.8 ± 0.3	2	1.4 ± 0.4	4
$e\ \mu\ \mu$	62.5 ± 10.3	50	69.2 ± 14.0	62
$\mu\ \mu\ \mu$	1.1 ± 0.2	1	0.3 ± 0.1	1
$e\ e\ t$	29.6 ± 4.6	20	33.5 ± 6.2	31
$e\ \mu\ t$	24.9 ± 4.1	33	26.5 ± 5.2	34
$\mu\ \mu\ t$	2.7 ± 0.4	5	1.9 ± 0.4	3
$e\ t\ t$	4.0 ± 0.7	1	2.6 ± 0.5	2
$\mu\ t\ t$	0.4 ± 0.2	0	0.4 ± 0.1	1
Total	243.5 ± 38.8	215	250.9 ± 48.3	241

Trilepton Control Regions: Flavors

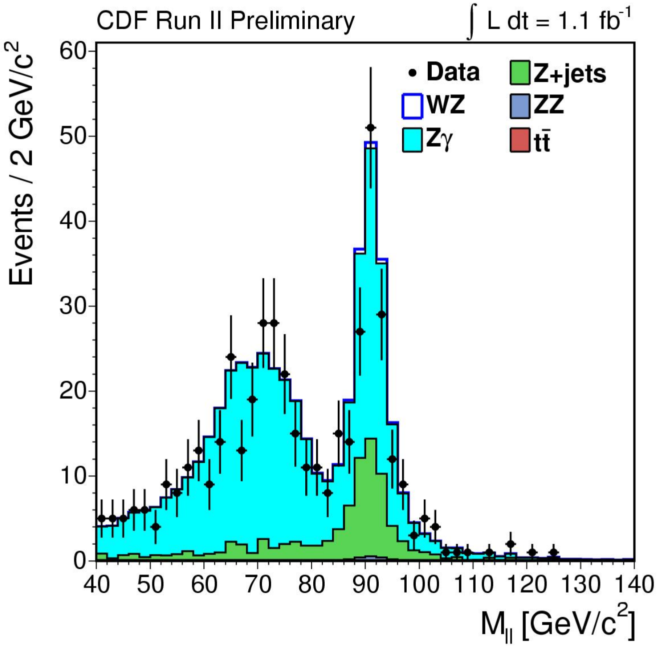
Low MET

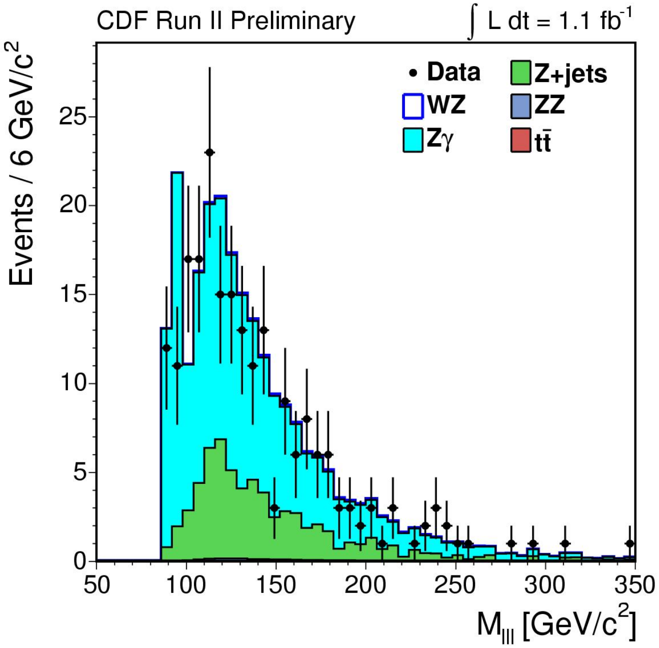


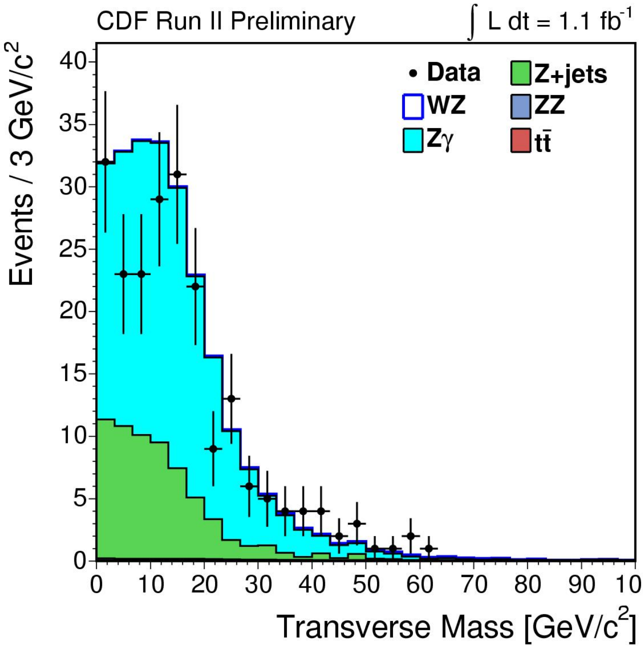
Z Veto

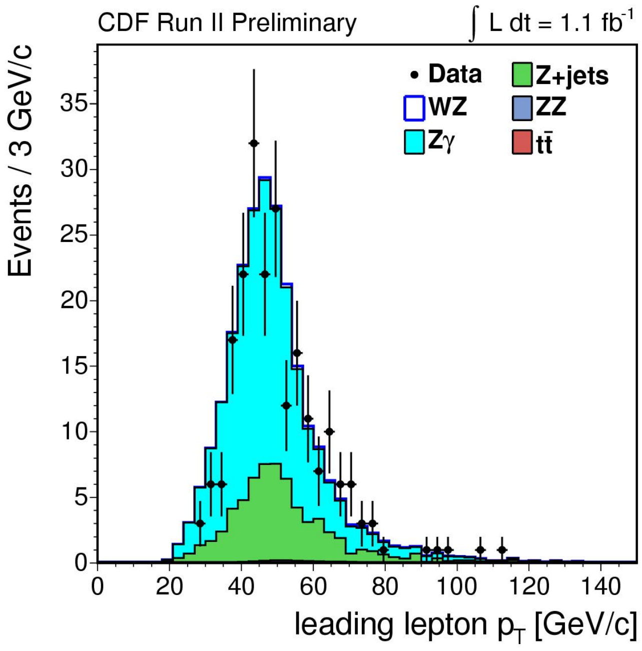


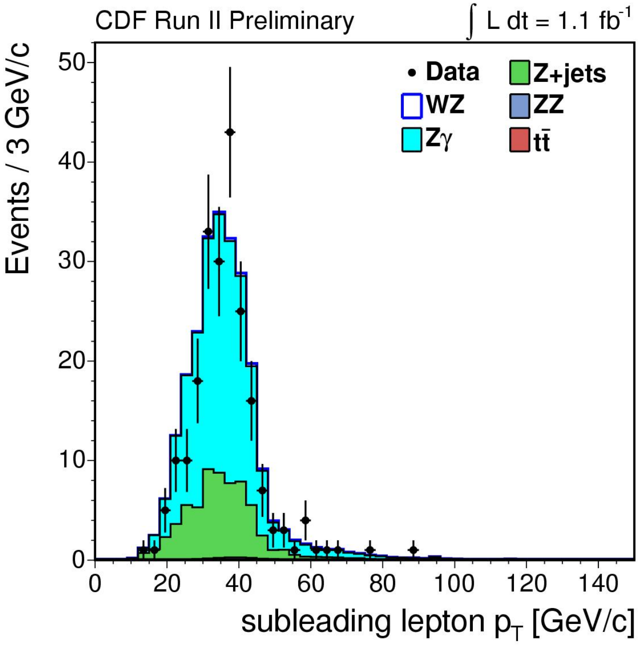
Low MET Region: Kinematics

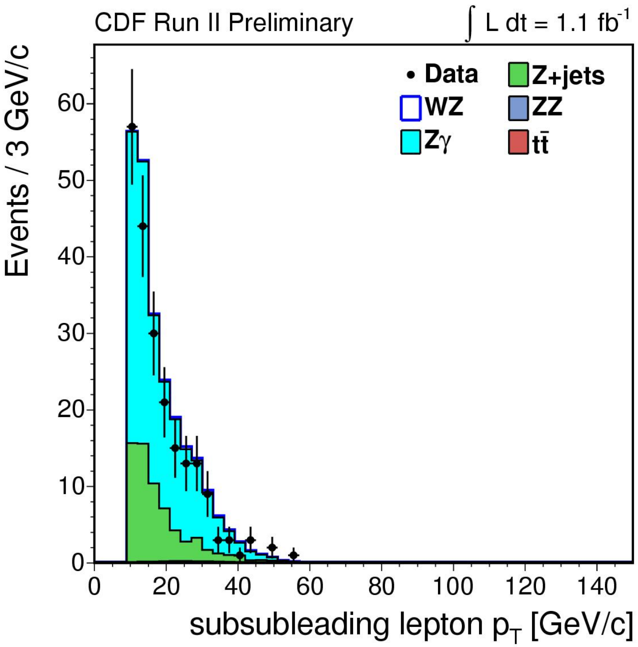




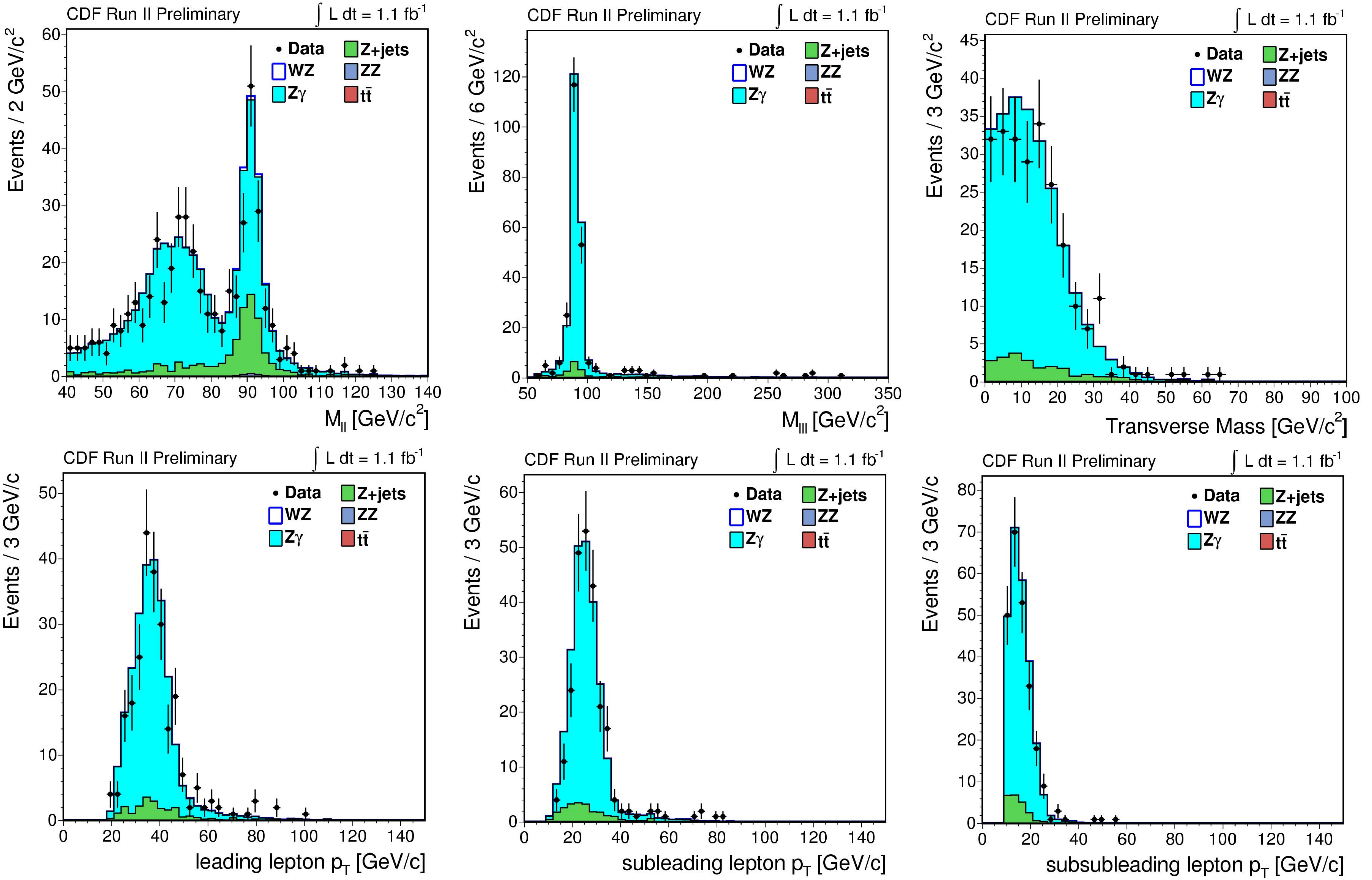




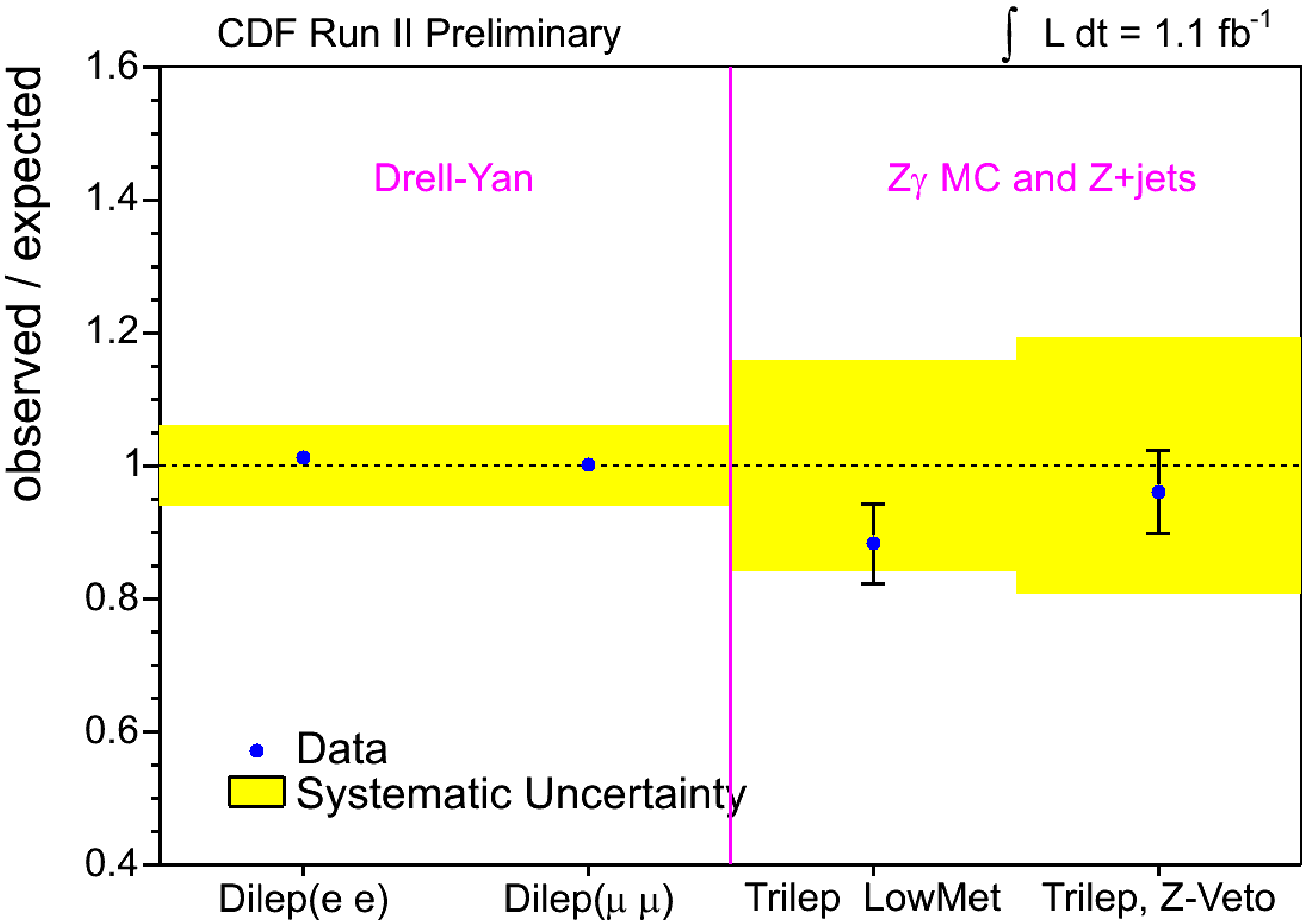




Z Veto Region: Kinematics



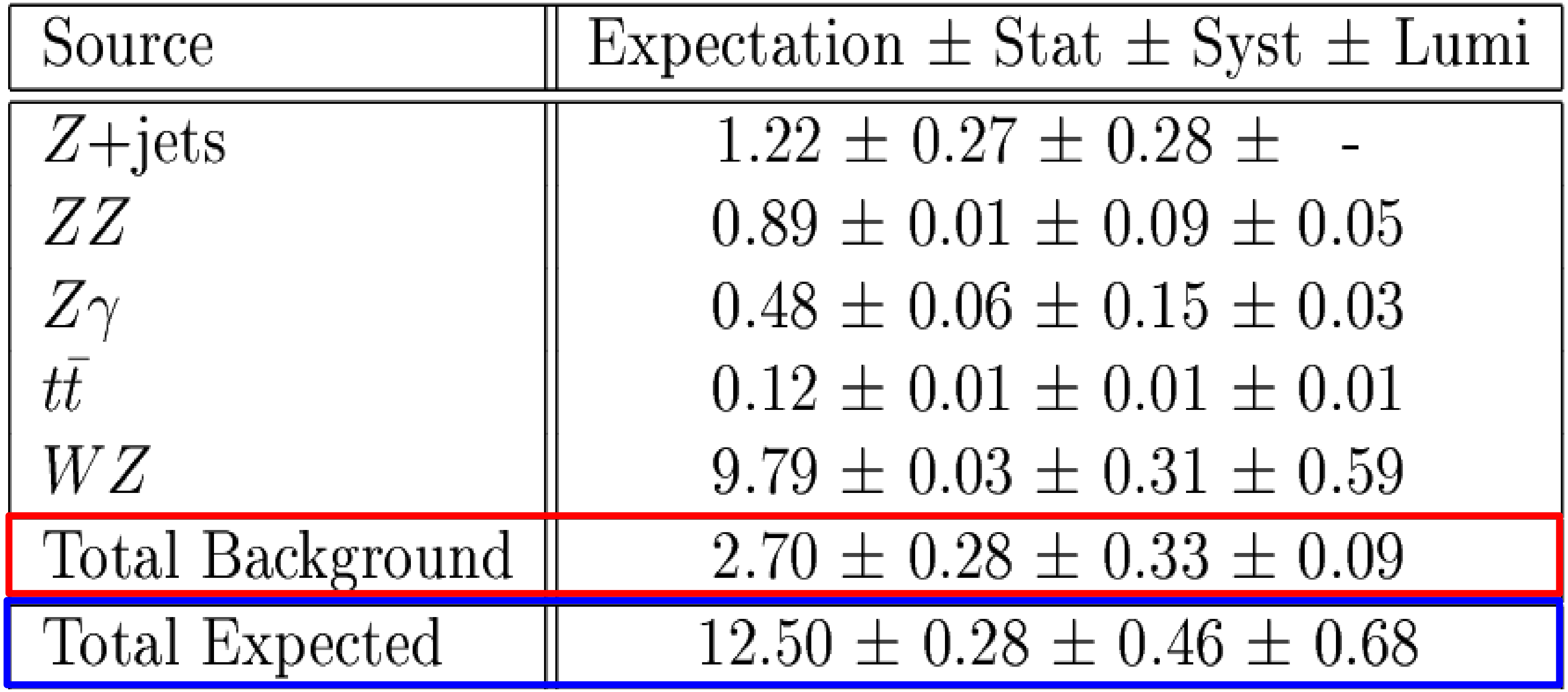
Control Region Summary



WZ Signal Region Expectations

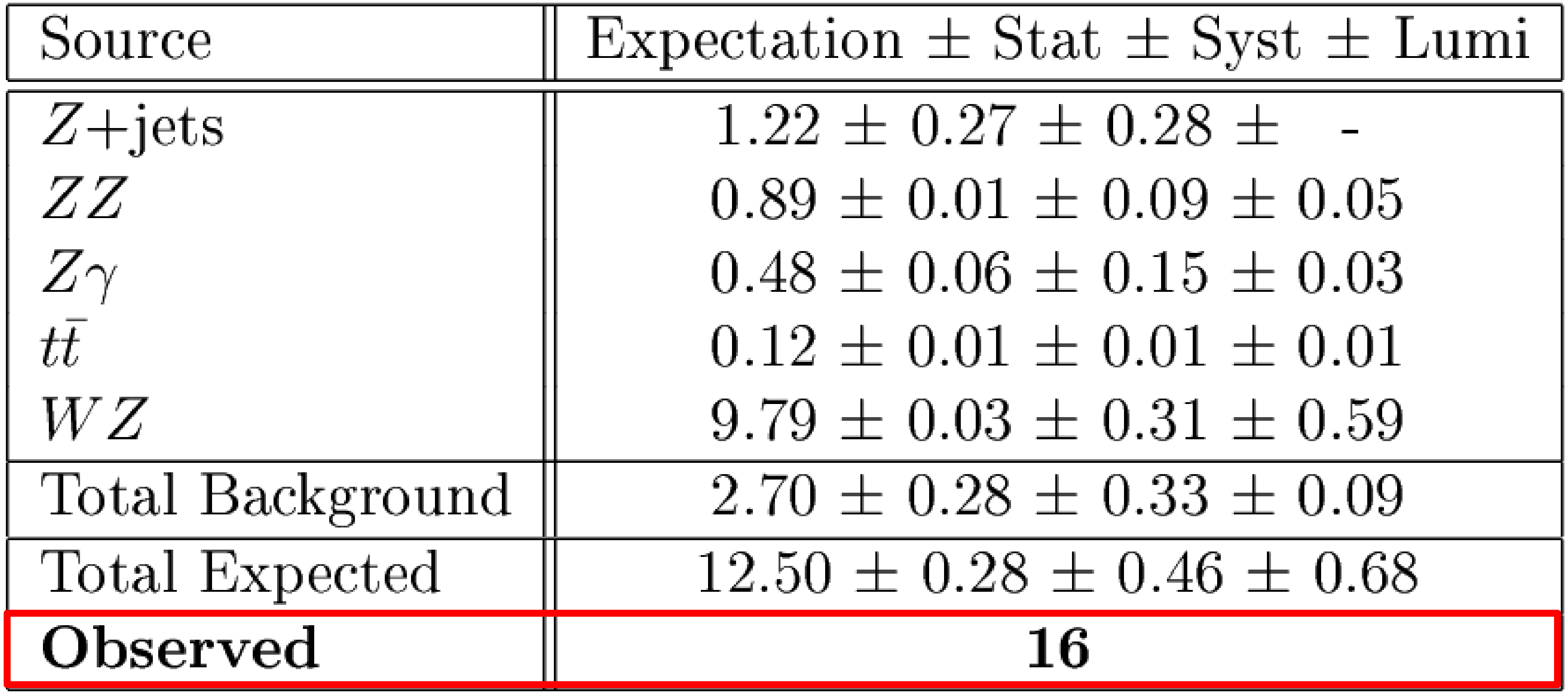
Good agreement in control regions validates
background modeling, acceptance calculations, and luminosity accounting

In the signal region:



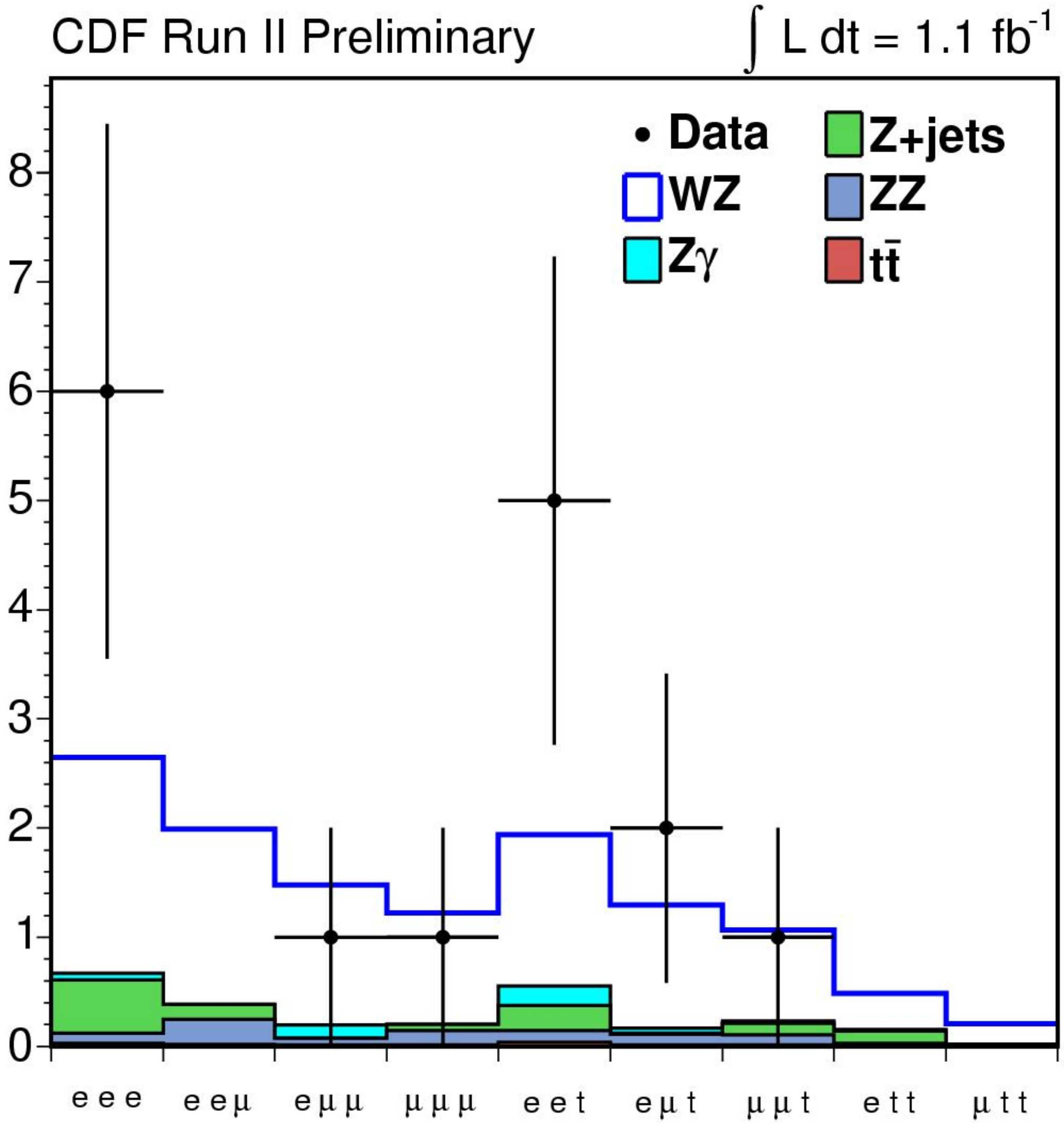
Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	$1.22 \pm 0.27 \pm 0.28 \pm$ -
ZZ	$0.89 \pm 0.01 \pm 0.09 \pm 0.05$
$Z\gamma$	$0.48 \pm 0.06 \pm 0.15 \pm 0.03$
$t\bar{t}$	$0.12 \pm 0.01 \pm 0.01 \pm 0.01$
WZ	$9.79 \pm 0.03 \pm 0.31 \pm 0.59$
Total Background	$2.70 \pm 0.28 \pm 0.33 \pm 0.09$
Total Expected	$12.50 \pm 0.28 \pm 0.46 \pm 0.68$

WZ Signal Region Results



Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	1.22 ± 0.27 ± 0.28 ± -
ZZ	0.89 ± 0.01 ± 0.09 ± 0.05
$Z\gamma$	0.48 ± 0.06 ± 0.15 ± 0.03
$t\bar{t}$	0.12 ± 0.01 ± 0.01 ± 0.01
WZ	9.79 ± 0.03 ± 0.31 ± 0.59
Total Background	2.70 ± 0.28 ± 0.33 ± 0.09
Total Expected	12.50 ± 0.28 ± 0.46 ± 0.68
Observed	**16**

Signal Region: Trilepton Types



6	(2.7 ± 0.2)	eee
0	(2.0 ± 0.2)	eeμ
1	(1.5 ± 0.1)	eμμ
1	(1.2 ± 0.1)	μμμ
5	(2.0 ± 0.2)	eet
2	(1.3 ± 0.1)	eμt
1	(1.1 ± 0.1)	μμt
0	(0.5 ± 0.1)	ett
0	(0.2 ± 0.1)	μtt

Determining the Significance

Use $\not{E}_T$ information in addition to the yields

Two bins in $\not{E}_T$ (optimized a priori for expected significance using independent DY samples):

- N_{obs} (25 < $\not{E}_T$ < 45 GeV) = 9   (2.0 ± 0.4 bkg exp)
- N_{obs} ($\not{E}_T$ > 45 GeV) = 7   (0.7 ± 0.1 bkg exp)

Fit for most likely signal yield…

$$\Delta(\ln L) = \ln L_{Nsignal=0} - \ln L_{best\ fit}$$

Our result has $2\Delta(\ln L) = 37.8$

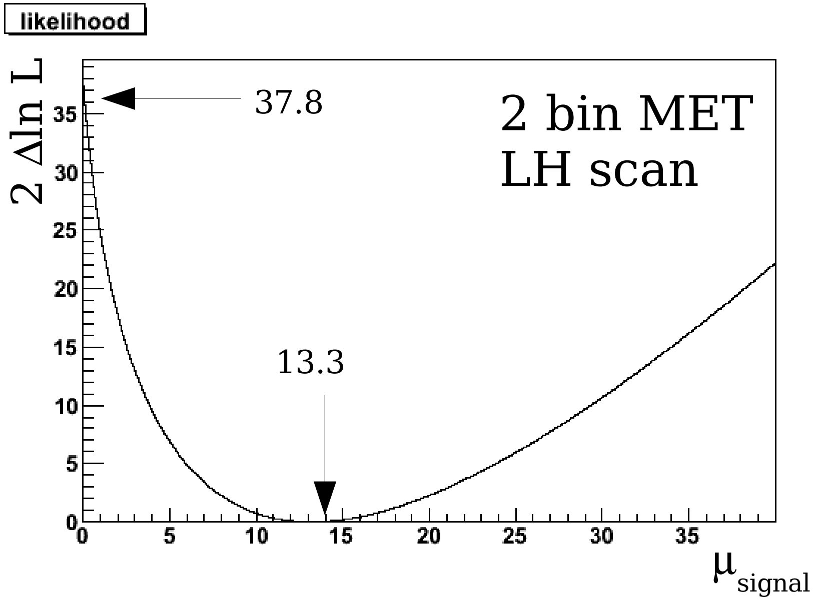
In 10 billion background-only pseudo-experiments, only 11 had $2\Delta(\ln L) > 37.8$

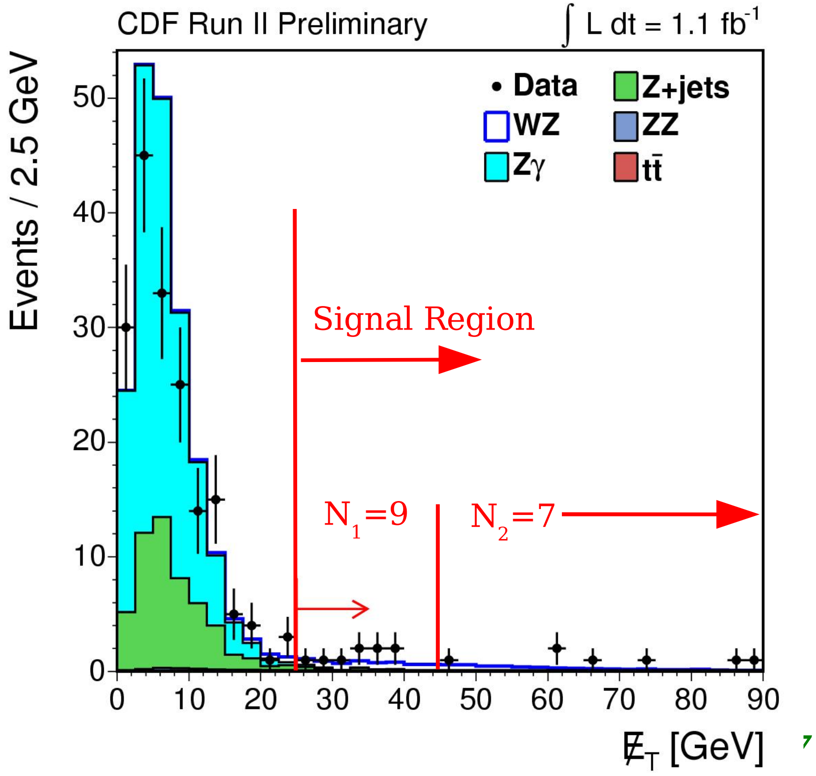
- Prob(background only) < 1.1×10^{-9} (6 σ)

⇒ First observation of WZ production!

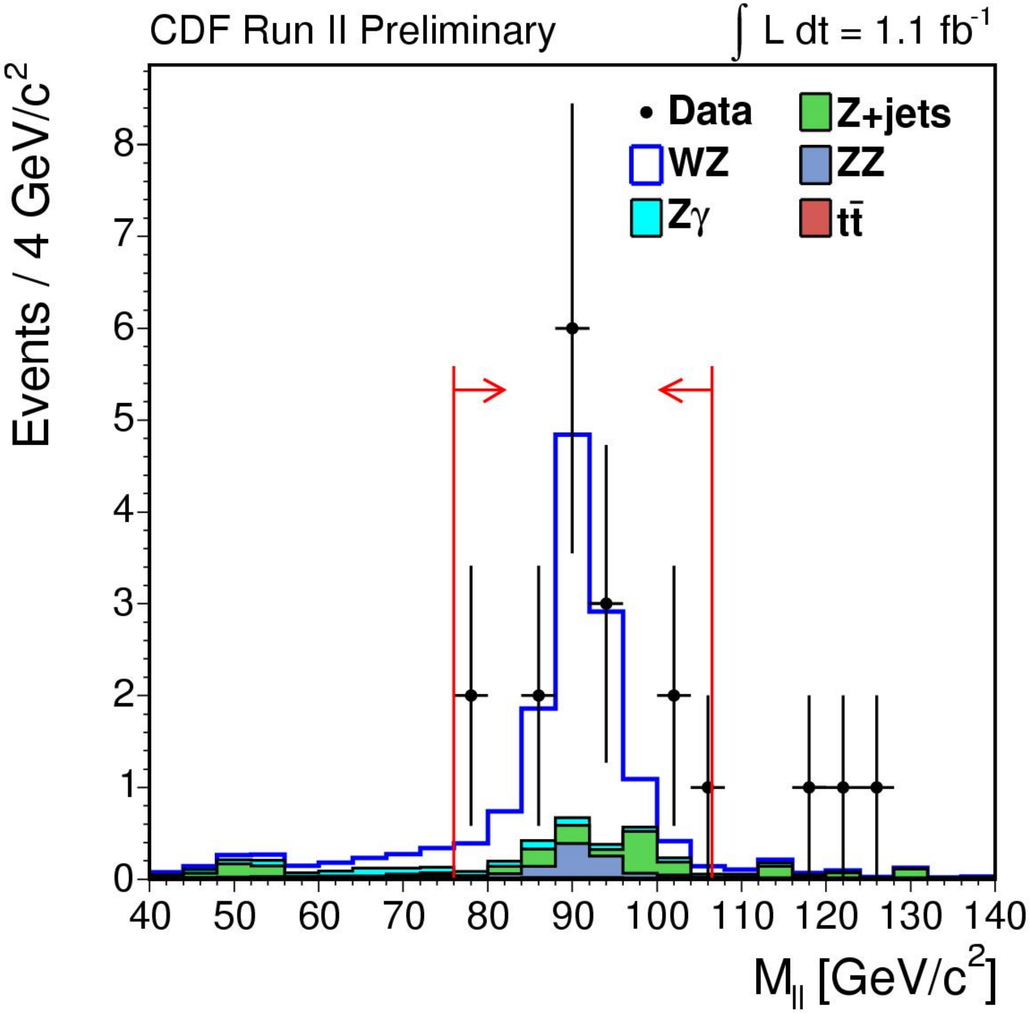
We also note that our 2-bin result is ordinary for the sum of Standard Model WZ and background.

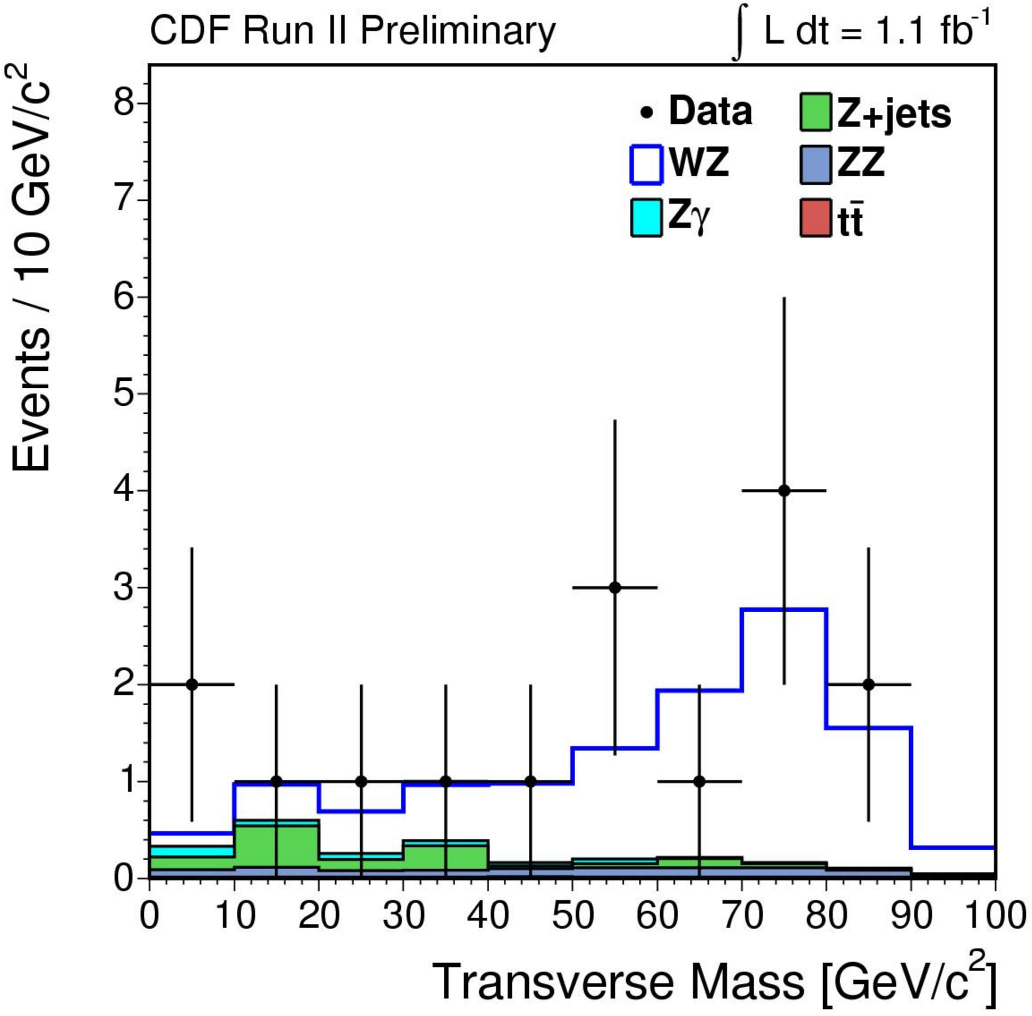
- 49% of pseudo-experiments have a joint 2-bin probability smaller than our data





Is it really WZ?



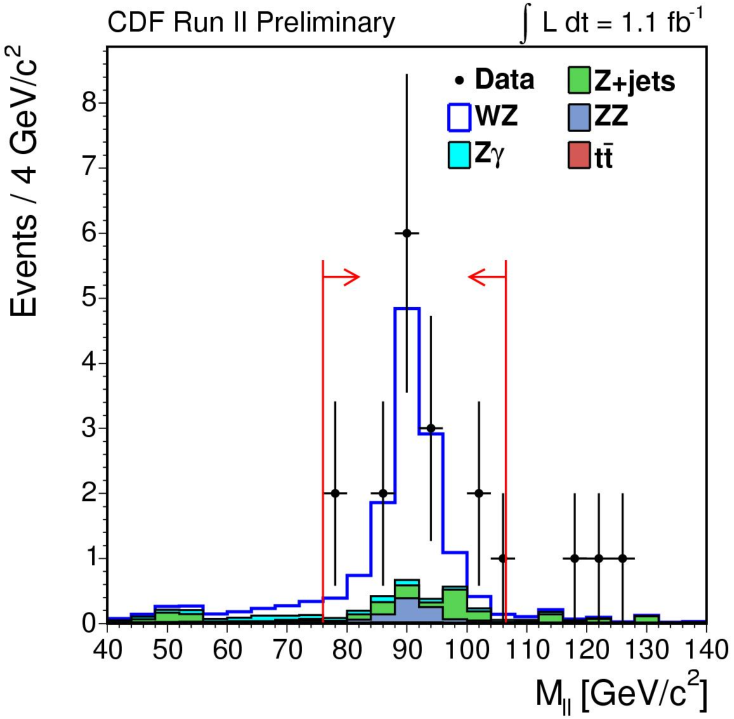


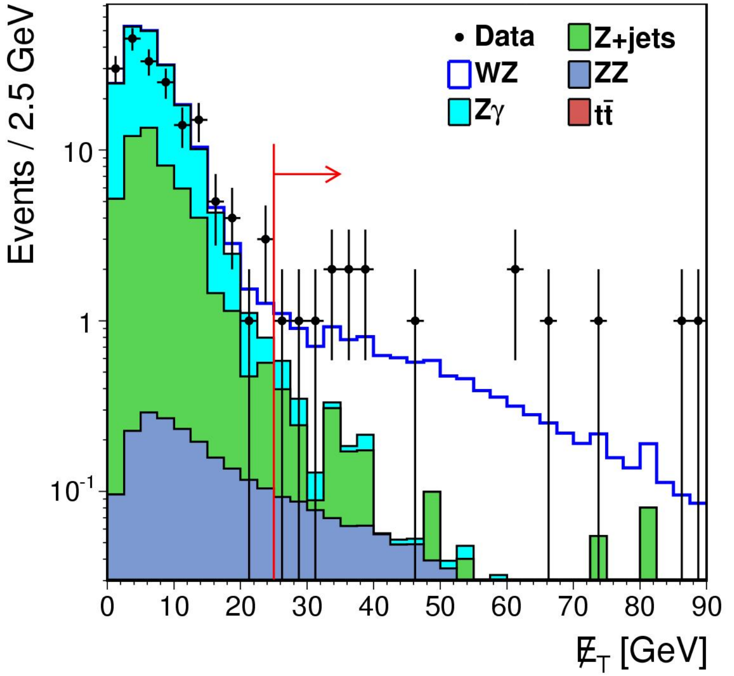
$$m_T c^2 = \sqrt{E_T \not{E}_T (1 - \cos\Delta\phi)}$$

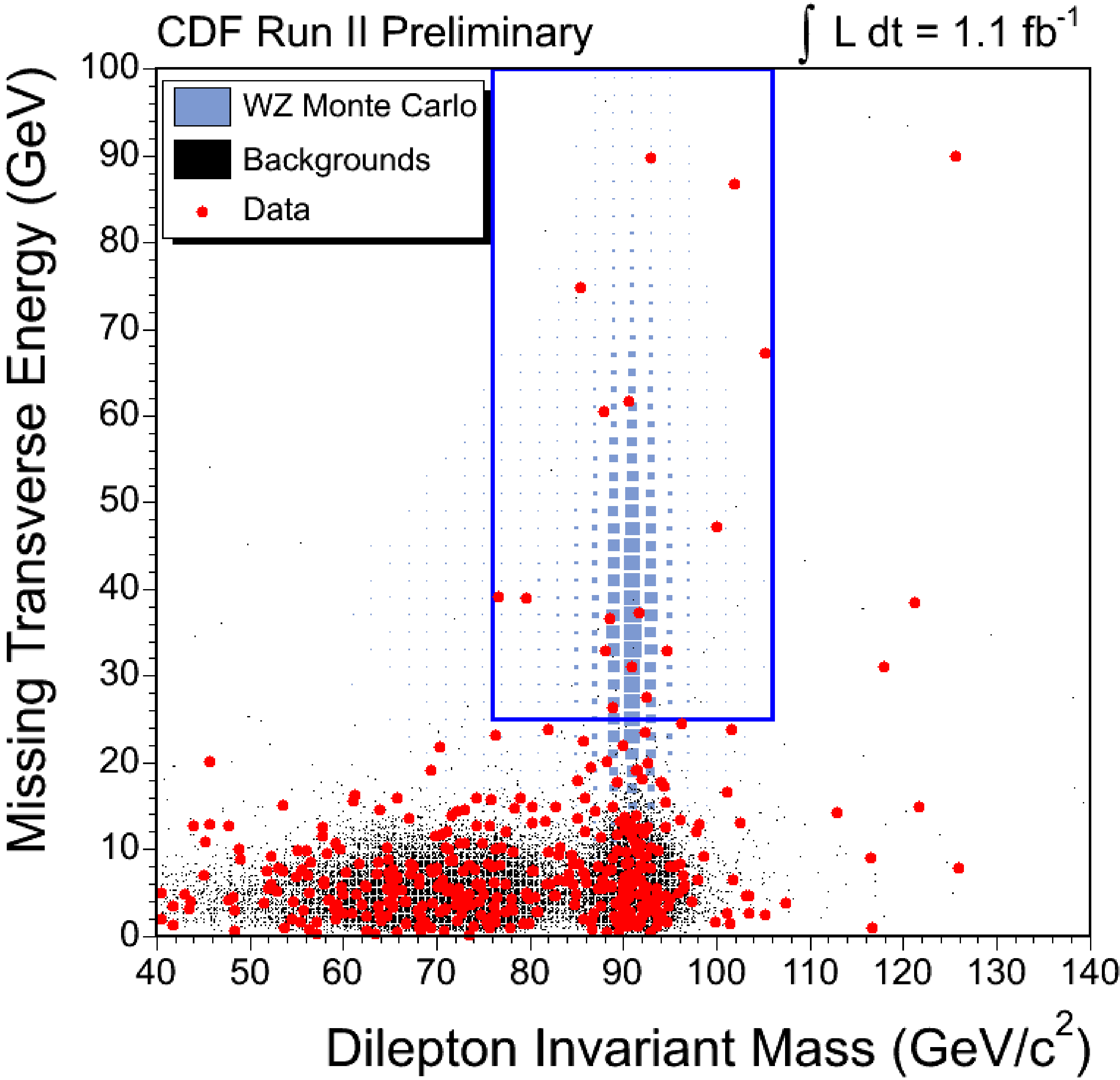
$$\boxed{\sigma(WZ) = 5.0^{+1.8}_{-1.6}\ \text{(stat.+syst.) pb}}$$

consistent with NLO
σ(WZ) = 3.7 ± 0.3 pb

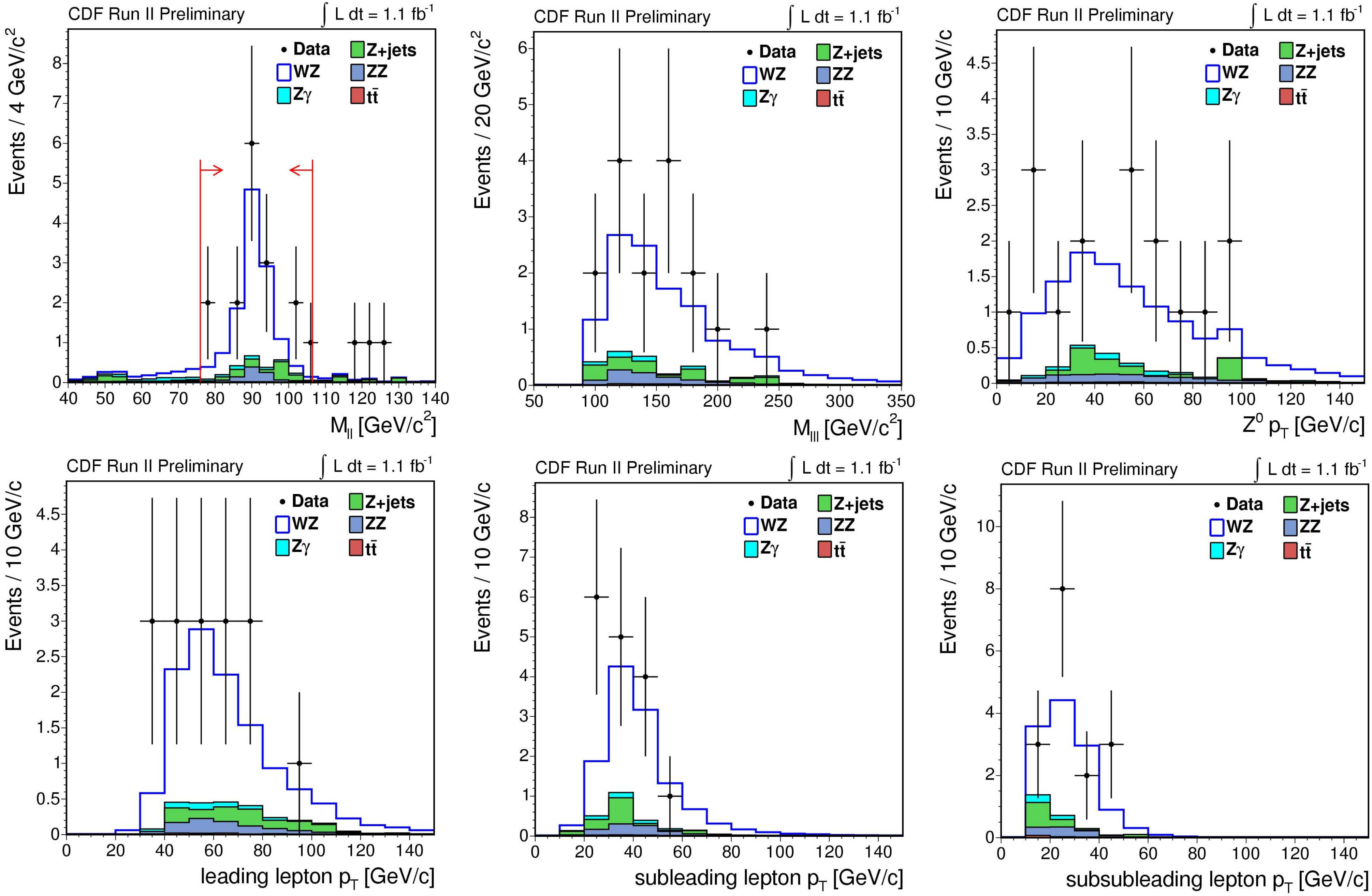
2-D Plot: MET vs. Mll







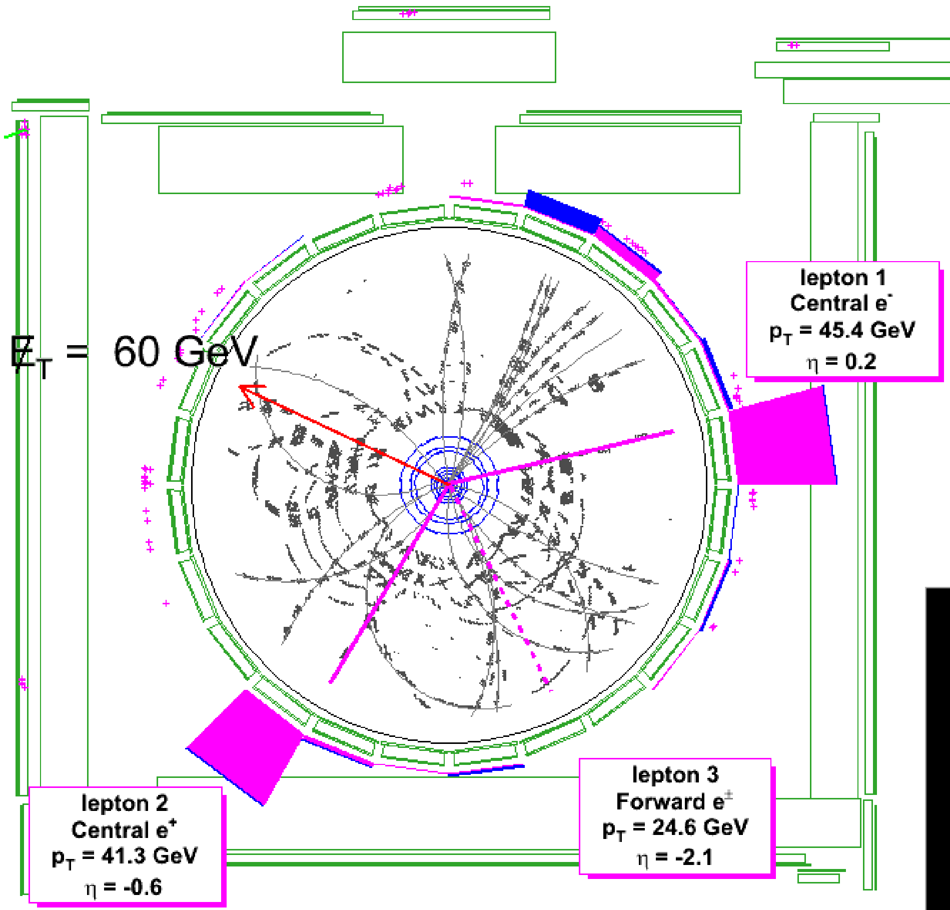
WZ Signal Region Kinematics



Mark Neubauer

SMU Seminar / Jan 22, 2007

$W^{\pm}Z^0 \rightarrow e^{\pm}\overset{(-)}{\nu}_e e^+e^-$ Candidate

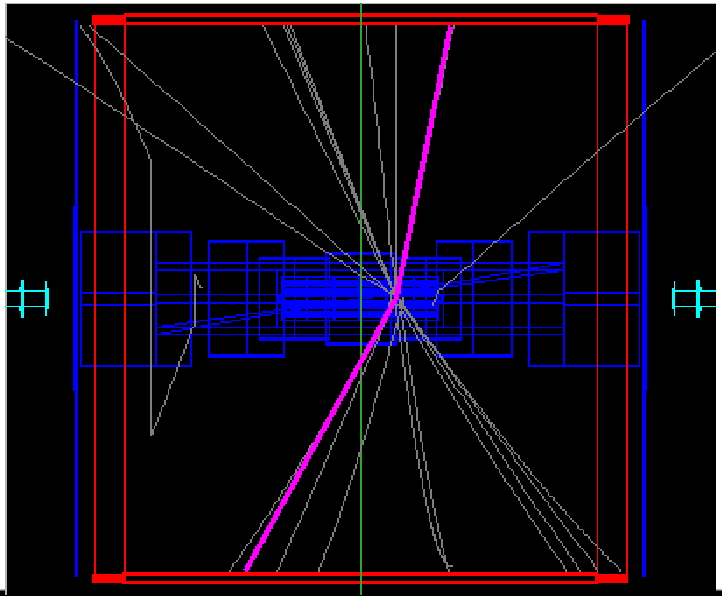


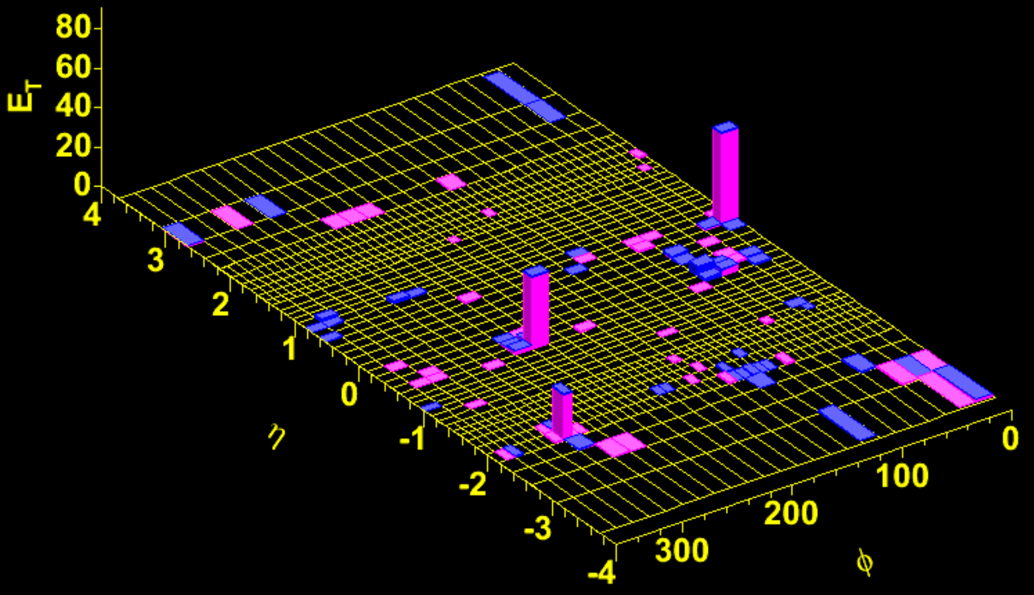
$\not{E}_T$ = 60 GeV

lepton 1
Central e^-
p_T = 45.4 GeV
η = 0.2

lepton 2
Central e^+
p_T = 41.3 GeV
η = -0.6

lepton 3
Forward $e^{\pm}$
p_T = 24.6 GeV
η = -2.1



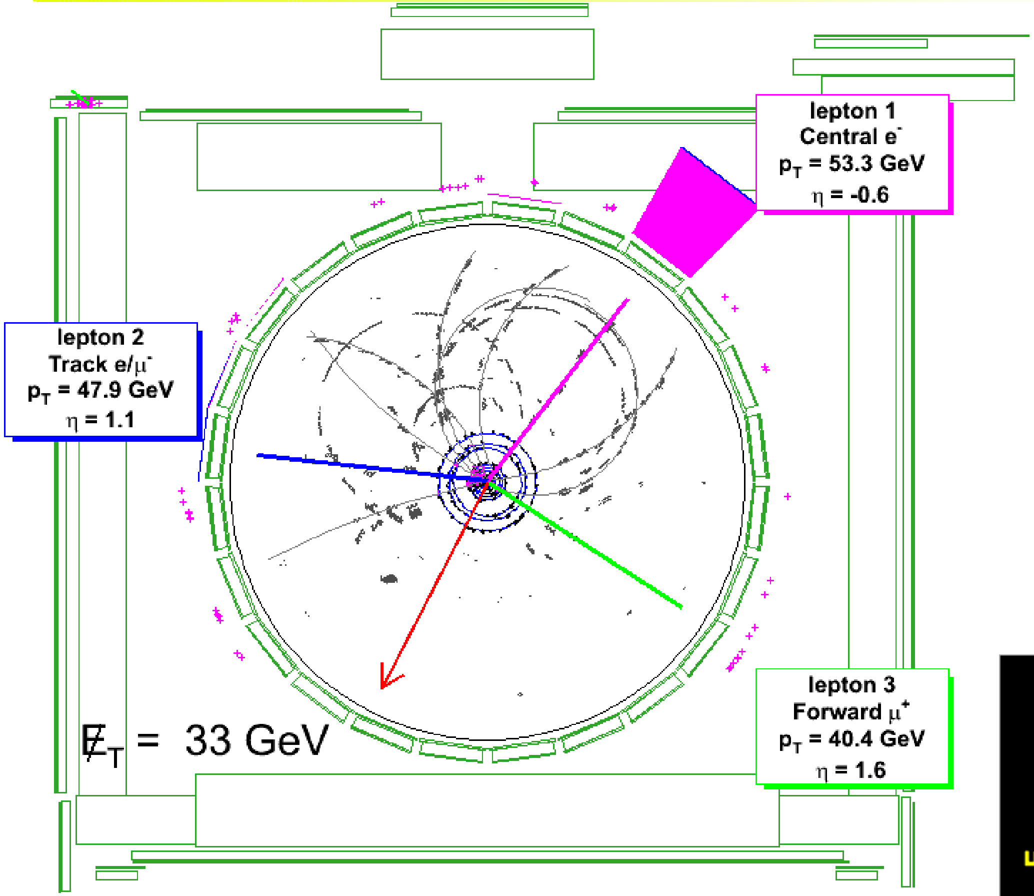


Run=154799 Event=1795709

m_{12}=87.91 GeV $|\not{E}_T|$=60.5 GeV
m_{13}=104.37 GeV $\Delta\phi(\not{E}_T, \text{lepton}, \text{jet})$=1.5
m_{23}=59.62 GeV

Type	p_t	η	ϕ
Central *e*	45.4	0.2	0.2
Central *e*	41.3	-0.6	-2.1
Forward *e*	24.6	-2.1	-1.1

$W^-Z^0 \to e^-\bar{\nu}_e\mu^+\mu^-$ Candidate

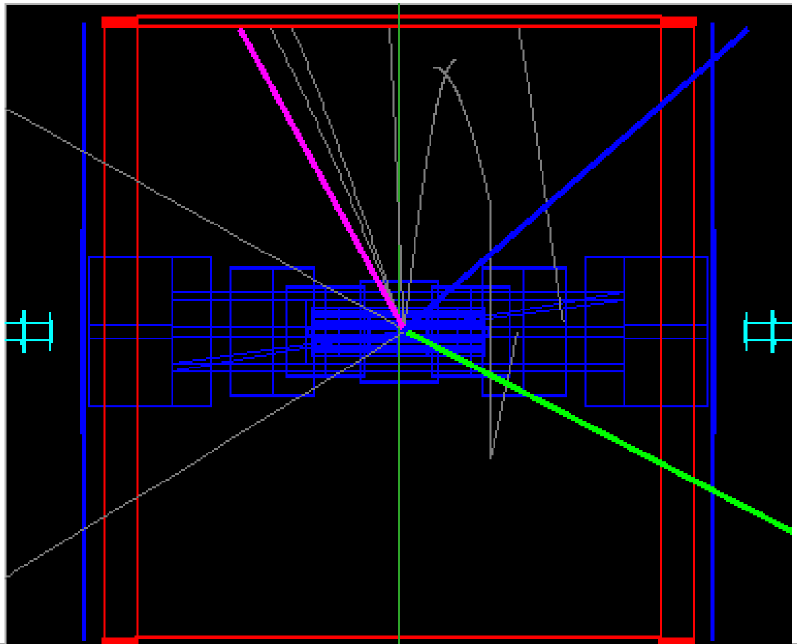


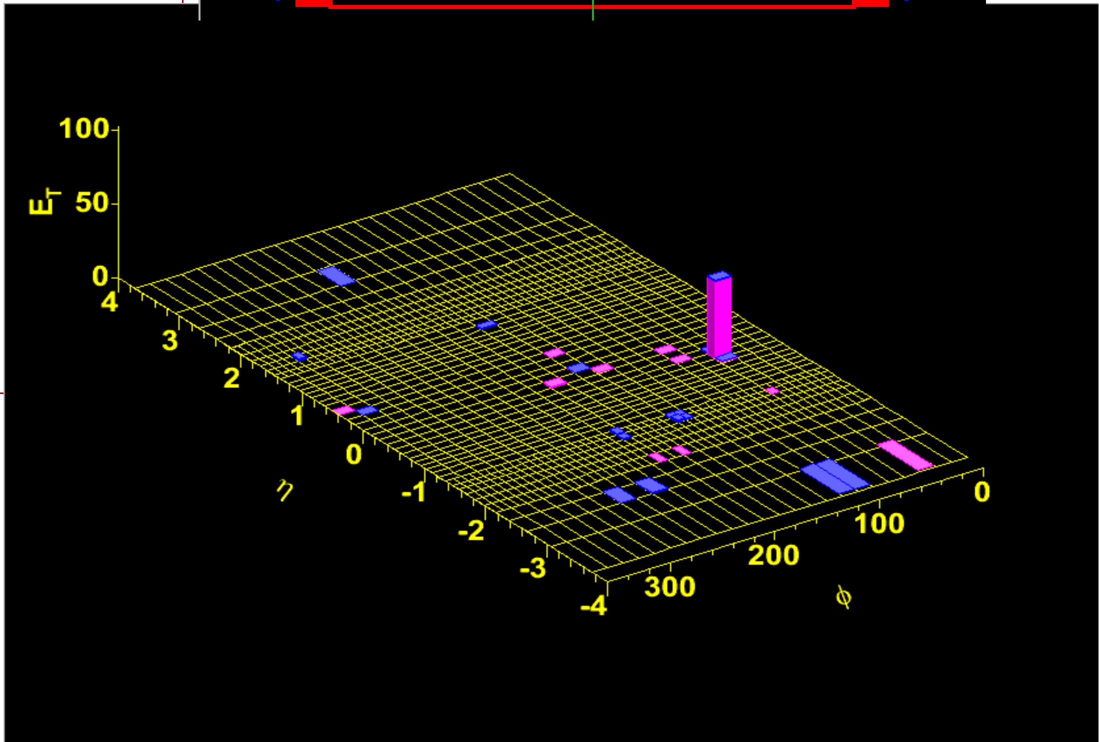
lepton 1
Central e^-
p_T = 53.3 GeV
η = -0.6

lepton 2
Track e/μ^-
p_T = 47.9 GeV
η = 1.1

lepton 3
Forward μ^+
p_T = 40.4 GeV
η = 1.6

$\not\!E_T$ = 33 GeV



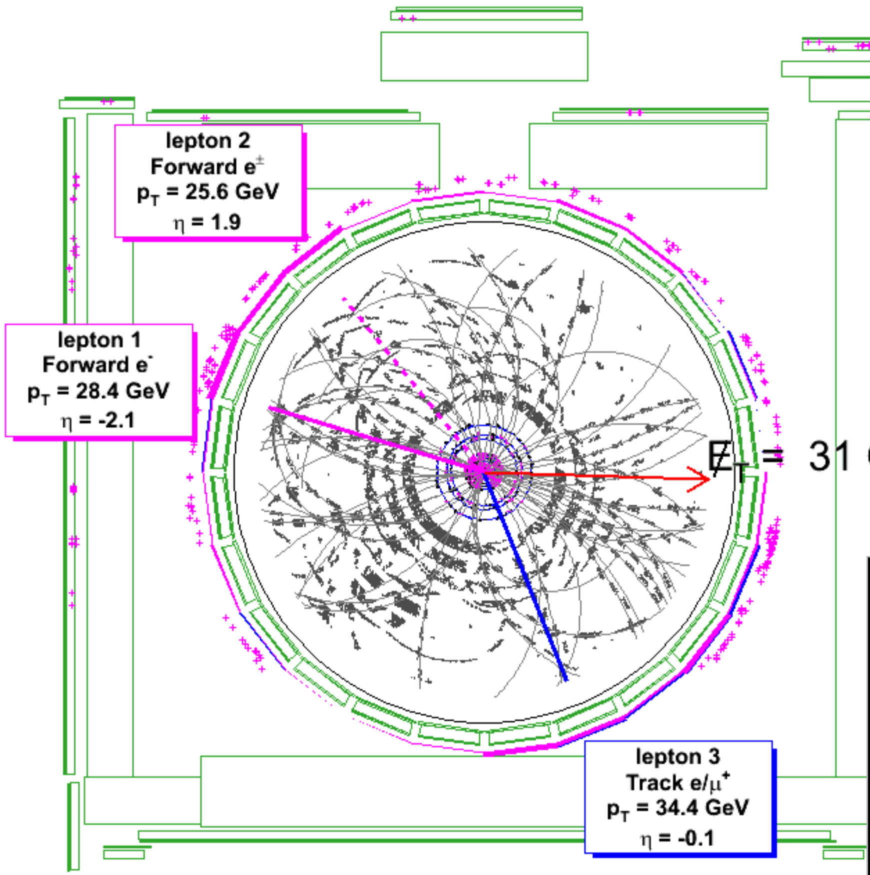


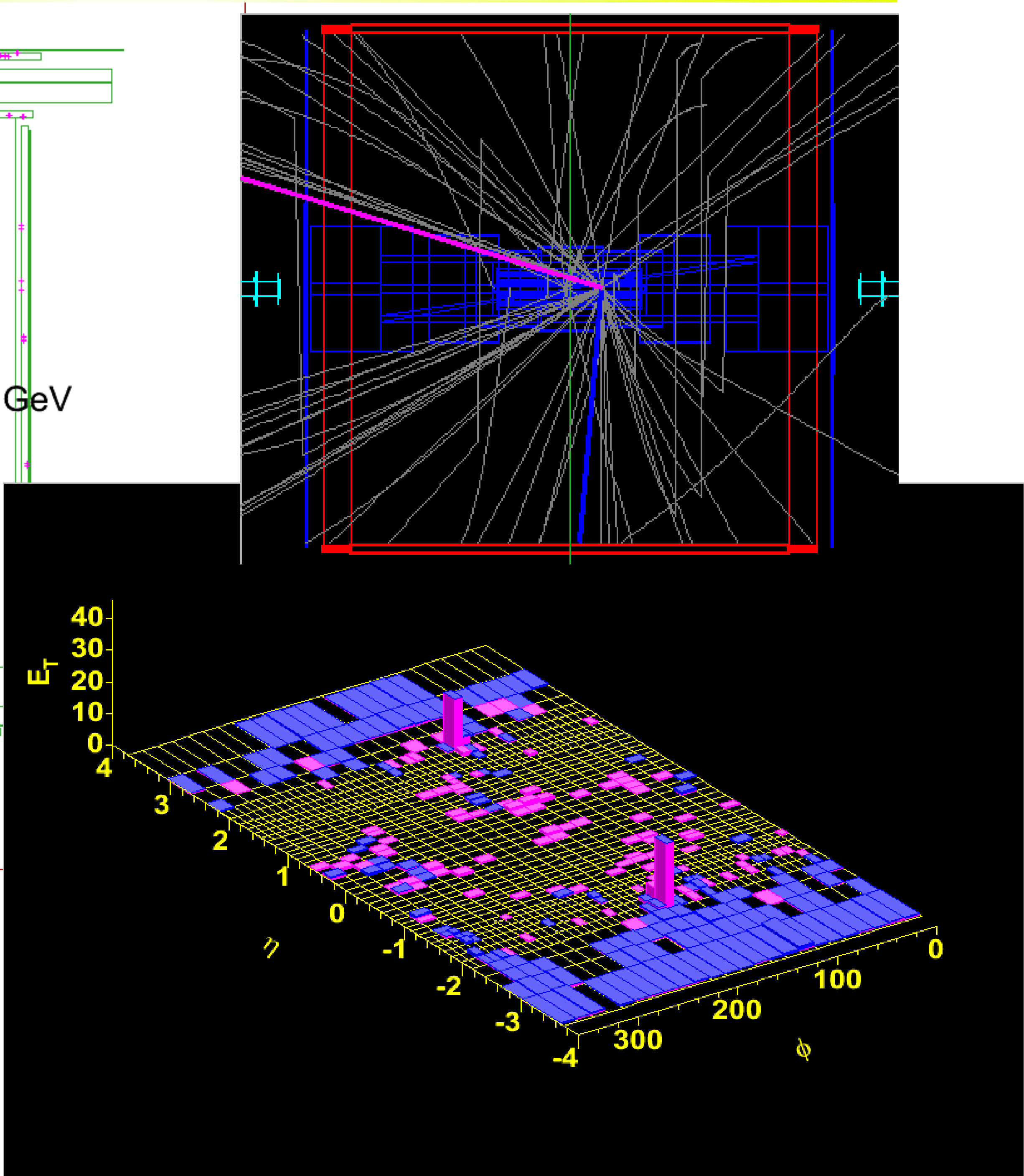
Run=167634 Event=627292

m_{12}=131.15 GeV $|\not\!E_T|$=32.8 GeV
m_{13}=136.36 GeV $\Delta\phi(\not\!E_T, \text{lepton}, \text{jet})$=1.2
m_{23}=88.09 GeV

Type	p_t	η	ϕ
Central e	53.3	-0.6	0.9
Track e/μ	47.9	1.1	3.0
Forward μ	40.4	1.6	-0.6

$W^{\pm}Z^{0} \rightarrow e^{\pm}\overset{(-)}{\nu}_{e}e^{+}e^{-}$ Candidate





Run=209534 Event=1735911

m_{12}=190.88 GeV $|\not{E}_T|$=31.1 GeV
m_{13}=90.82 GeV $\Delta\phi(\not{E}_T, \text{lepton}, \text{jet})$=1.2
m_{23}=90.88 GeV

Type	p_t	η	ϕ
Forward e	34.4	-2.1	2.8
Forward e	28.4	1.9	2.2
Track e/μ	25.6	-0.1	-1.2

WZ Summary

Yield improvements over previous (Winter 2006) analysis:

- Improved lepton idenfication: $\approx \times 2$
- Added forward electron + $\not{E}_T$ trigger: $\approx$ 10%
- Additional data: 30-40% (depending on channel)

WZ results

- Observe signal with significance of 6σ
- Measured cross section:

$$\boxed{\sigma(WZ) = 5.0^{+1.8}_{-1.6}\ \text{(stat.+syst.) pb}}$$

consistent with NLO prediction:

σ(WZ) = 3.7 ± 0.3 pb (Campbell, Ellis)

$ZZ \to \ell^+\ell^-\ell^+\ell^-$ Search Analysis

$Z^0Z^0 \to \ell^+\ell^-\ell^+\ell^-$ Selection:

- Same leptons as WZ search
- Triggers:
  Central e±, Central μ± (CMUP,CMX)
- 4 leptons (e,μ) with E_T > 20,10,10,10 GeV
- Z mass regions:

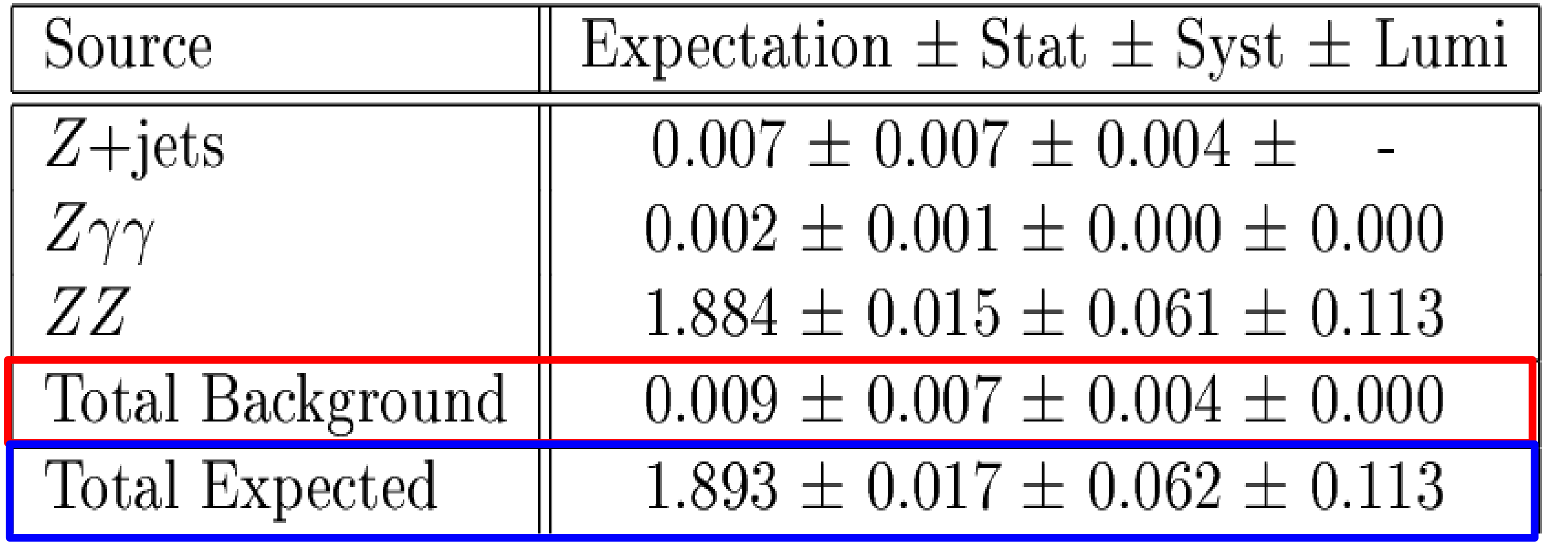
  ≥1 opposite-charge, same-flavor lepton pair in (76, 106) GeV/c^2

  ≥1 additional opposite-sign, same-flavor pair in (40, 140) GeV/c^2

Background estimation:

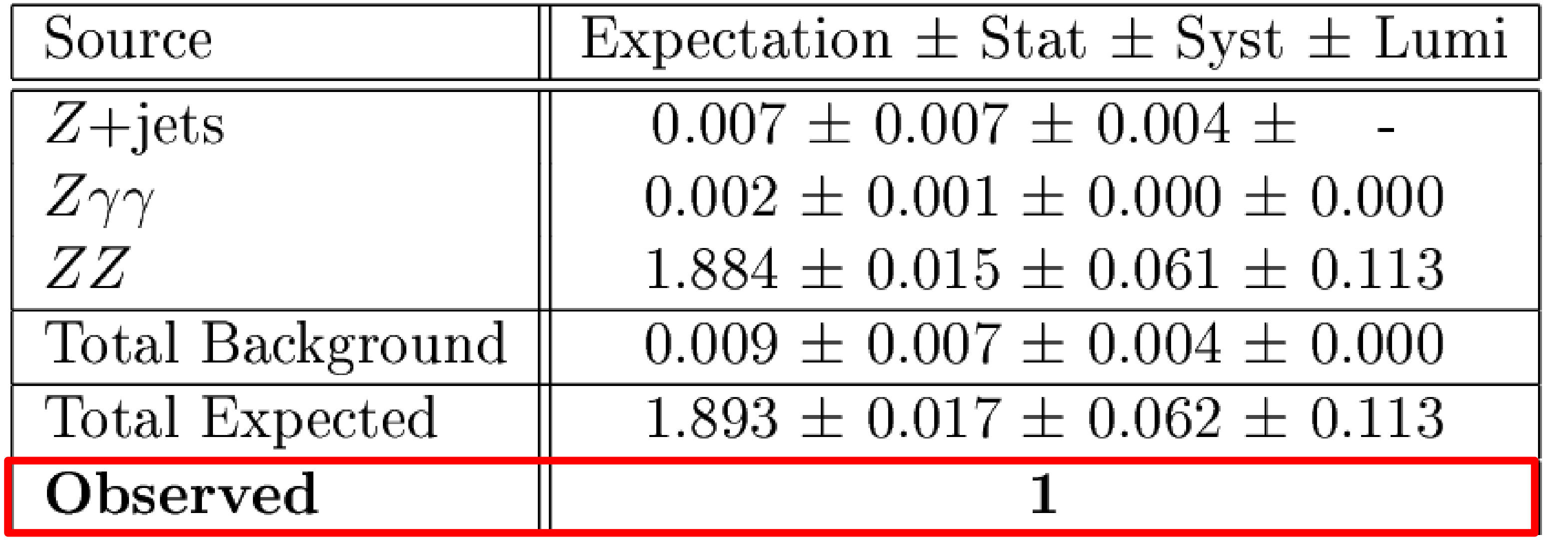
Expected backgrounds from Z+jets, Zγγ

- Zγγ: Madgraph + Pythia + GEANT
- Z+jets from data



Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	0.007 ± 0.007 ± 0.004 ± -
$Z\gamma\gamma$	0.002 ± 0.001 ± 0.000 ± 0.000
ZZ	1.884 ± 0.015 ± 0.061 ± 0.113
Total Background	0.009 ± 0.007 ± 0.004 ± 0.000
Total Expected	1.893 ± 0.017 ± 0.062 ± 0.113

ZZ $\rightarrow \ell^+\ell^-\ell^+\ell^-$ Results



Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	0.007 ± 0.007 ± 0.004 ± -
$Z\gamma\gamma$	0.002 ± 0.001 ± 0.000 ± 0.000
ZZ	1.884 ± 0.015 ± 0.061 ± 0.113
Total Background	0.009 ± 0.007 ± 0.004 ± 0.000
Total Expected	1.893 ± 0.017 ± 0.062 ± 0.113
Observed	**1**

We can exclude the background-only hypothesis at 2.6 σ

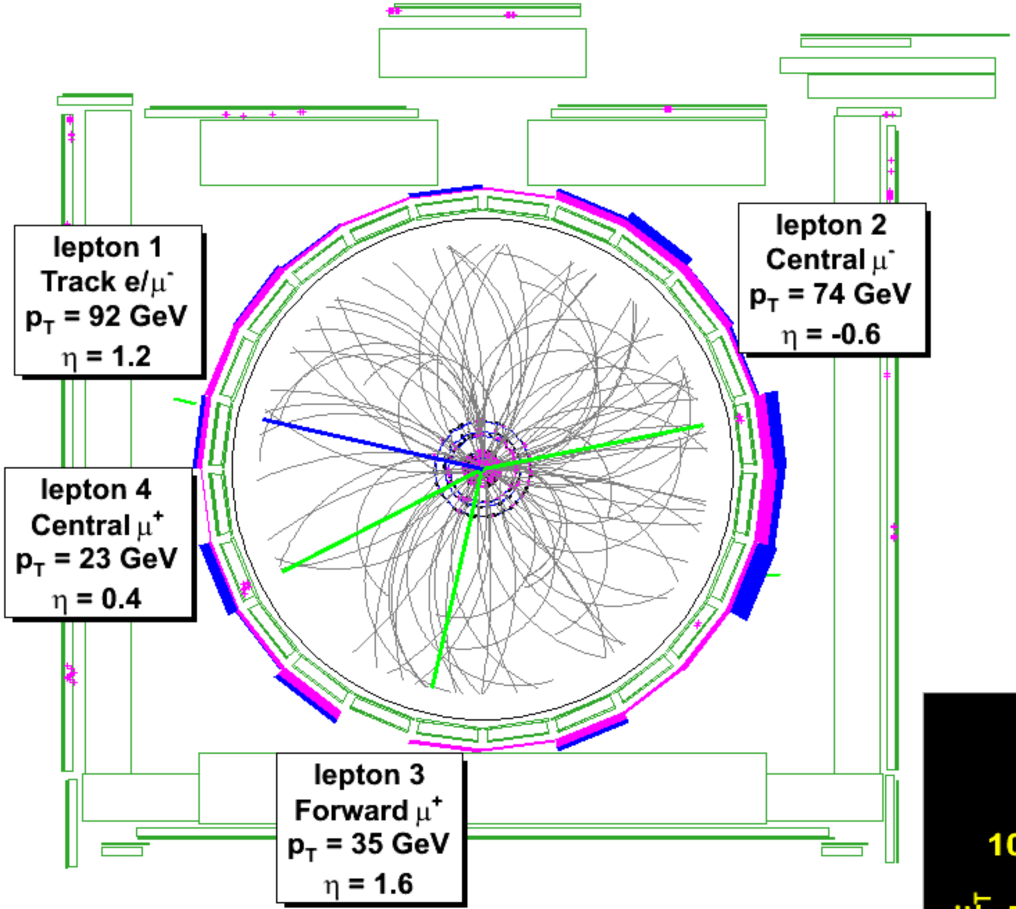
We determine:

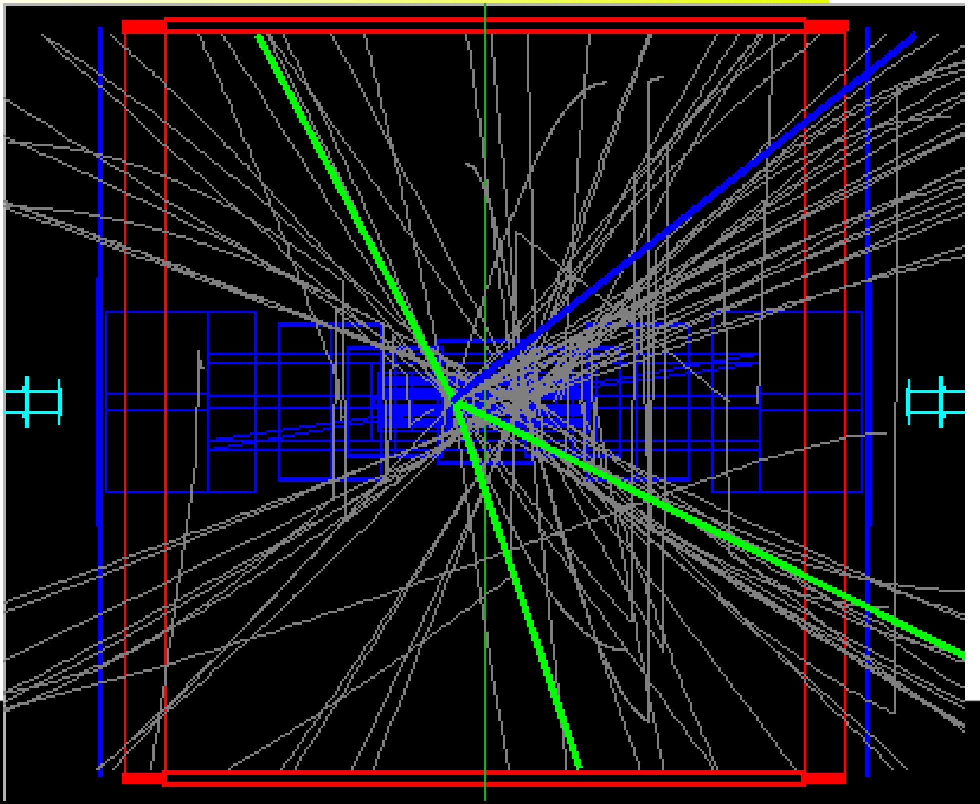
$\sigma(ZZ) < 3.8$ pb (95% C.L.)

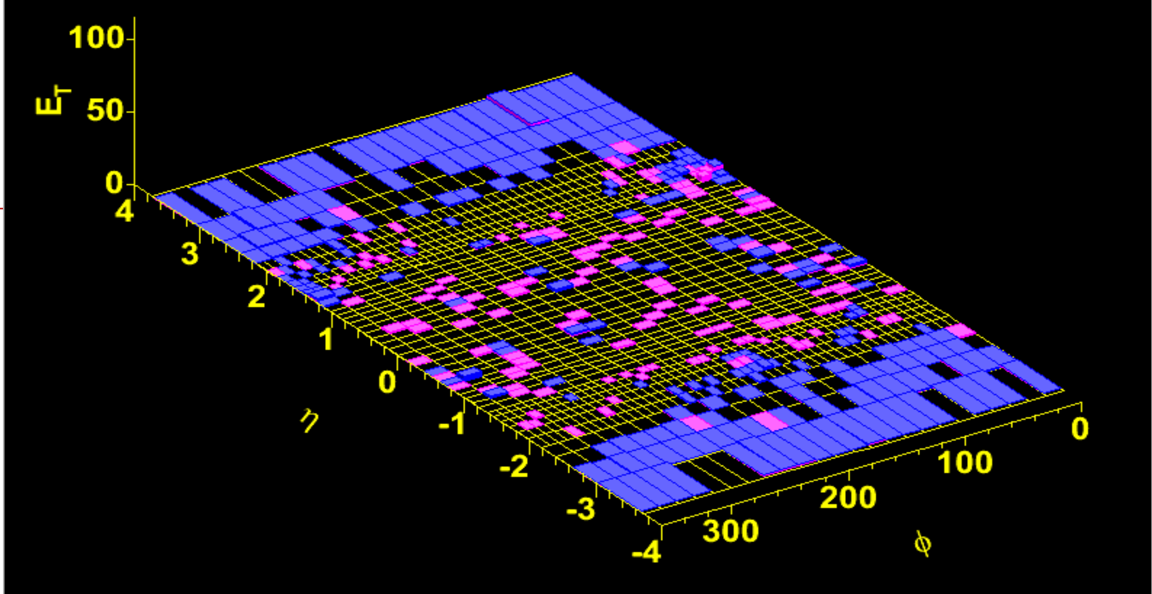
consistent with NLO prediction:

$\sigma(ZZ) = 1.4 \pm 0.1$ pb (Campbell, Ellis)

$Z^0Z^0 \to \mu^+\mu^-\mu^+\mu^-$ Candidate







Run=211311 Event=233113

m_{ll1}=90.92 GeV

m_{ll2}=83.03 GeV

M_{llll}=312.4 GeV/c^2

$|\not\!\!E_T|$=8.7 GeV

$N_{jets} = 0$

Type	p_t	η	ϕ
Track e/μ	91.5	1.2	2.9
Central μ	74.1	-0.6	0.2
Forward μ	34.5	1.6	-1.8
Central μ	22.5	0.4	-2.7

Summary and Conclusions

Using $\int \mathcal{L}\, dt$ = 1.1 fb^{-1} of data, we searched for WZ and ZZ production.

We observe 16 WZ → 3 leptons + $\not{E}_T$ candidates with an expected background of 2.70 ± 0.28 (stat.) ± 0.34 (syst.)

⇒ First observation (6σ) of WZ production!

(including $\not{E}_T$ information)

The measured cross section is:

$$\boxed{\sigma(WZ) = 5.0^{+1.8}_{-1.6}\ \text{(stat.+syst.) pb}}$$

We observe 1 ZZ → $\mu^+\mu^-\mu^+\mu^-$ candidate with an expected background of

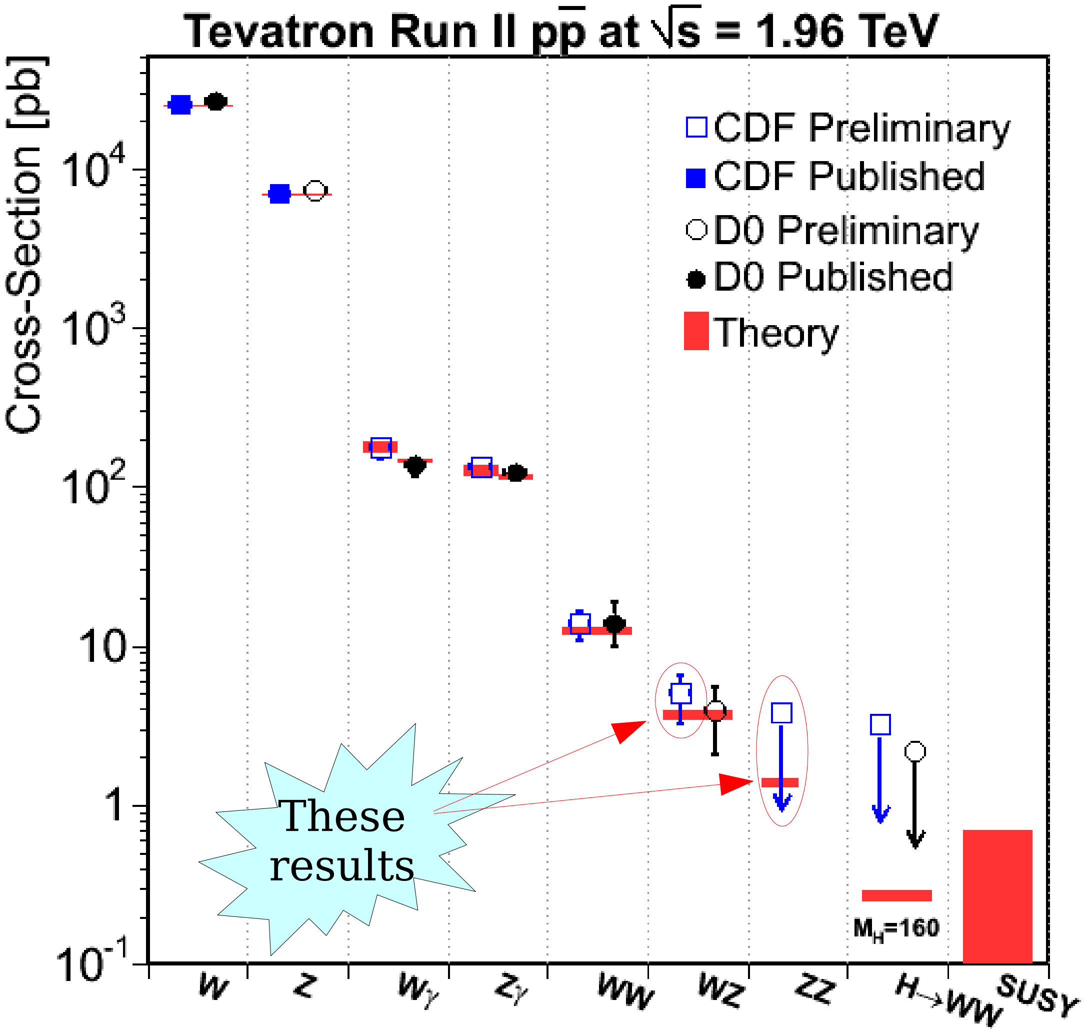
0.009 ± 0.007 (stat.) ± 0.004 (syst.)

and ZZ signal of

1.884 ± 0.015 (stat.) ± 0.128 (syst.)

We set the following limit:

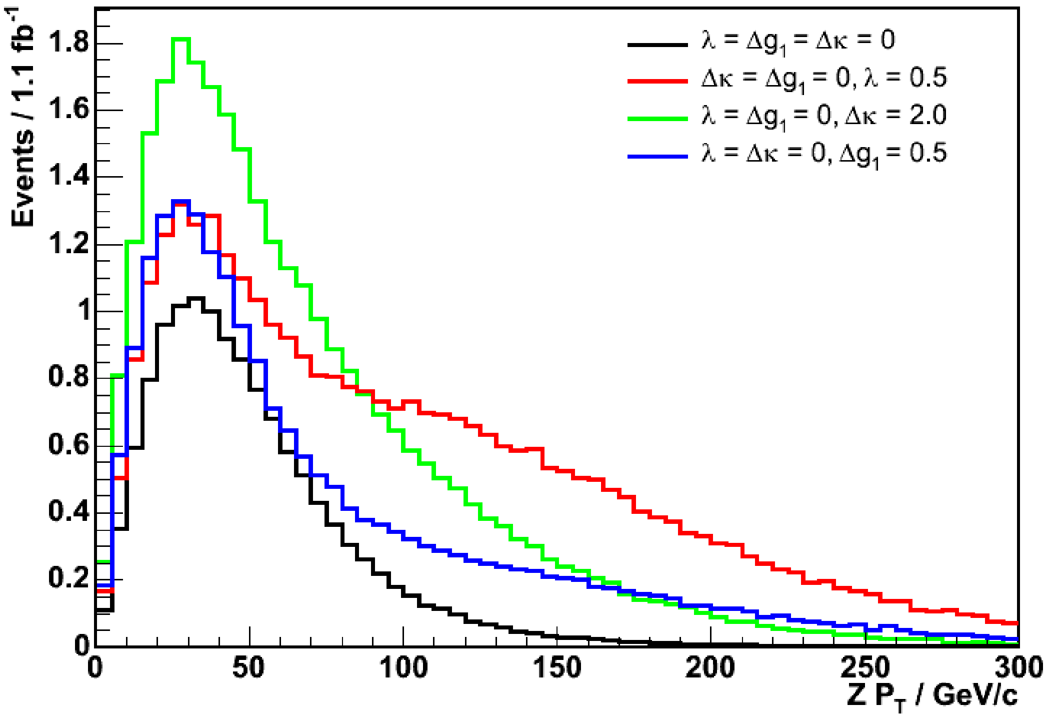
$$\boxed{\sigma(ZZ) < 3.8\ \text{pb (95\% C.L.)}}$$

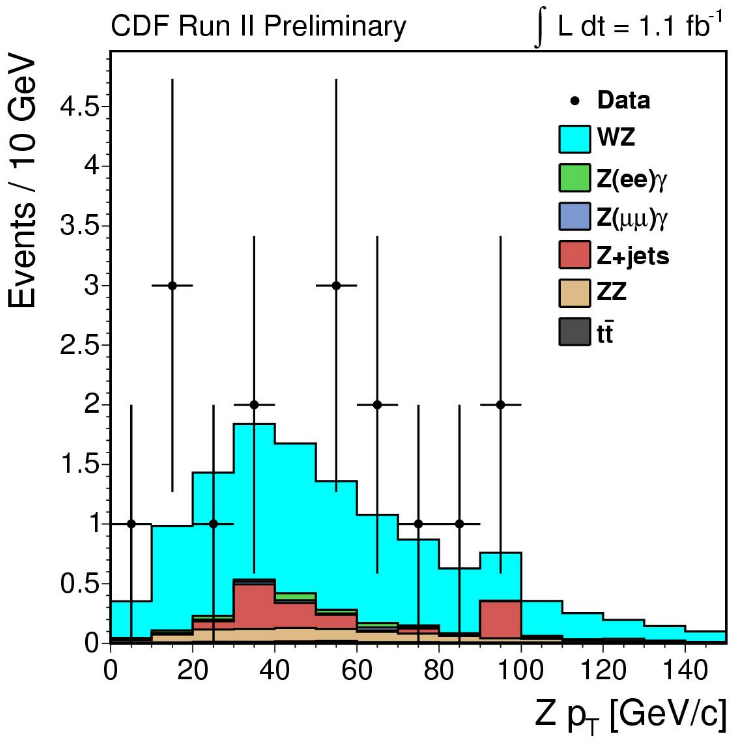


The observation of WZ represents an important experimental milestone in pursuit of Higgs and new physics at the Tevatron!

Plans for anomalous TGCs..

… place stringent model-independent limits on anomalous WWZ triple gauge coupling

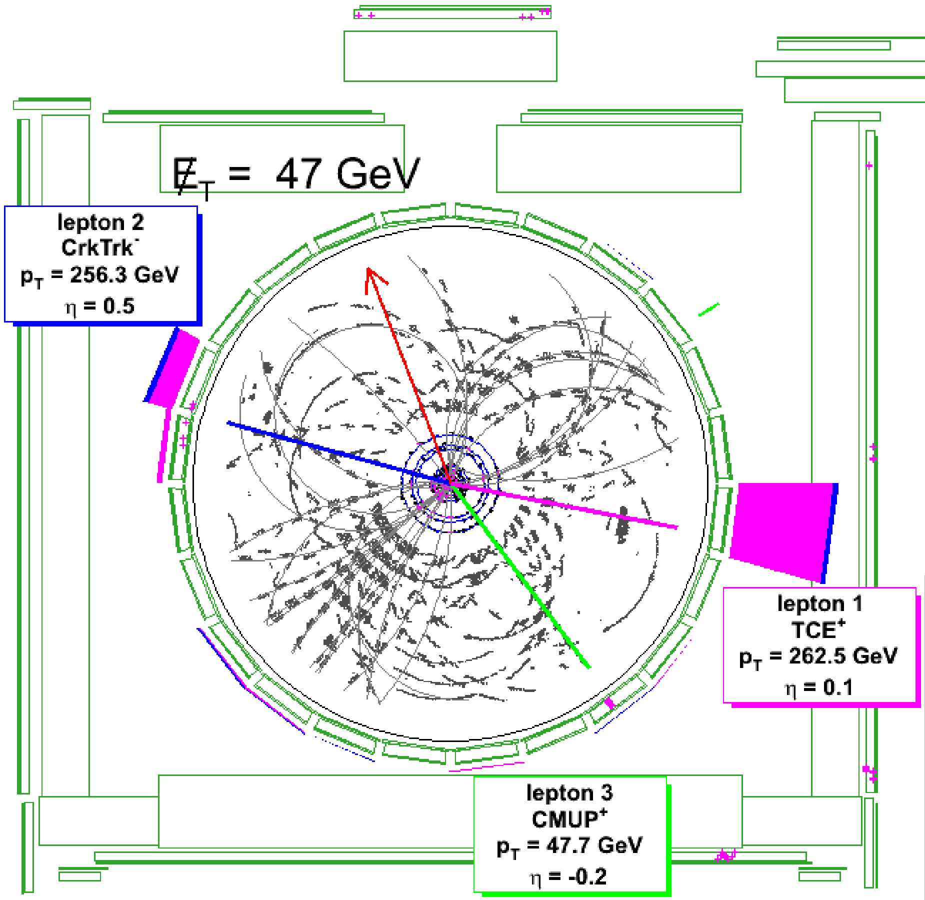


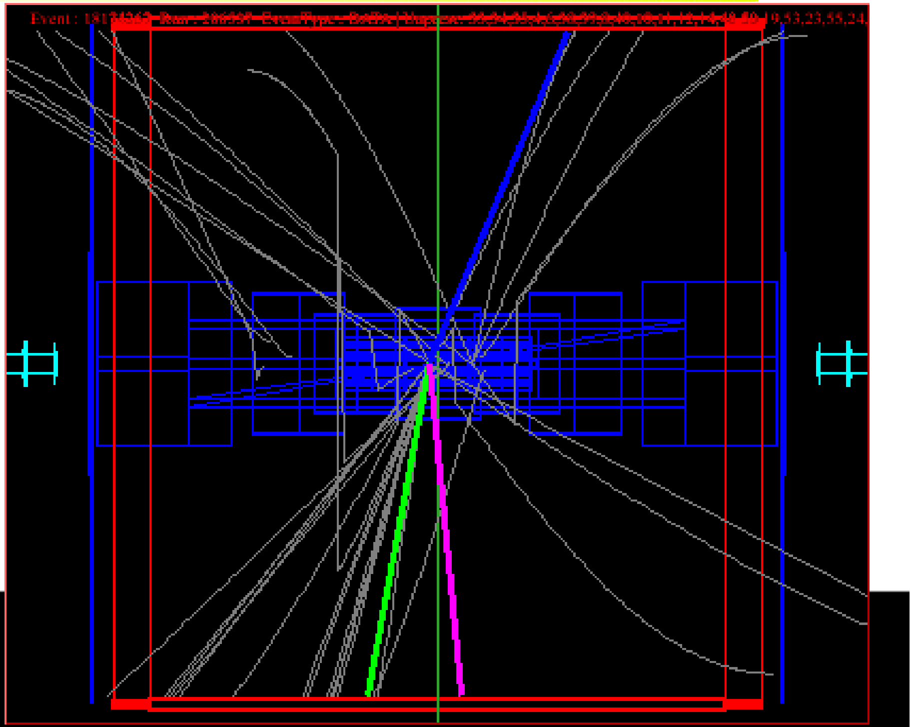


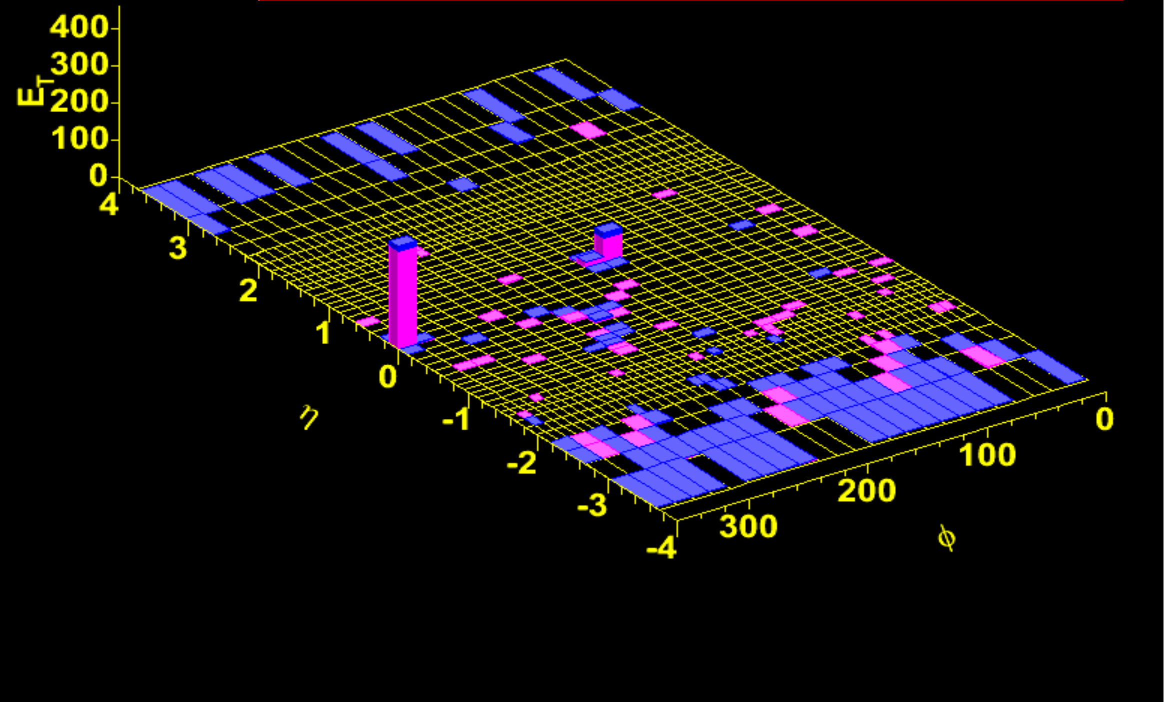
But what about that

"... or maybe something completely unexpected?"

Something Unexpected...







Run=206537 Event=18174367

m_{12}=526.54 GeV $|\not{E}_T|$=46.9 GeV

m_{13}=88.37 GeV $\Delta\phi(\not{E}_T, \text{lepton}, \text{jet})$=0.9

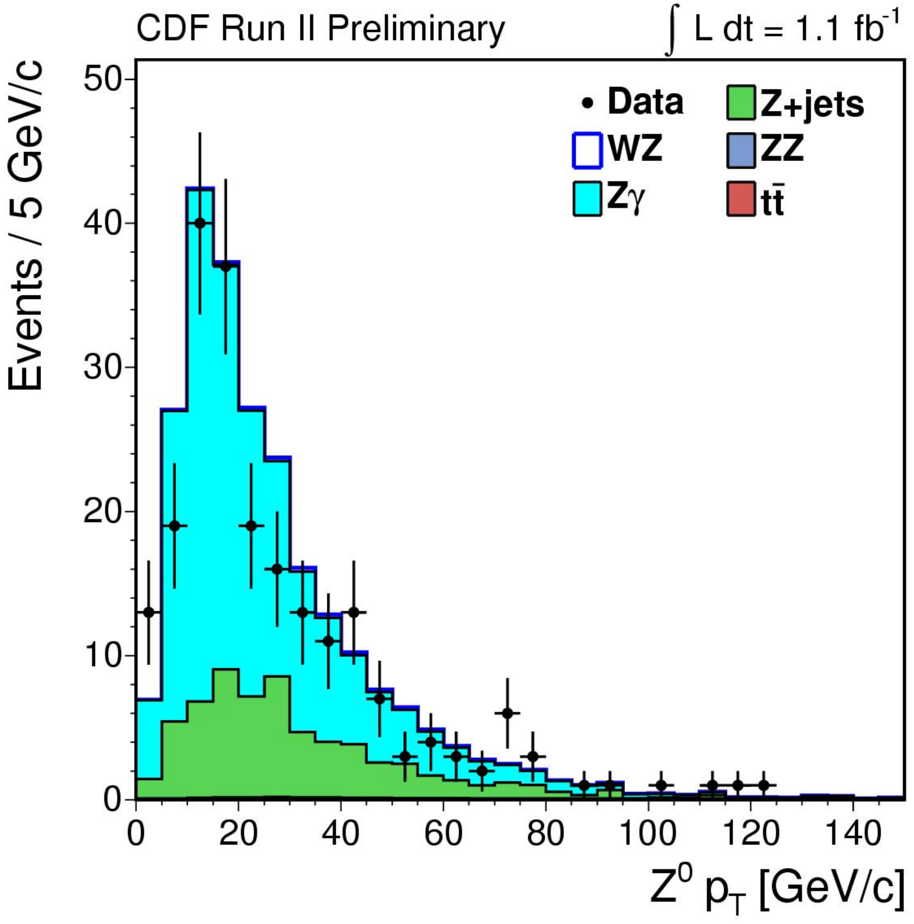
m_{23}=223.02 GeV

Type	p_t	η	ϕ
Central e	262.5	0.1	-0.2
Track e/μ	256.3	0.5	2.9
Central μ	47.7	-0.2	-0.9

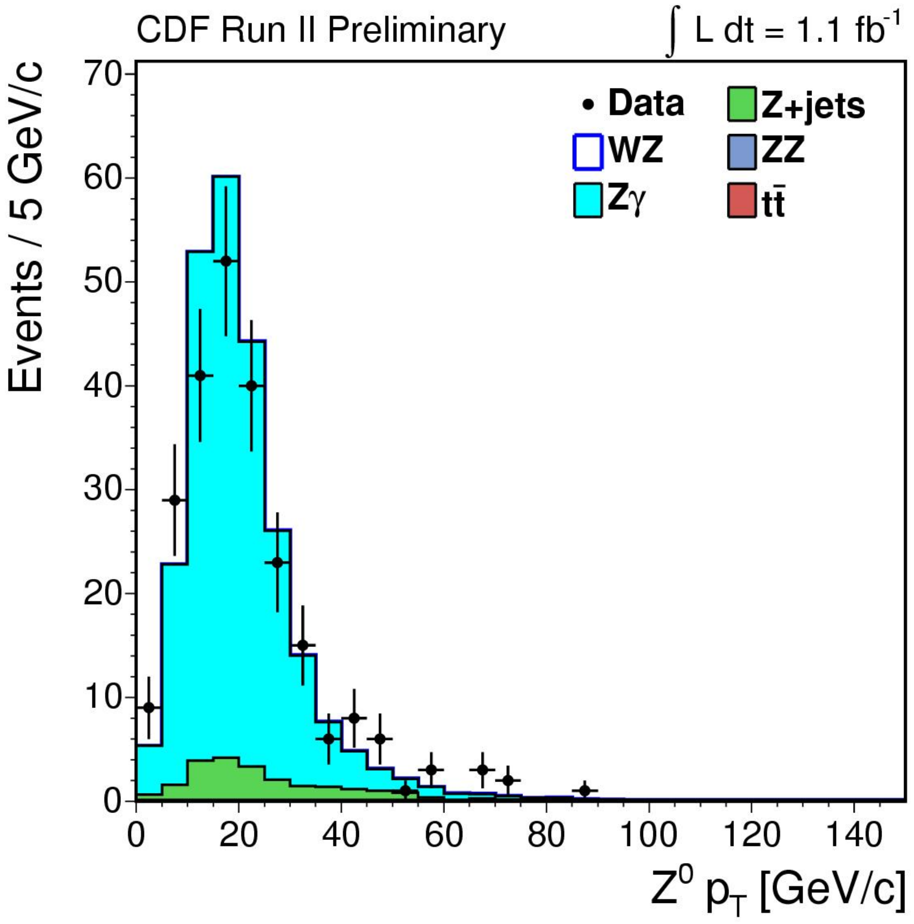
Extras

Control Regions: Z Pt

Low MET



Z Veto

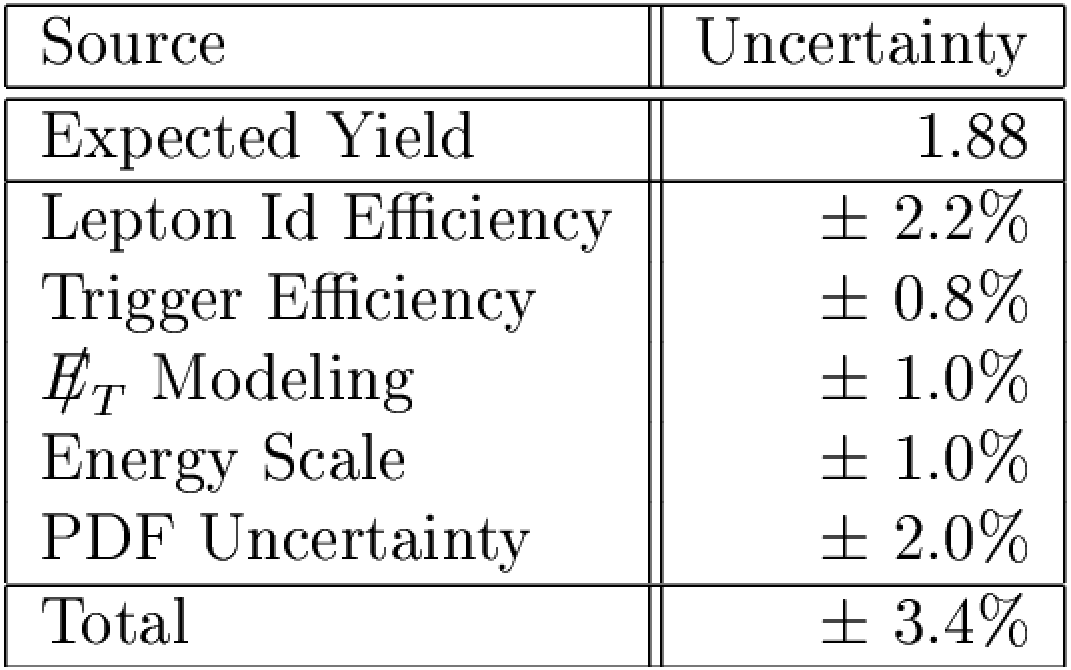


WZ Analysis Systematics

Variation	ZZ	$Z\gamma$	$t\bar{t}$	WZ
Expected Yield	0.9	0.5	0.1	9.8
Lepton Id Efficiency	± 2.0%	± 1.9%	± 1.2%	± 1.9%
Trigger Efficiency	± 0.6%	± 0.9%	± 0.4%	± 0.6%
$\not\!\!E_T$ Modeling	± 1.0%	± 25.0%	± 1.0%	± 1.0%
Energy Scale	± 1.0%	± 1.0%	-	± 1.0%
PDF Uncertainty	± 2.0%	± 2.0%	± 2.0%	± 2.0%
Cross-Section	± 10.0%	± 20.0%*	± 10.0%	-
Total	± 10.5%	± 32.2%	± 10.3%	± 3.2%

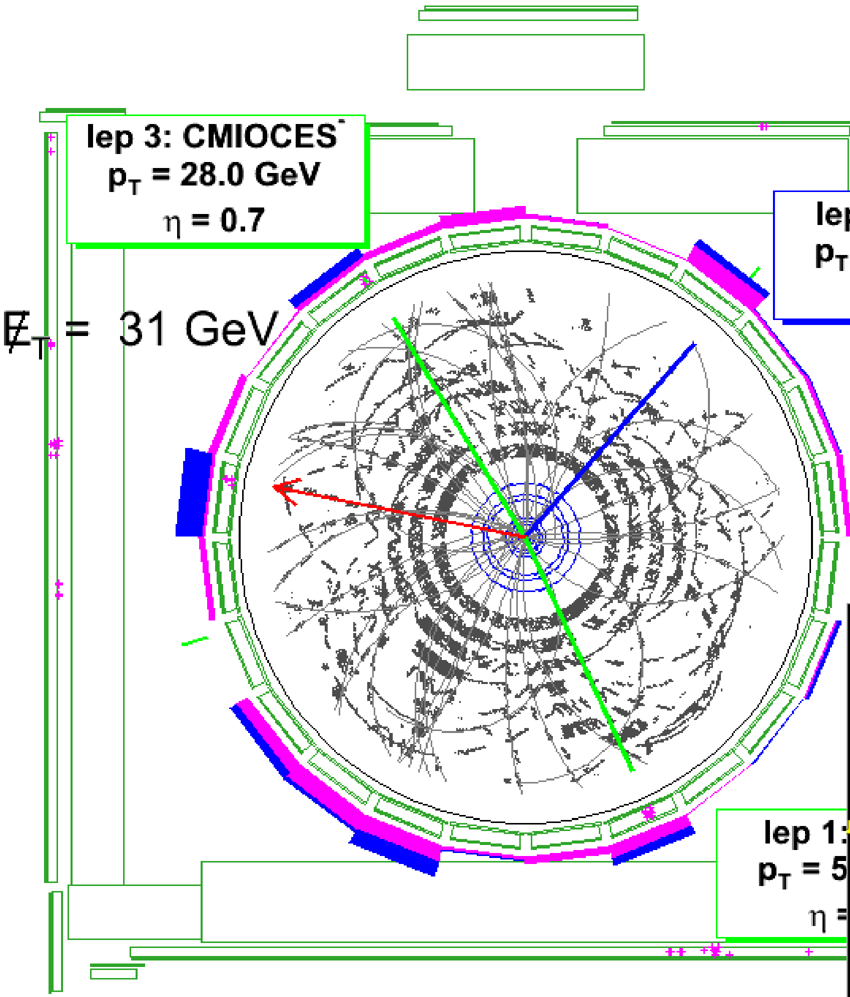
* includes conversion and material description systematics.

ZZ Analysis Systematics



Source	Uncertainty
Expected Yield	1.88
Lepton Id Efficiency	± 2.2%
Trigger Efficiency	± 0.8%
$\not\!\!E_T$ Modeling	± 1.0%
Energy Scale	± 1.0%
PDF Uncertainty	± 2.0%
Total	± 3.4%

MlepTrk vetoed event



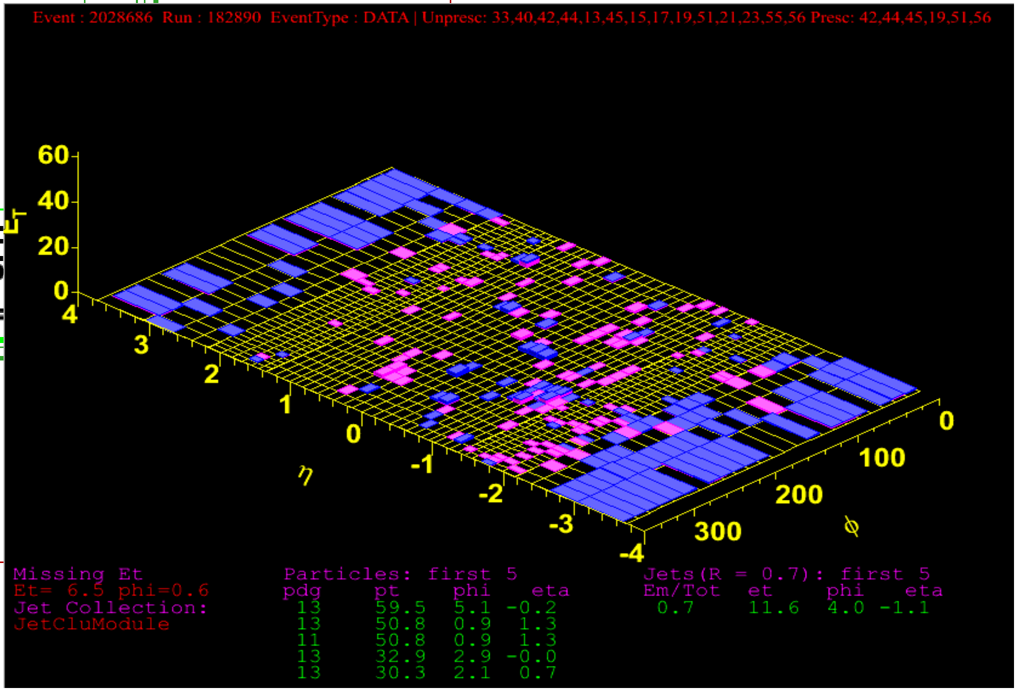
Run=182890 Event=2028686

m_{12}=131.40 GeV $|\not{E}_T|$=31.3 GeV

m_{13}=90.61 GeV $\Delta\phi(\not{E}_T, \text{lepton}, \text{jet})$=0.8

m_{23}=49.63 GeV

Type	p_t	η	ϕ
CMUP	59.9	-0.2	-1.1
CrkTrk	49.5	1.3	0.9
CMIOCES	28.0	0.7	2.1

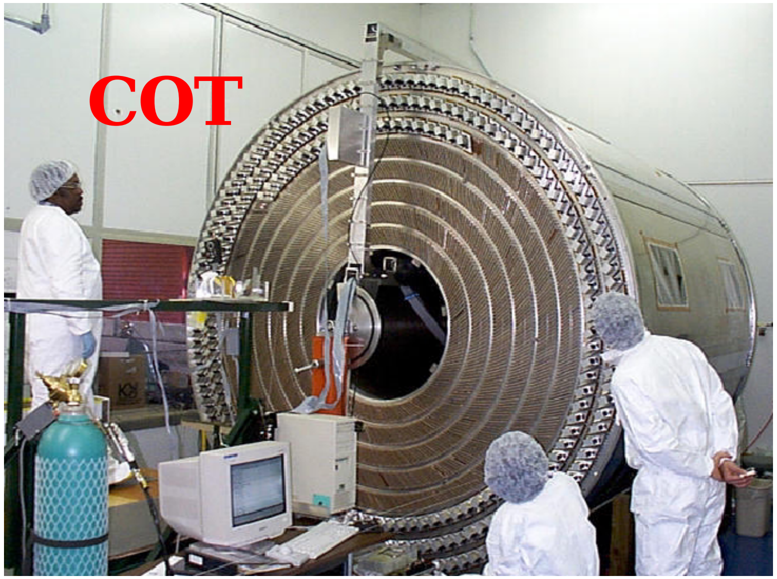


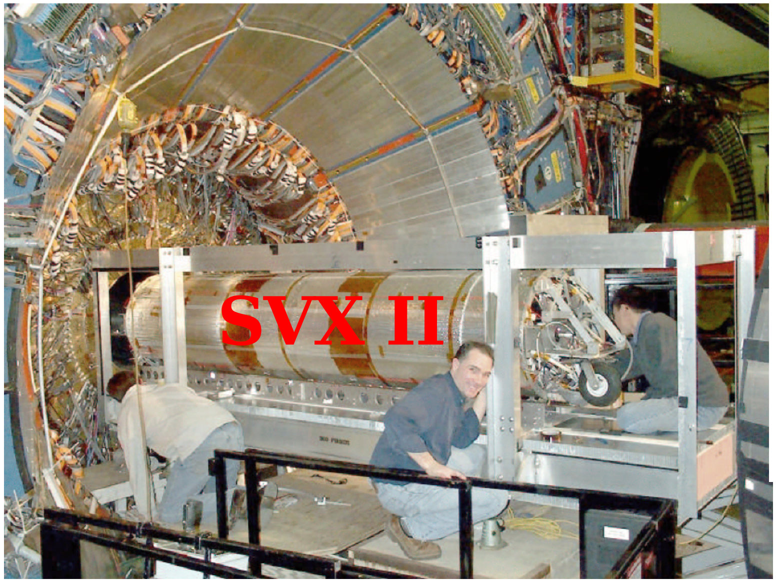
```
Event : 2028686  Run : 182890  EventType : DATA | Unpresc: 33,40,42,44,13,45,15,17,19,51,21,23,55,56 Presc: 42,44,45,19,51,56
```

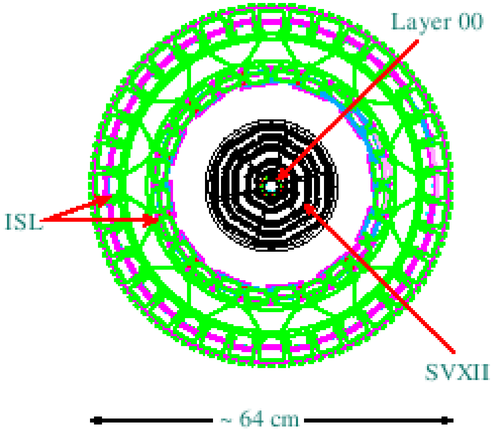
```
Missing Et              Particles: first 5          Jets(R = 0.7): first 5
Et= 6.5 phi=0.6         pdg     pt    phi   eta     Em/Tot   et    phi  eta
Jet Collection:          13    59.5   5.1 -0.2       0.7    11.6   4.0 -1.1
JetCluModule             13    50.8   0.9  1.3
                         11    50.8   0.9  1.3
                         13    32.9   2.9 -0.0
                         13    30.3   2.1  0.7
```

Veto track right behind MET vector
Iso = 0.15
Track pt ~ MET so we'd get small METcorr
Probably ZZ → 4 μ event that we (rightly) vetoed

Integrated Tracking System







Silicon system:

SVX II
- 5 layers double-sided silicon → r-ϕ, r-z tracking
- 2.5 < r < 10.6 cm
- 96 cm long
  → ×2 RunI acceptance

ISL
- 2 additional Si layers
- r < 28 cm; cover |η|<2

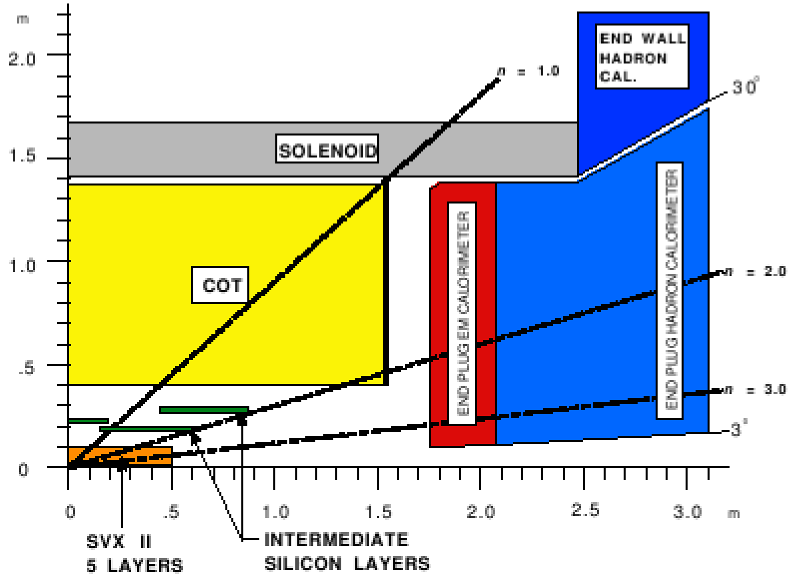
L00
- inner Si layer at beam pipe (R = 1.5 cm)

(L00 not used in our analysis)

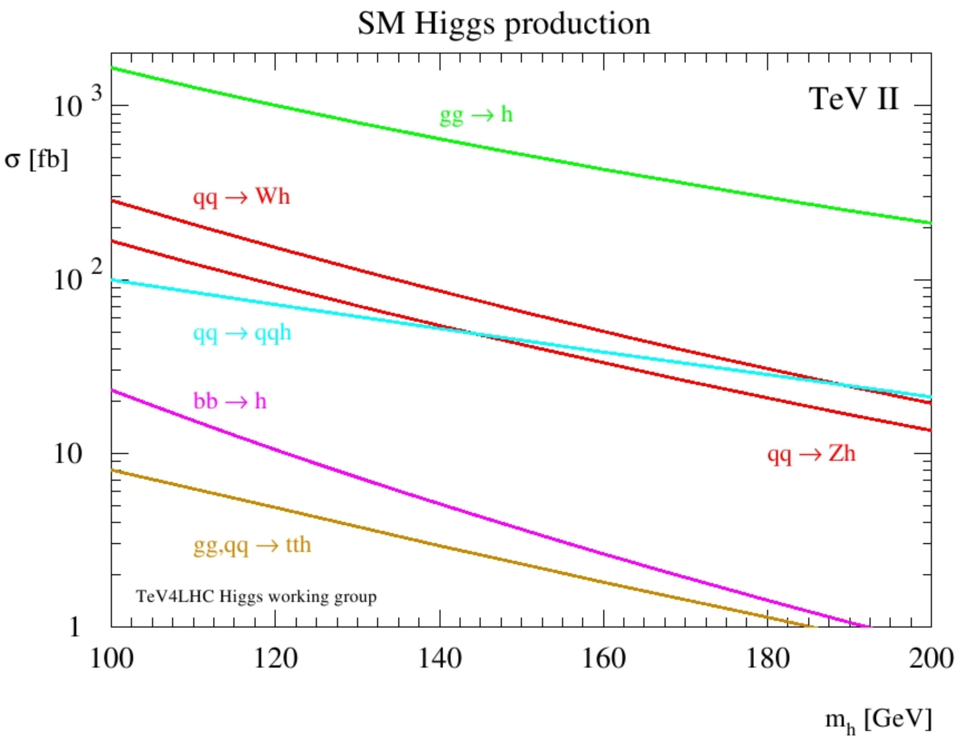
Tracking in a nutshell:

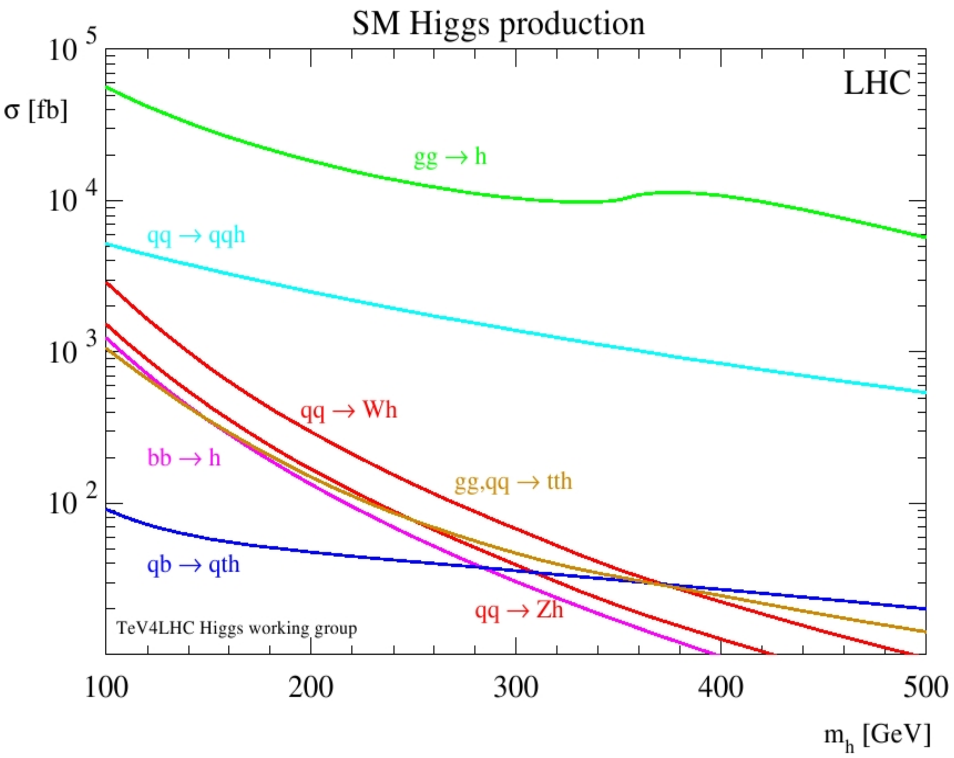
1) Segments formed from hits each COT superlayer (SL)
2) Segments linked together to form 2D track
3) Stereo segments linked into 2D track and helix fit is performed
4) COT track extrapolated into SVXII, outer layers first
5) SVXII hits consistent with COT track are added succession, with track refit after each iteration

CDF Tracking Volume



Higgs Production: TeV vs. LHC



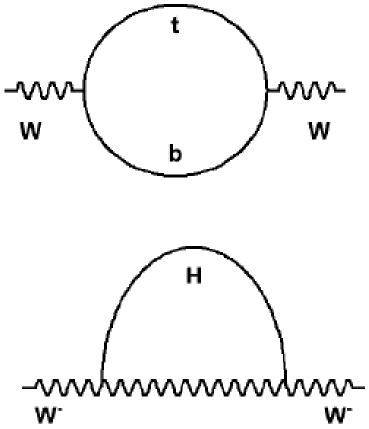


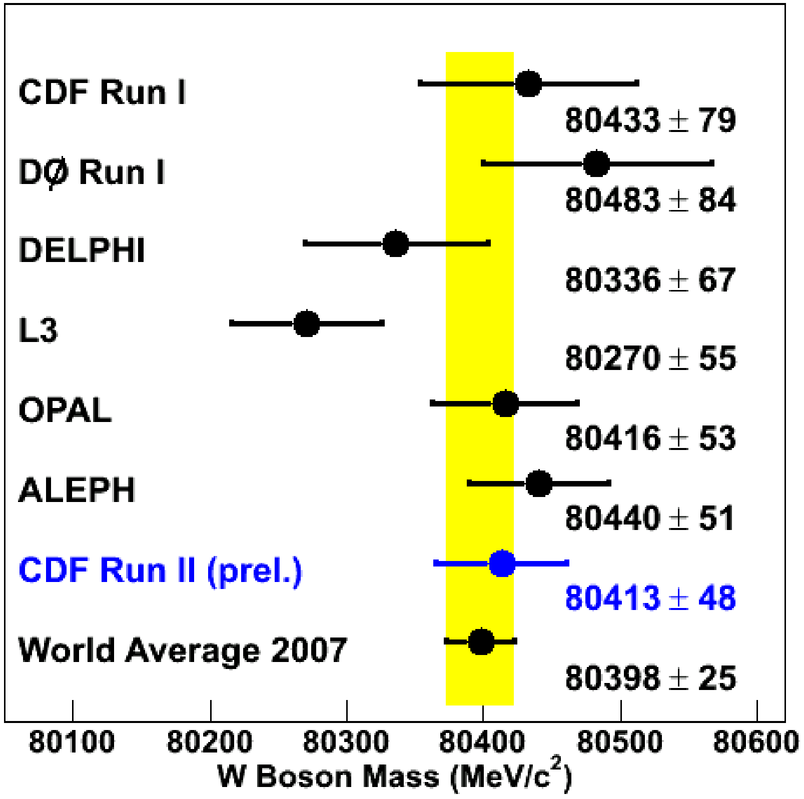
Recent CDF W Mass Result

$$m_W^2 = \frac{\pi\alpha_{EM}}{\sqrt{2}G_F \sin^2\theta_W(1 - \Delta r)}$$

Radiative corrections dominated by top, Higgs

Top mass uncertainty (1.2%) contributes 0.016% to δm_W





SM Higgs mass: 80^{+36}_{-26} GeV