Boson Production & Properties at CDF & D0

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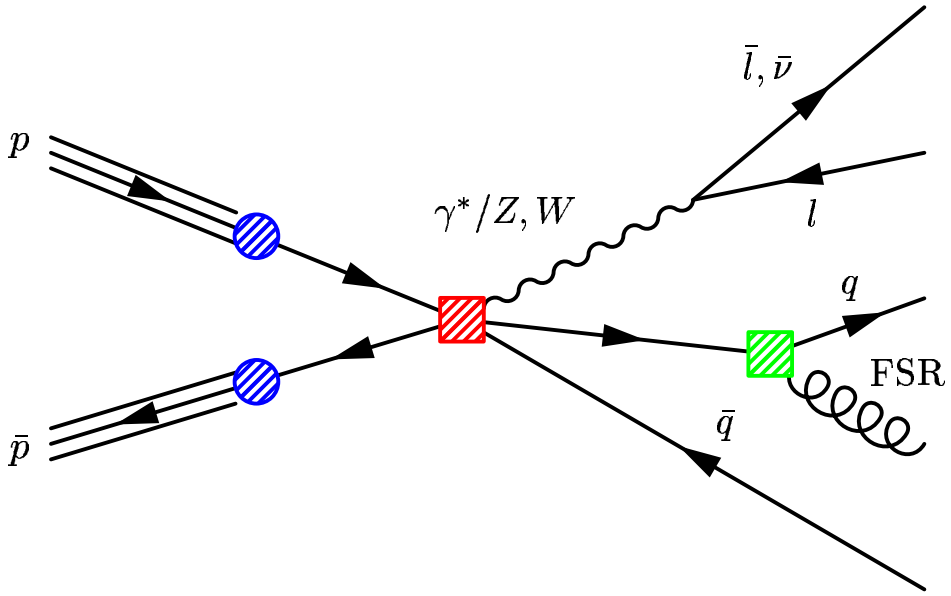
Fermilab User's Meeting

- Boson Production Measurements
- Search for New Bosons: Z' and others
- Standard Model Diboson Production and the Search for Anomalous Couplings

Boson Production Measurements

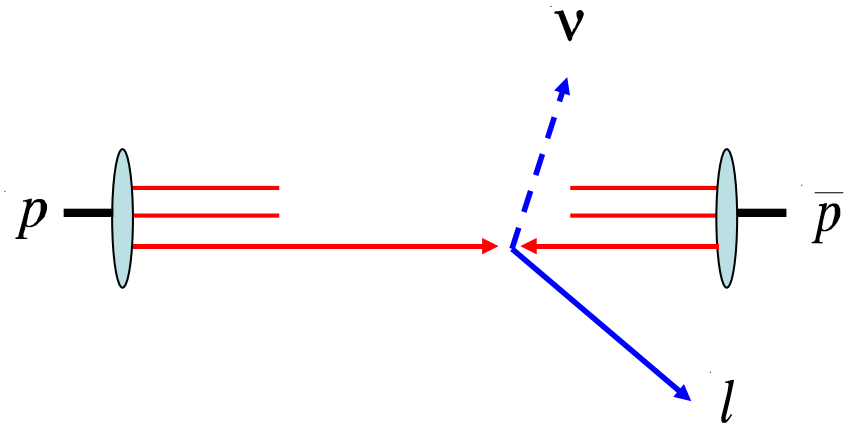
Understanding Hadron Collisions

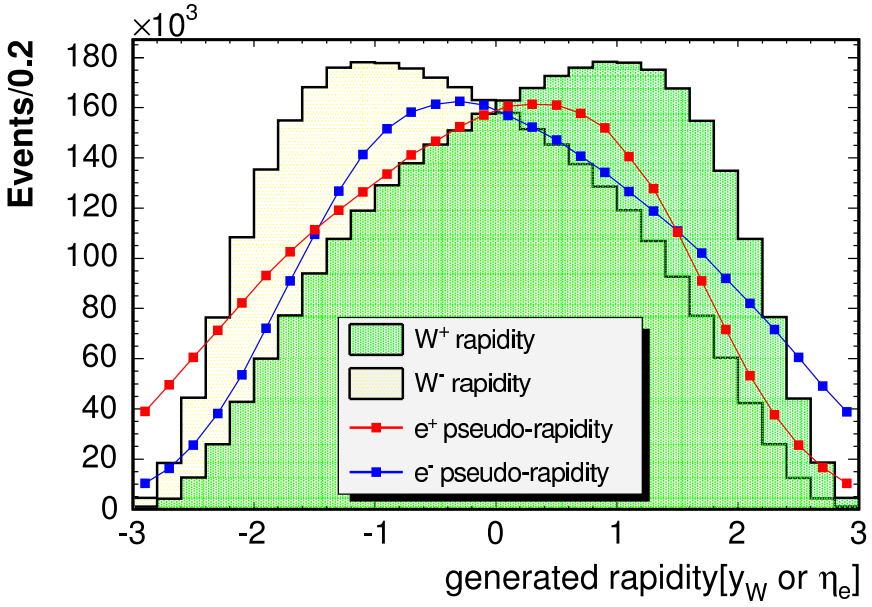


- Parton Distribution Functions (the structure of the proton)
  - Differential cross-section, W charge asymmetry, Z forward-backward asymmetry
- Boundary between perturbative QCD and parton showers (phenomenological)
  - W+jets & Z+jets $\rightarrow$ the haystack under which new physics may lie

Boson Production Measurements

W Charge Asymmetry





W's are produced asymmetrically

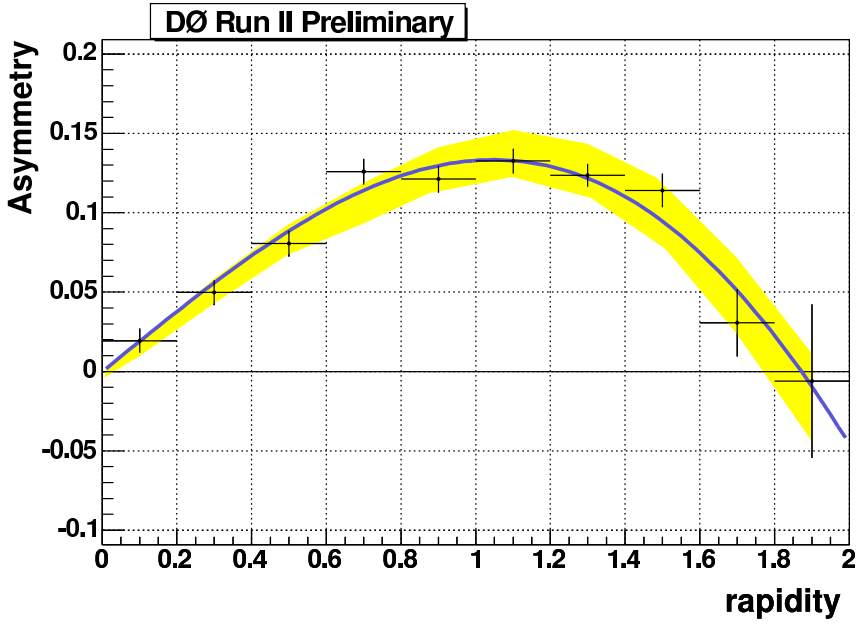
$$A_W(y_W) \equiv \frac{d\sigma_{W^+}/dy_W - d\sigma_{W^-}/dy_W}{d\sigma_{W^+}/dy_W + d\sigma_{W^-}/dy_W} \approx \frac{d(x_1)u(x_2) - d(x_1)u(x_2)}{d(x_1)u(x_2) + d(x_1)u(x_2)}$$

- Measure asymmetry of charged lepton daughter of W
- W decay washes out the effect

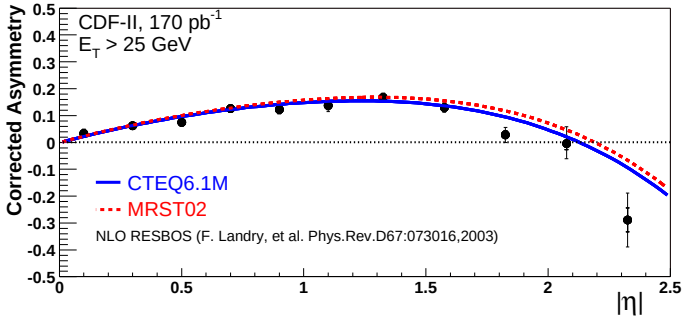
$$A_l(\eta_l) \equiv \frac{d\sigma_{l^+}/d\eta_l - d\sigma_{l^-}/d\eta_l}{d\sigma_{l^+}/d\eta_l + d\sigma_{l^-}/d\eta_l}$$

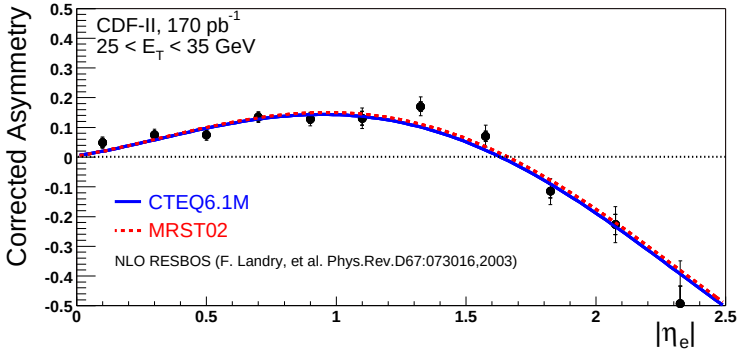
Boson Production Measurements

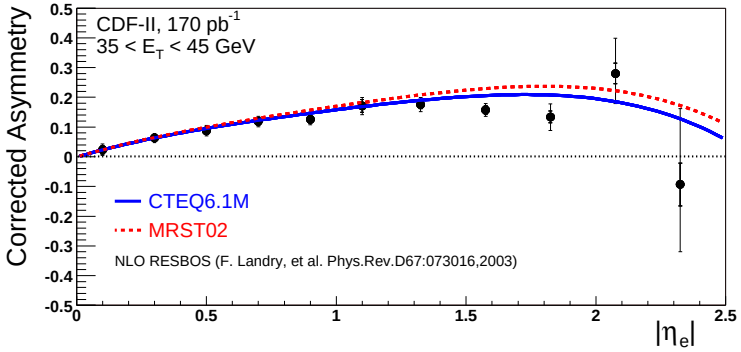
W Charge Asymmetry - Latest CDF & D0 Measurements



D0 $W \rightarrow \mu\nu$ Results (230 pb^{-1})







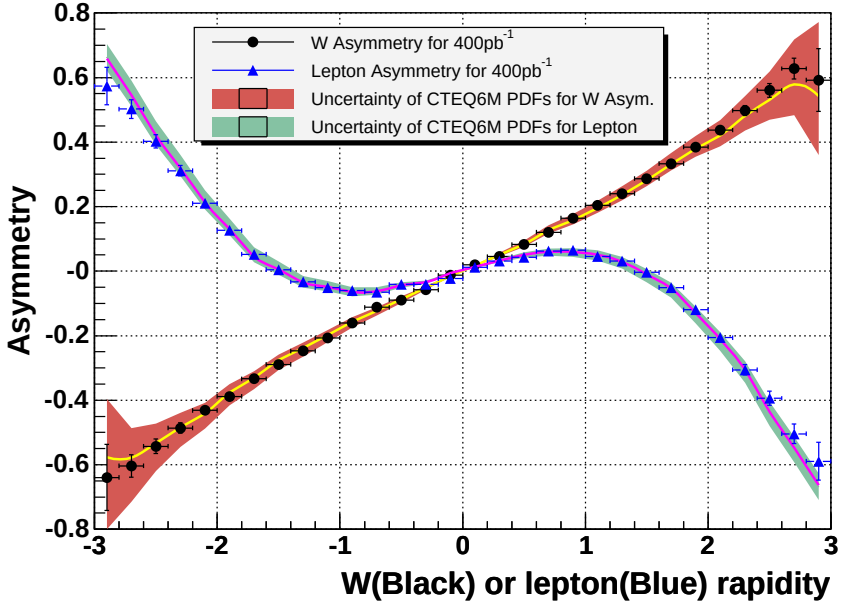
CDF $W \rightarrow e\nu$ (170 pb^{-1})

Measurement Basics

- Selection: isolated lepton + $\not{E}_T$
- Major issue: charge mis-id
  - Measure mis-id rate with $Z \rightarrow ll$
- CP conservation $\rightarrow$ $A_l(-\eta_l) = -A_l(\eta_l)$

Boson Production Measurements

W Charge Asymmetry - Getting back the W rapidity

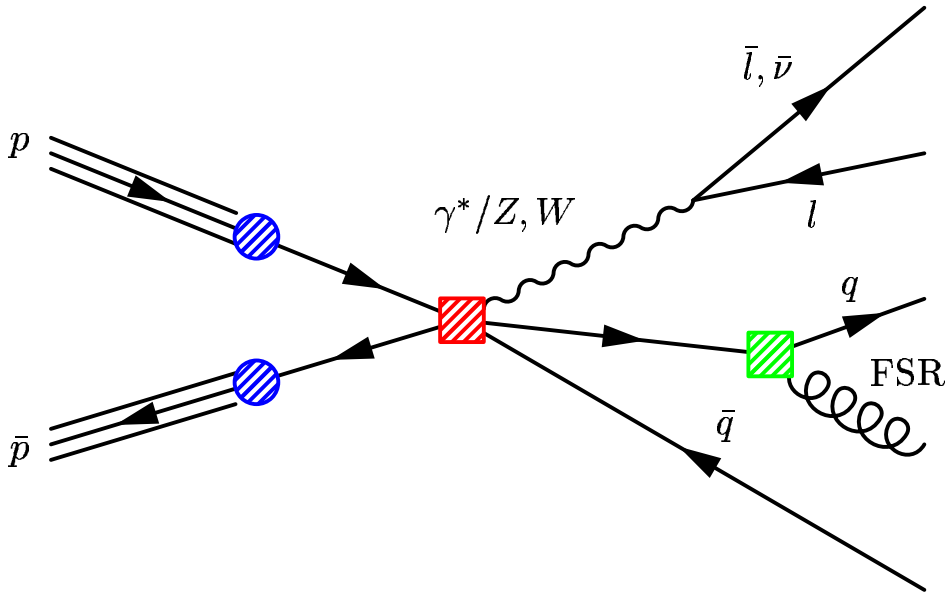


CDF Monte Carlo Estimate of Sensitivity

- Would like to measure W rapidity not μ/e pseudo-rapidity
- Measure $\vec{p_l}$ and $\vec{p_T} = \vec{\not{E}_T}$ of ν but missing p_z
- Use W-mass constraint $\Rightarrow$ two solutions
- Weight solutions based on production and decay model
  - Iterate because W rapidity charge asymmetry part of the model

Boson Production Measurements

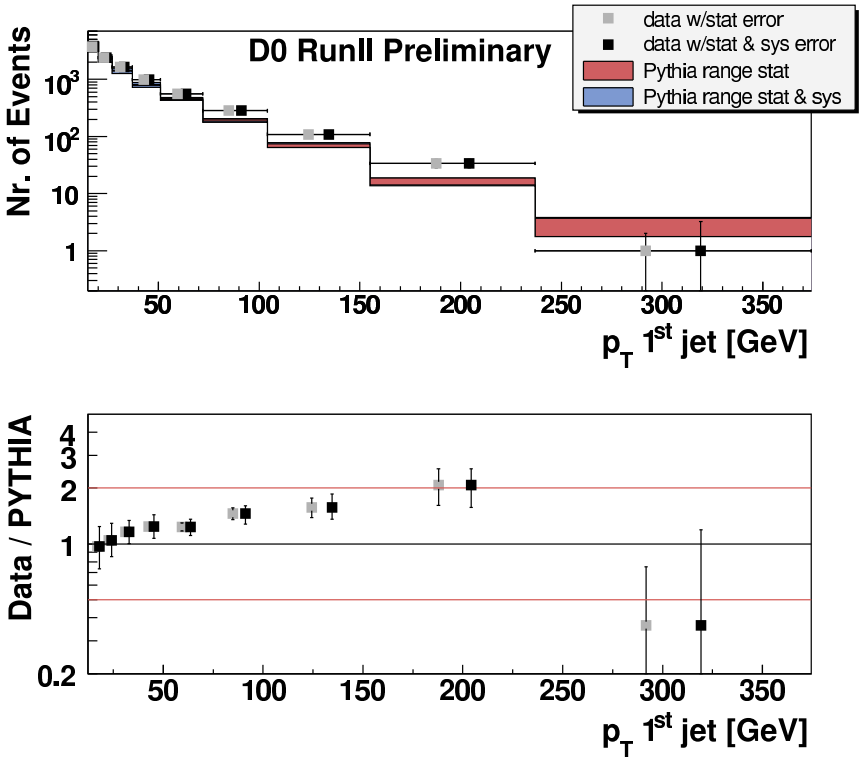
Understanding Hadron Collisions



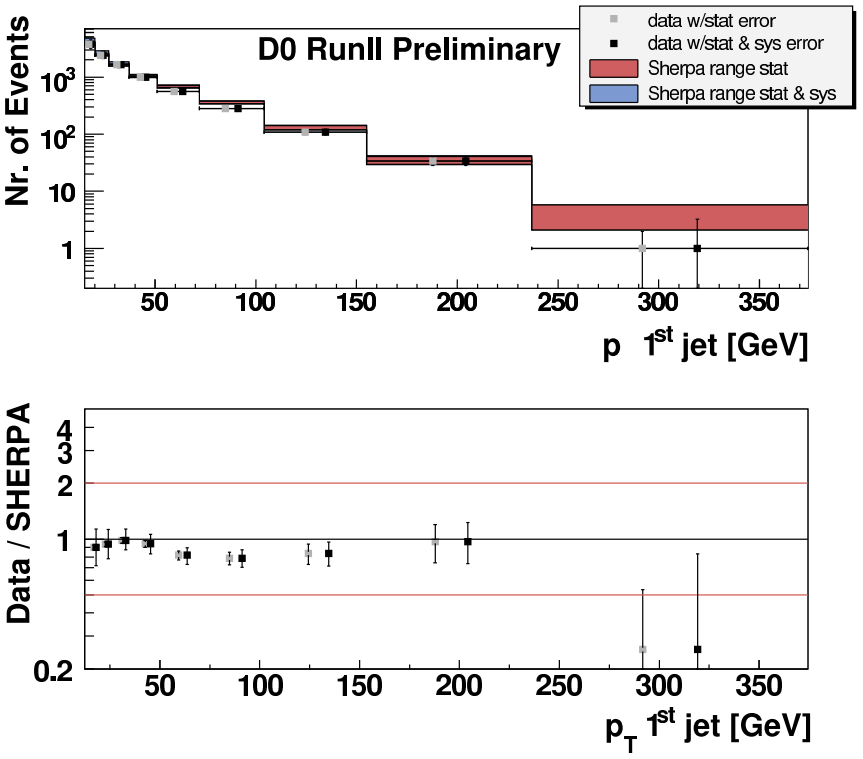
- Hard QCD interactions are perturbative: calculable with matrix elements
- Soft QCD interactions introduce soft and collinear divergences: phenomenological models
- We need to be able to model both regimes well

Boson Production Measurements

Precision Tests of QCD: Z+jets at D0 (950 pb^{-1})



Pythia

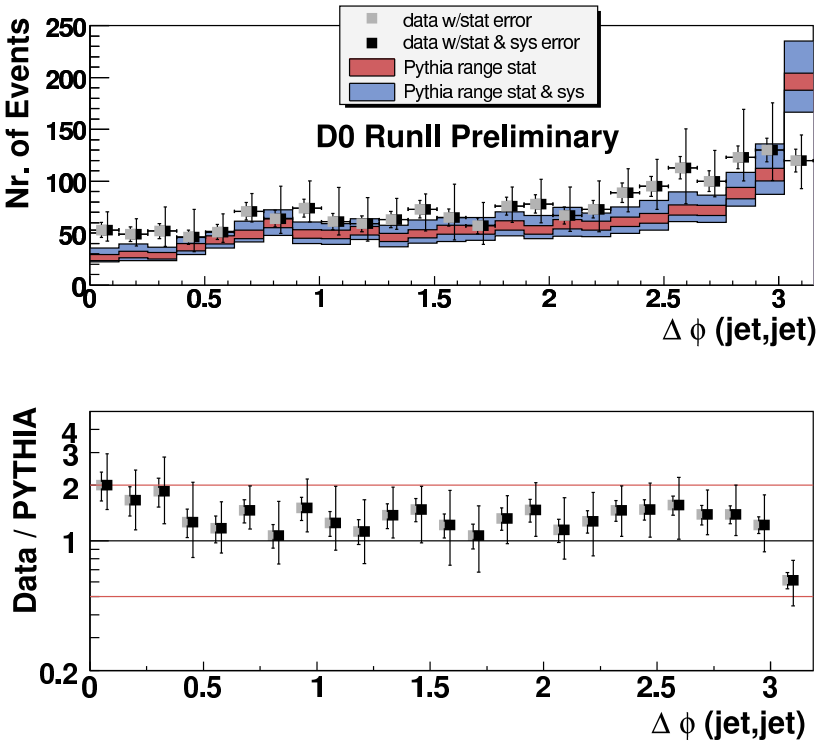


Sherpa

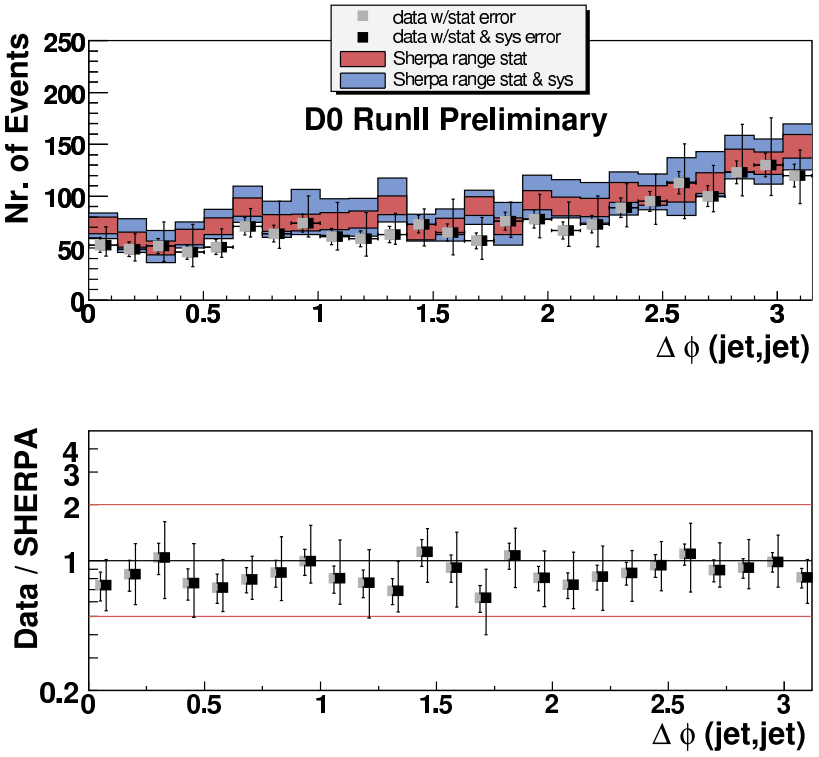
- Pythia: Phenomenlogical model using splitting functions
- Sherpa: perturbative + parton showers to fill in regions where divergences occur
- Monte Carlo smeared to account for detector resolution

Boson Production Measurements

Precision Tests of QCD: Z+jets at D0 (950 pb^{-1})



Pythia

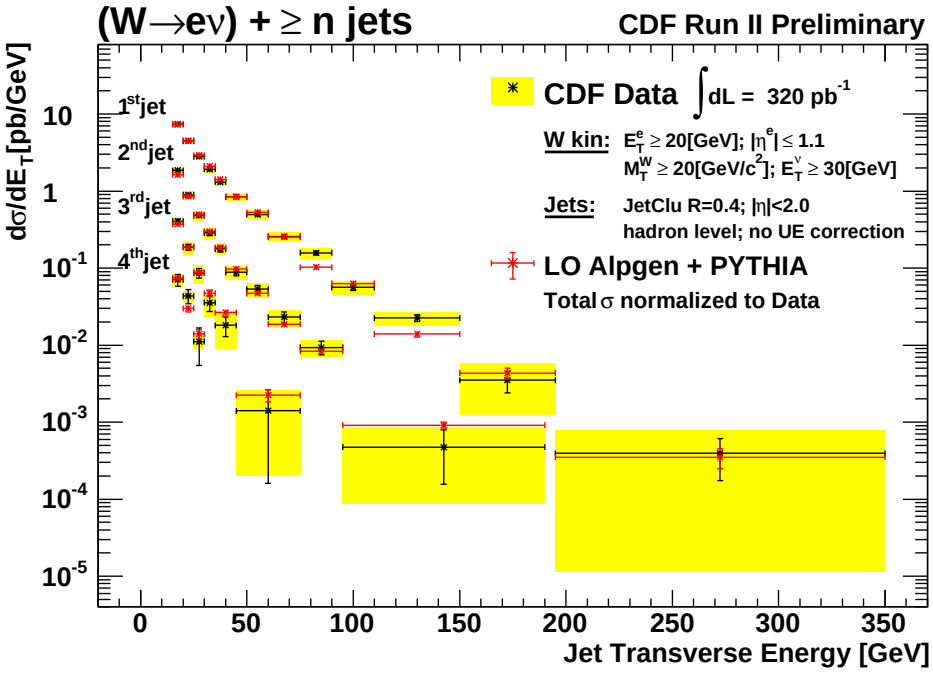


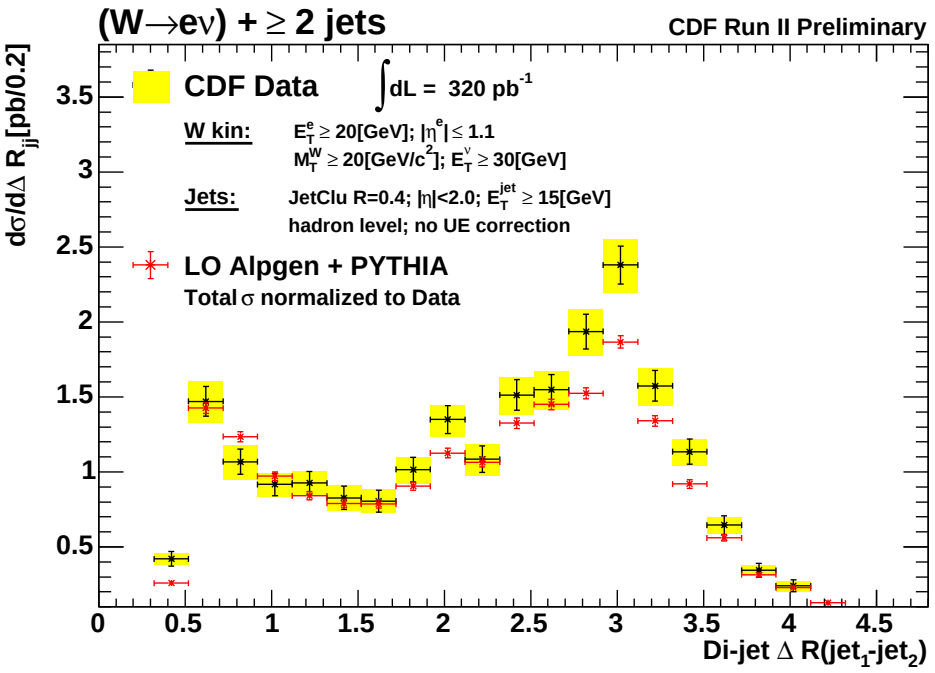
Sherpa

- Angles between jets related to masses
- Sophisticated likelihood and neural net techniques for searches depend on these being right

Boson Production Measurements

Precision Tests of QCD: W+jets at CDF



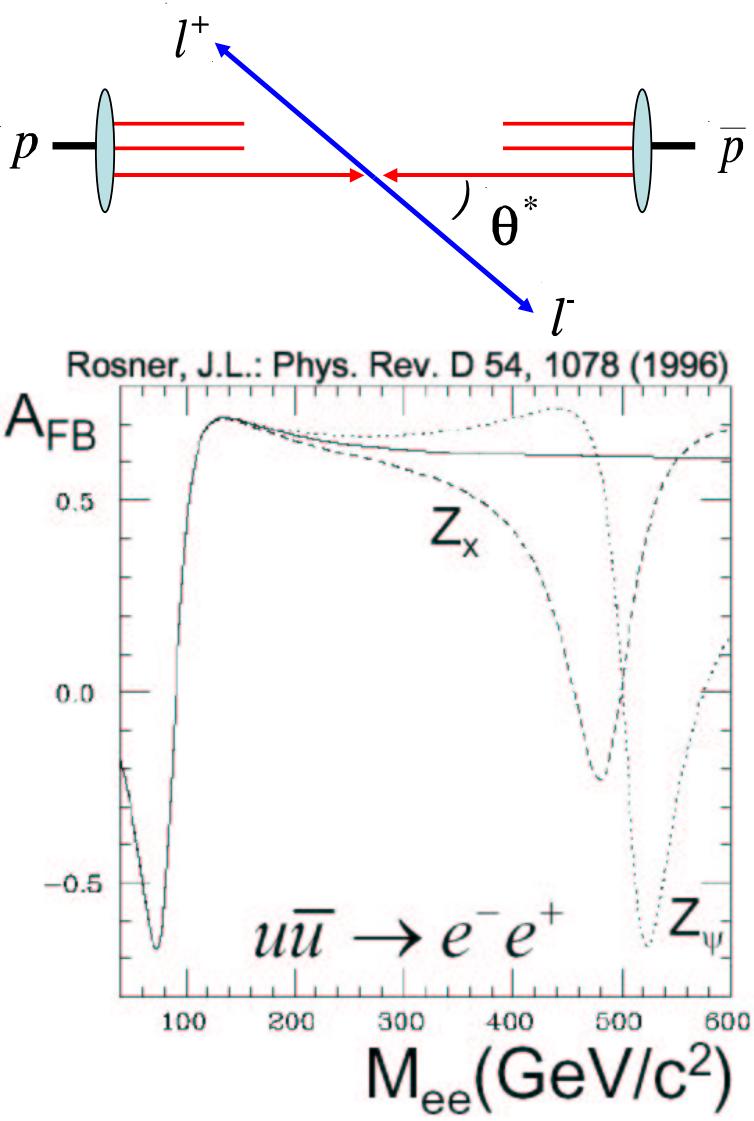


- Jets corrected back to hadron level (before detector effects)
- Alpgen for hard interactions + Pythia for soft interactions

Search for New Bosons

$Z' \to ll$ Searches

- Common prediction of extensions of the Standard Model
  - Bigger gauge groups: Left-right symmetric, GUT, string theory, ...
  - Little Higgs uses a Z' to cancel Higgs mass quadratic divergence
- Strong constraints from LEP if Z' mixes with the SM Z

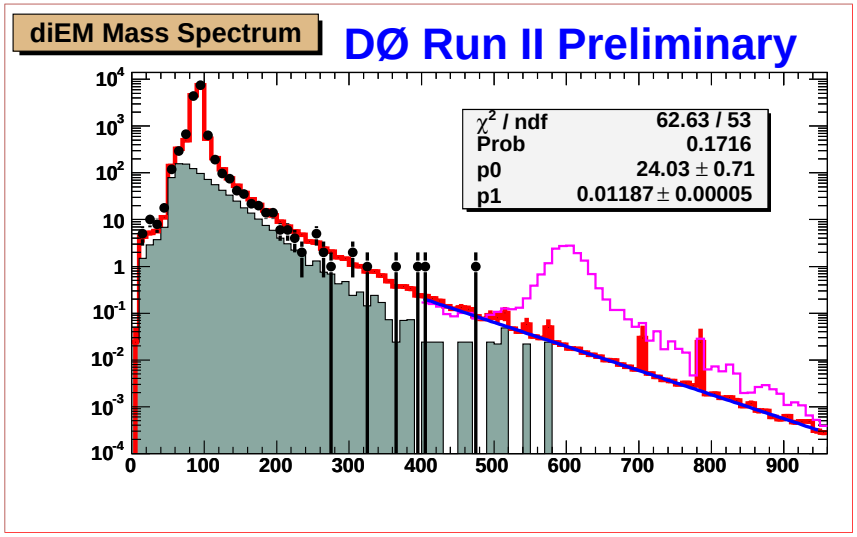


Two methods

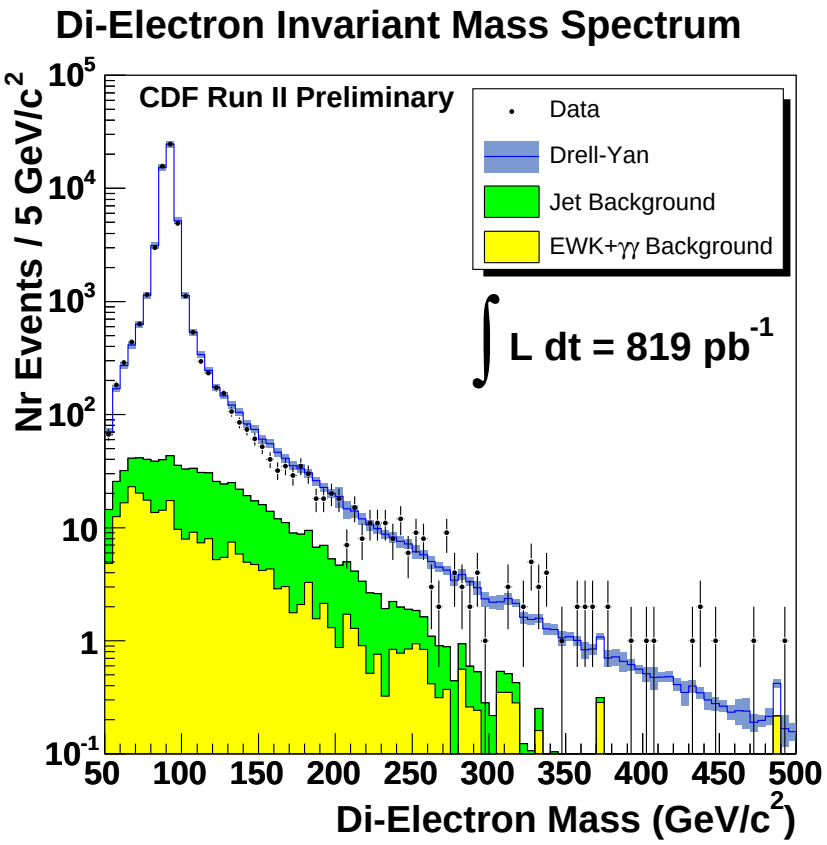
- Just use mass distributions: least assumptions ≈ most general
- Use angular information to improve sensitivity

Search for New Bosons

$Z' \to ee$ Searches



D0 $\gamma^*/Z/Z' \to ee$ (200 pb^{-1})



CDF $\gamma^*/Z/Z' \to ee$ (820 pb^{-1})

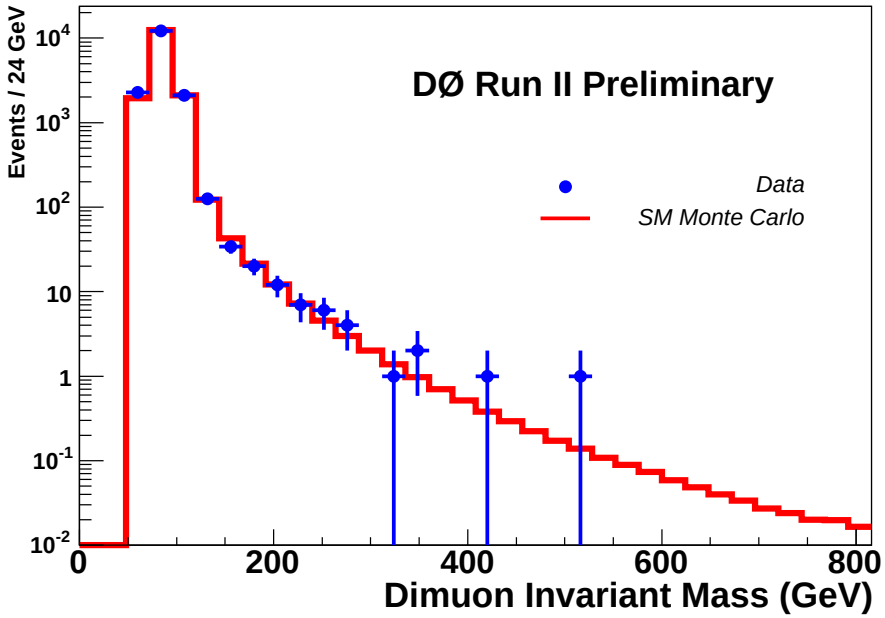
- Main background is dijets
- SM Models is NNLO mass dependent K-factor

Use Z'_{SM} as bench mark

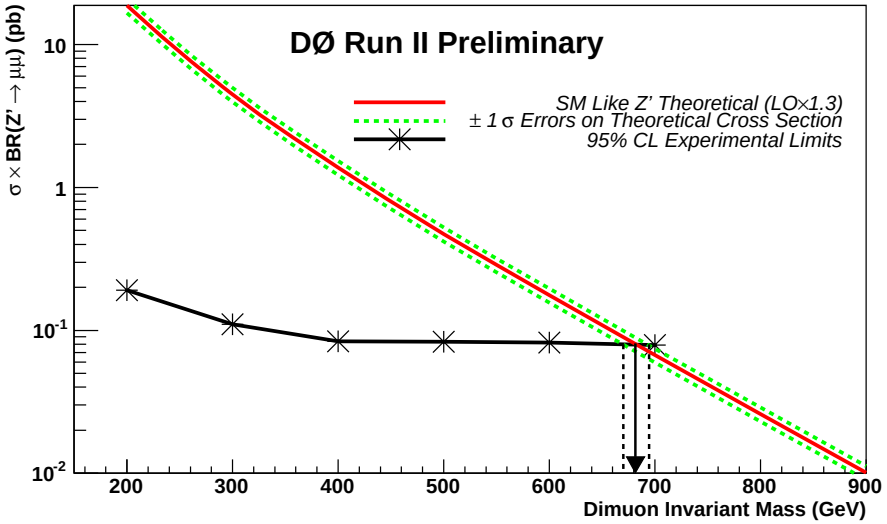
D0 $M_{Z'_{SM}} < 780 GeV (@95\% CL)$ CDF $M_{Z'_{SM}} < 850 GeV (@95\% CL)$

Search for New Bosons

$Z' \to \mu\mu$



D0 $\gamma^*/Z/Z' \to \mu\mu$ (250 pb^{-1})

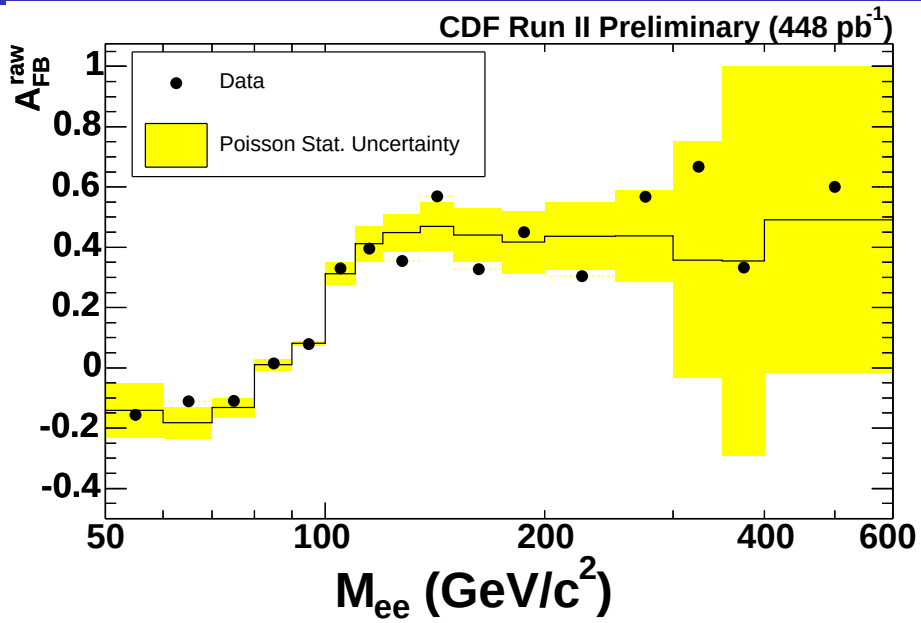


Limit $M_{Z'_{SM}}$ < 680 GeV (@95% CL)

- LEP limits don't apply if Z' doesn't couple to electrons
- High p_T muons trickier than electrons
  - High mass Z' just looks $\approx$ straight back-to-back tracks
  - Use p_T balance to suppress poorly measured masses

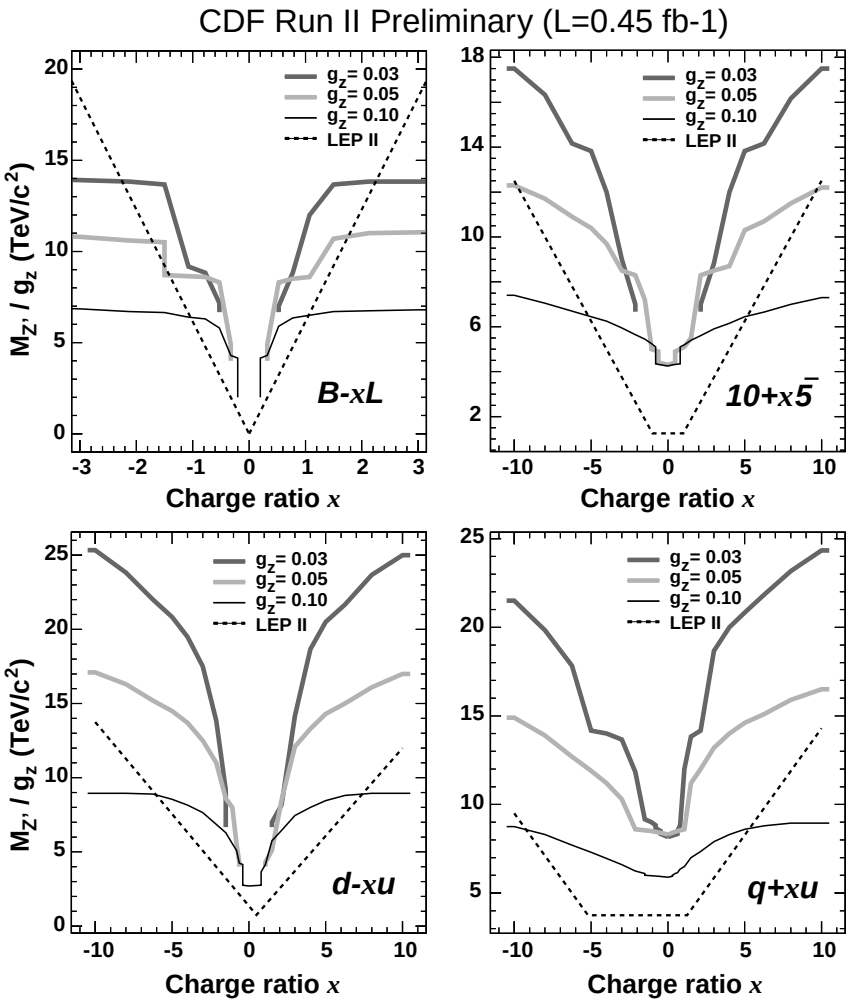
Search for New Bosons

$Z' \to ee$ Searches using $cos\theta^*$ Information



CDF (448 pb^{-1})

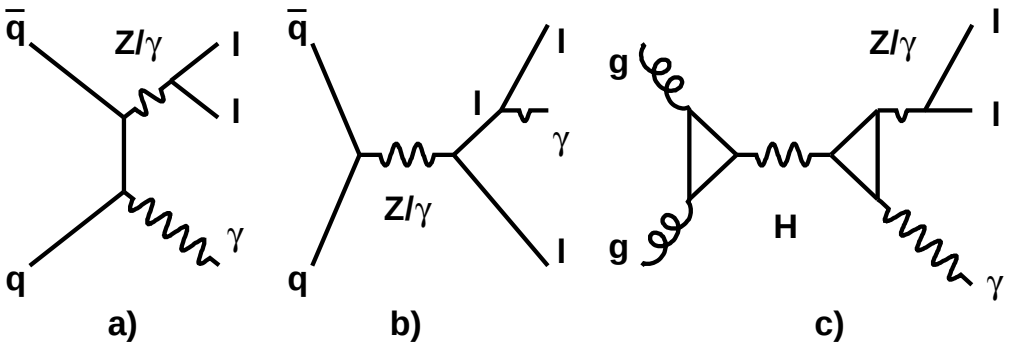
- Gain in sensitivity depends on model ($\approx$ 25% more $\mathcal{L}_{eff}$ for Z'_{SM})
- Carena, et al. have categorized a set of "non-exotic" Z' models



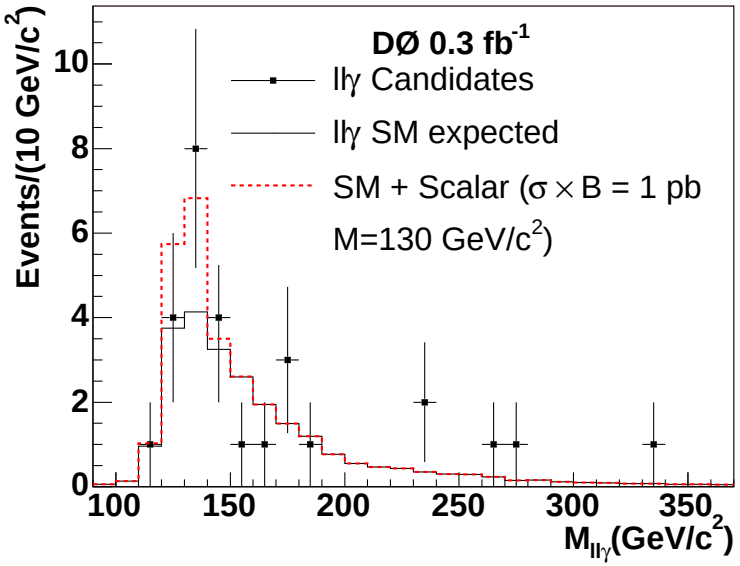
Z_{SM}	Z_χ	Z_ψ	Z_η	Z_I	Z_N	Z_{sec}	$Z_H^{0.3}$	$Z_H^{0.5}$	$Z_H^{0.7}$	$Z_H^{1.0}$
850	740	725	745	650	710	680	625	760	830	900

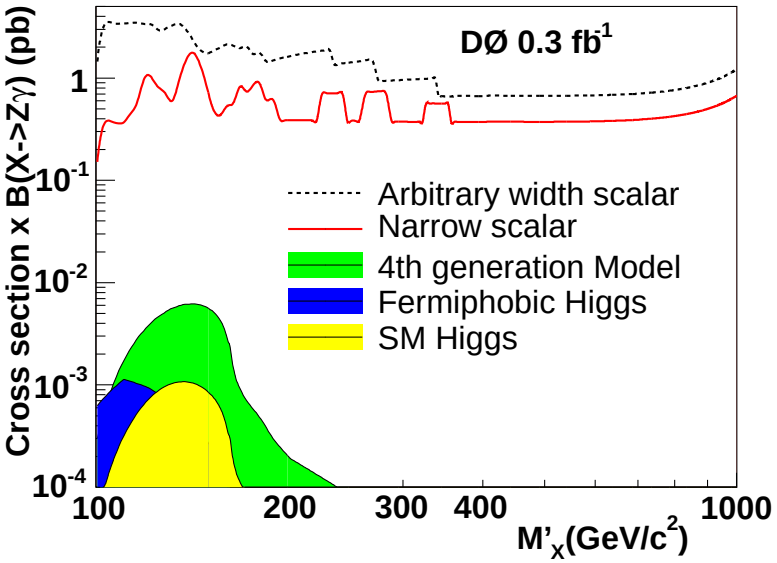
Search for New Bosons

D0 Search for $X \to Z\gamma$ (300 pb^{-1})



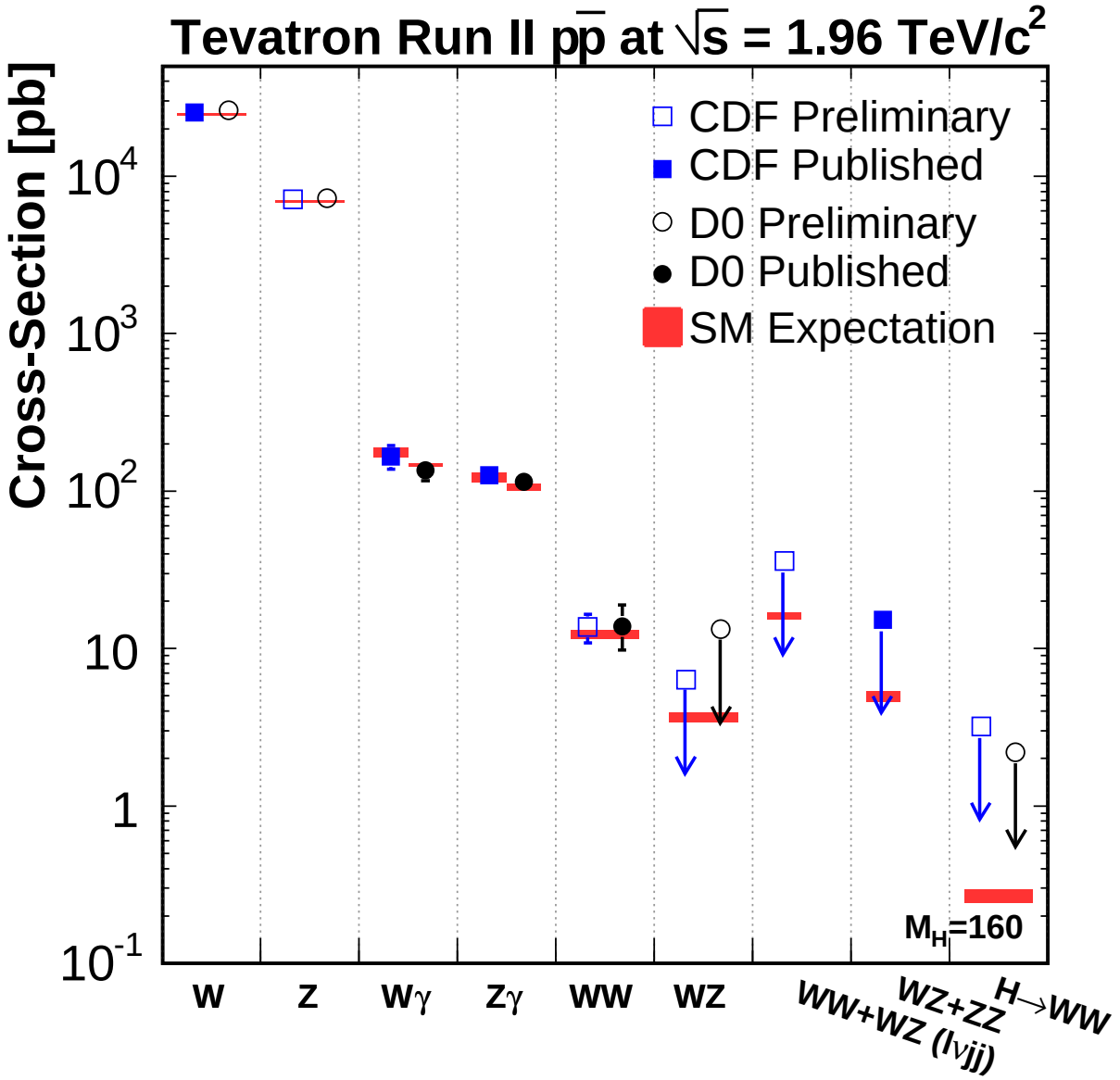
- Spin may suppress a new particles decays into fermions
- Model independent search, but lots of possible models
  - Higgs ($\mathcal{B}(H \to Z\gamma) \approx \mathcal{O}(10^{-3})$)
  - Z', Kaluza-Klein gravitons, ...
- Backgrounds SM $Z\gamma$, Z+jets with a jet faking a γ
  - DO and CDF have nice measurements SM $Z\gamma$

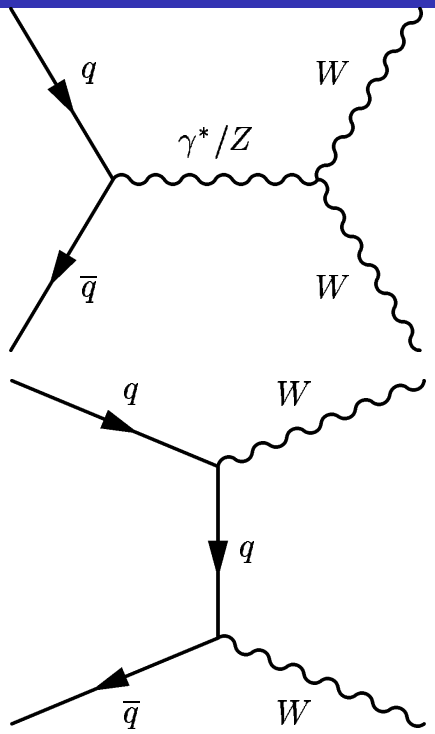




Diboson Production

Overview



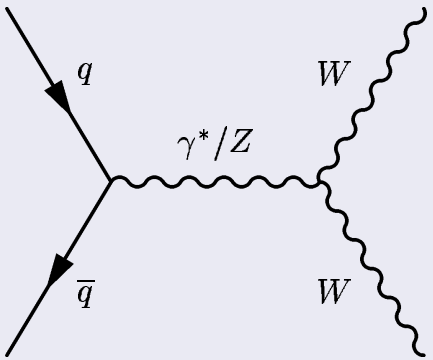


Goals

- Measure triple gauge couplings
- SM *WW* main background to $H \to W^*W$

Anomalous Triple Gauge Couplings

- Measuring the couplings between γ, W, and Z
- 14 couplings Q^2 dependent couplings
- Use other constraints to reduce them to 5: $\Delta\kappa_\gamma, \Delta\kappa_Z, \lambda_\gamma, \lambda_Z, g_1^Z$
- LEP made precision measurements at $Q \approx 2 \times M_W$
- Couplings effect rates and distributions



TGC diagram

Picking a mode for *WW* & *WZ*

mode ($l = e, \mu, \tau$)	*WW*	*WZ*	
$ll\nu\nu/lll\nu$	10.3 %	3.5 %	clean but low rate
$l\nu jj/lljj$	43.6 %	22.4/7.5 %	hard
$jj\nu\nu$	-	14.0 %	?
$jjjj$	46.2 %	48.8 %	*really hard*

Diboson Production

$WW \to ll\nu\nu$

Selection Outline (example CDF, D0 similar)

- Start with 2 e or μ leptons
- Suppression of $\gamma^*/Z \to ll$
  - $\not{E}_T > 25$ GeV
  - min $\Delta\phi(\not{E}_T, l) > 20°$ if $\not{E}_T < 50$ GeV
  - if ll=$ee/\mu\mu$ and $76\ GeV < M_{ll} < 106\ GeV$ then require $\not{E}_T/\sqrt{\sum E_T} > 3.0\ GeV^{1/2}$
- $t\bar{t}$ Suppression: no jets $E_T >$ 15 GeV and $|\eta| < 2.5$

CDF Preliminary with $825 pb^{-1}$

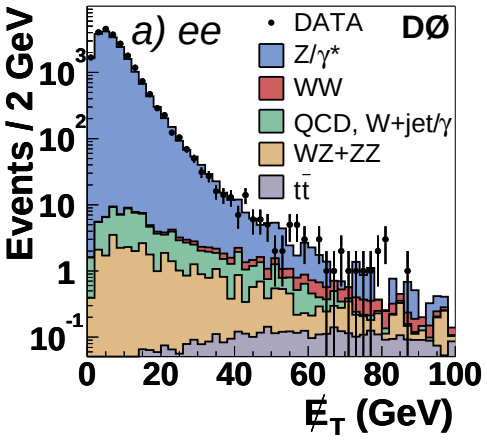
Contribution	Expected Events
SM WW	$52.4 \pm 0.1 \pm 4.3$
Drell-Yan	$11.8 \pm 0.8 \pm 3.1$
$t\bar{t}$	$0.2 \pm 0.0 \pm 0.0$
$WZ + ZZ$	$7.9 \pm 0.0 \pm 0.8$
$W\gamma$	$6.8 \pm 0.2 \pm 1.4$
W+jets	$11.0 \pm 0.5 \pm 3.2$
Sum Bkg	$37.8 \pm 0.9 \pm 4.7$
Total Expected	$90.2 \pm 0.9 \pm 6.4$
Data	95

D0 ($224 - 252\ pb^{-1}$):

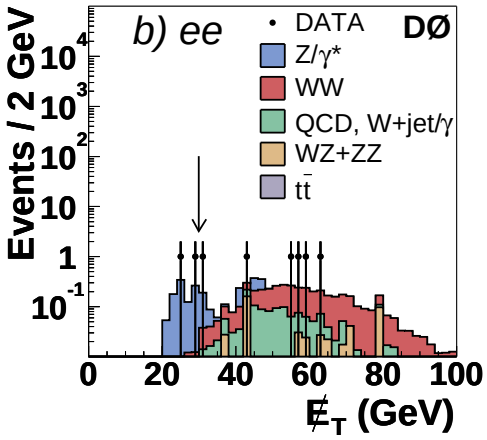
25 evts with bkg of 8.1 ± 0.6(stat) ± 0.6(sys) ± 0.5(lumi)

Diboson Production

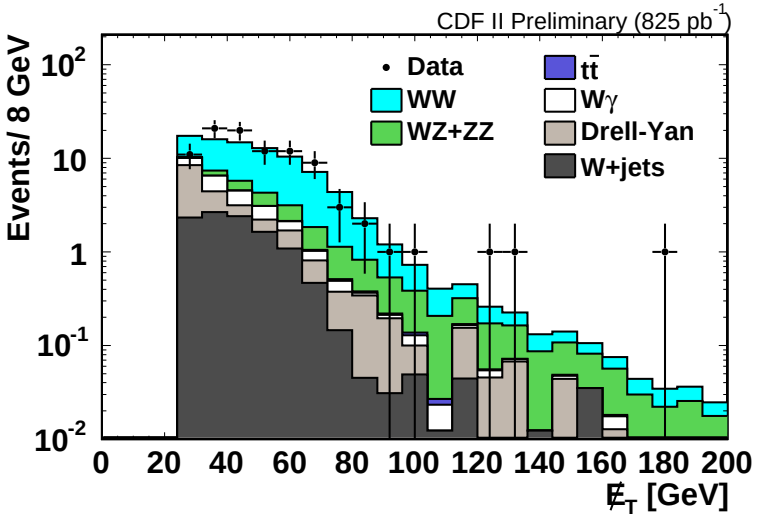
$WW \to ll\nu\nu$



D0 before other cuts



D0 after other cuts



D0 ($224 - 252\ pb^{-1}$)

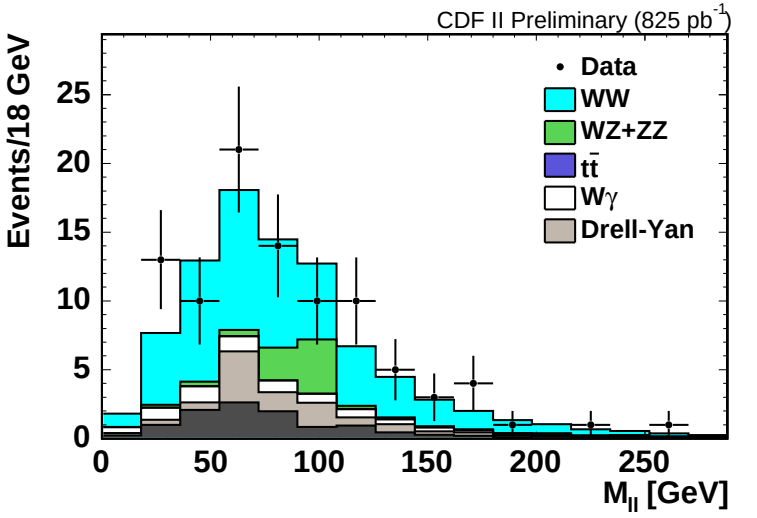
$$\sigma = 13.8^{+4.3}_{-3.8}(stat)^{+1.2}_{-0.9}(sys) \pm 0.9(lum)\ pb$$

CDF ($825\ pb^{-1}$)

$$\sigma = 13.6 \pm 2.3(stat) \pm 1.6(sys) \pm 1.2(Lm)\ pb$$

NLO Theory: Campbell,Ellis

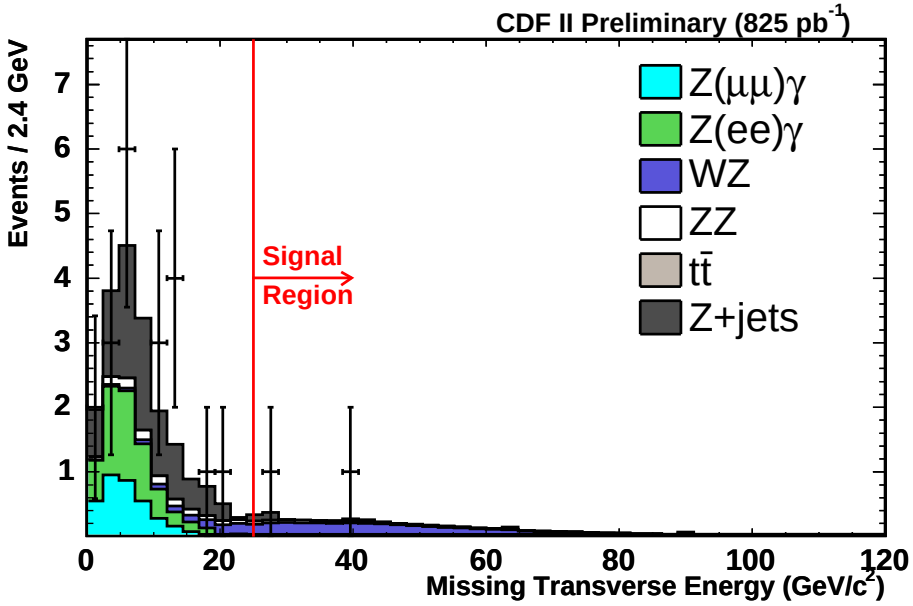
$$\sigma^{WW}_{NLO} = 12.4 \pm 0.8 pb$$



CDF with $825 pb^{-1}$

Diboson Production

$WZ \to lll\nu$



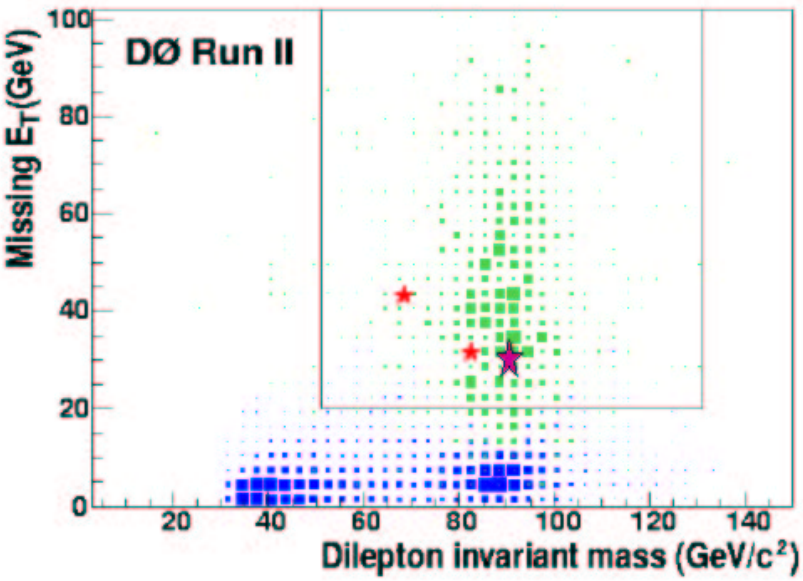
Selection Outline (example CDF, D0 similar)

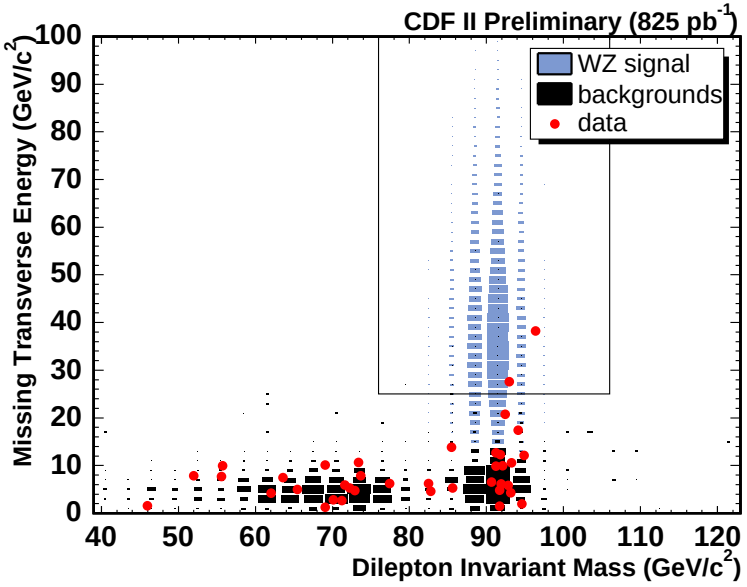
- 3 e or μ leptons (leading lepton: p_T>20 GeV, others:p_T>10 GeV)
- $\not{E}_T > 25$ GeV to suppress Z+jets and $Z\gamma$
- ZZ: veto on extra track

Diboson Production

$WZ \to lll\nu$

- D0 (300 pb^{-1})
  - observed 3 evts
  - expected 2.0 ± 0.2 signal and 0.71 ± 0.08 background
  - $\sigma(WZ) < 13.3\ pb$ @ 95% CL, $4.5^{+3.8}_{-2.6}(stat + sys)pb$
- CDF (825 pb^{-1})
  - observed 2 evts
  - expected 3.7 ± 0.3 signal and 0.9 ± 0.2 background
  - $\sigma(WZ) < 6.34\ pb$ @ 95% CL
- NLO $\sigma(WZ) = 3.7 \pm 0.1 pb$ (Campbell, Ellis)

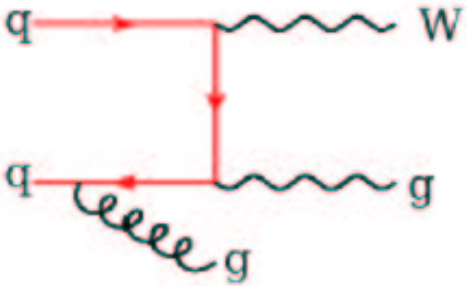




Diboson Production

$WW + WZ \to l\nu jj$

WW/WZ TGC diagram

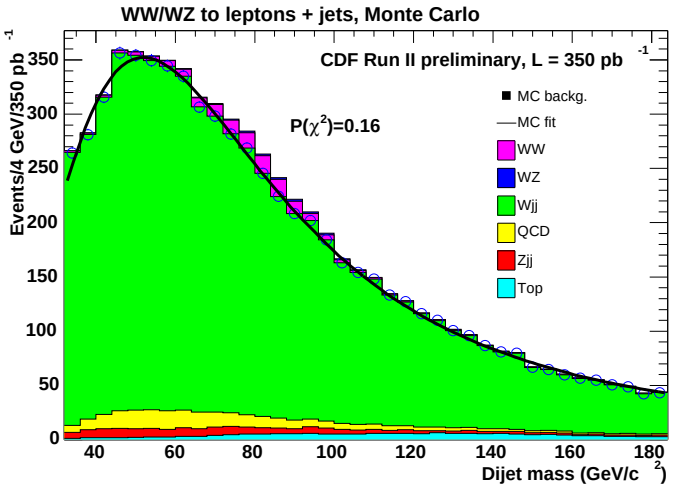


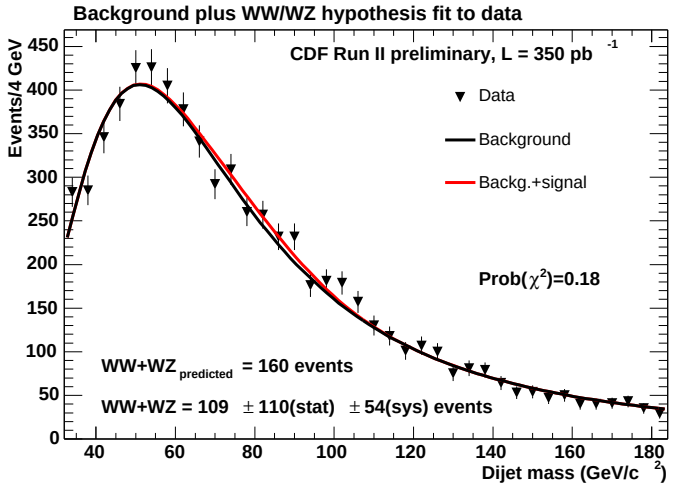
Example W+2j diagram

- $\approx 4\times$ larger BR $WW \to ll\nu\nu$
- $\approx 10\times$ larger BR $WZ \to lll\nu$
- Large background from W+jets (need to understand W+jets)

Selection Outline

- 1 lepton (p_T>25 GeV), $\not{E}_T$ > 25 GeV
- $\geq$2 jets (p_T > 15 GeV)

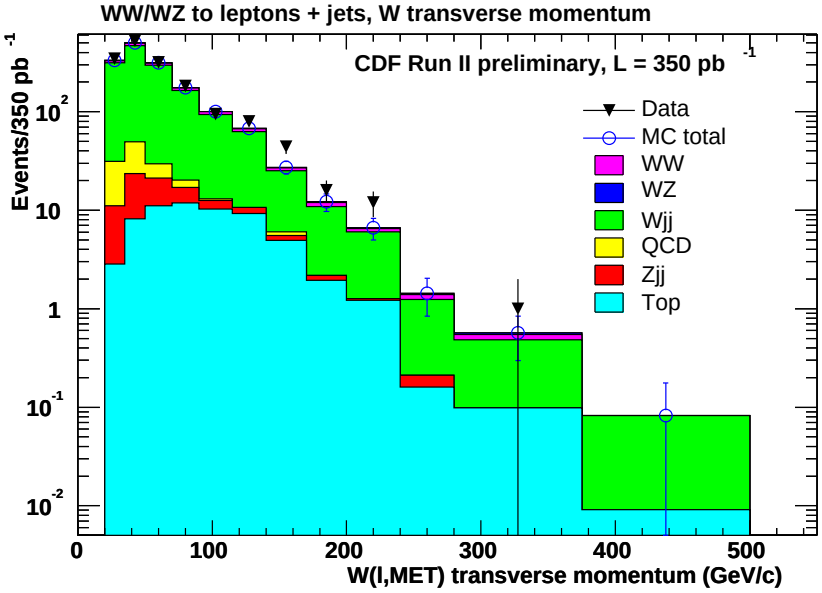




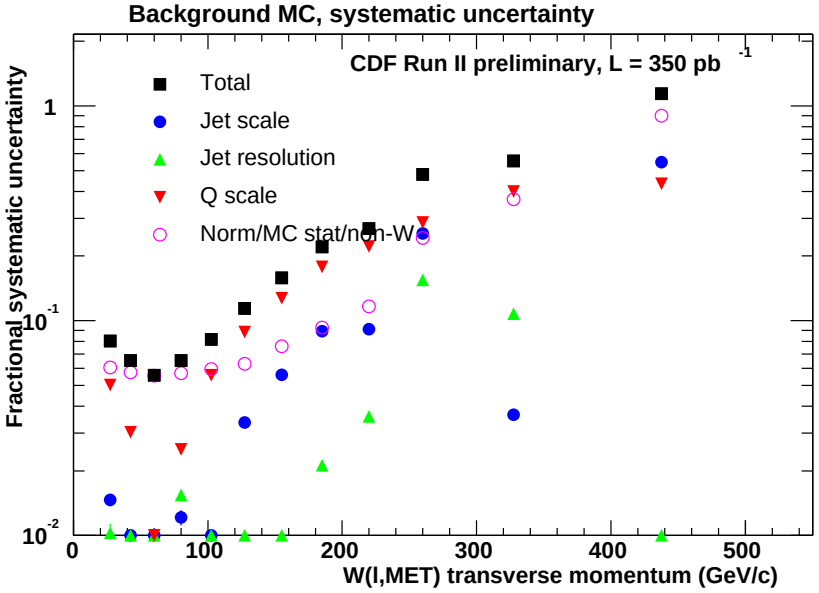
W+jets falls at high p_T where anomalous couplings can enhance signal

Diboson Production

$WW + WZ \to l\nu jj$ limits on anomalous couplings



$W(l, \not{E}_T)\ p_T$

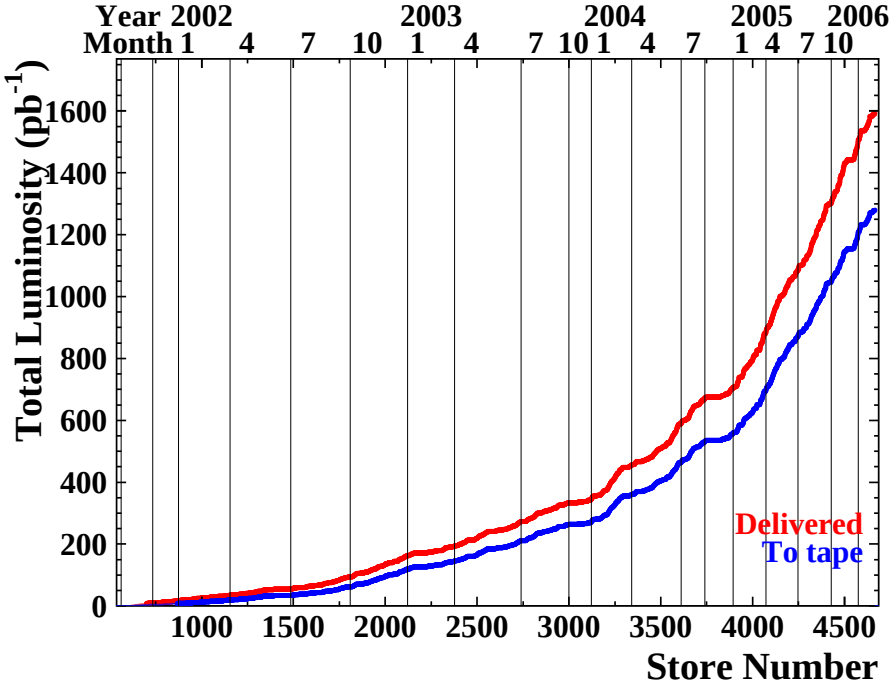


Background systematics

- Select dijet mass $56 < m_{jj} < 112$ GeV peak region
- Minimize likelihood for $W(l, \not{E}_T)\ p_T$ distribution
  - Anomalous couplings tend to enhance the rate at high p_T
- Results (parameters are zero in the Standard Model)

$$-0.51 < \Delta\kappa < 0.44 \qquad -0.28 < \lambda < 0.28$$

Summary



- Luminosity makes a difference
- Precision work is helping to develop better models of hadron collisions
- Searches are improving from both luminosity and sophistication of techniques
- New Standard Model modes are become accessible