Di-Boson Physics @ the Tevatron

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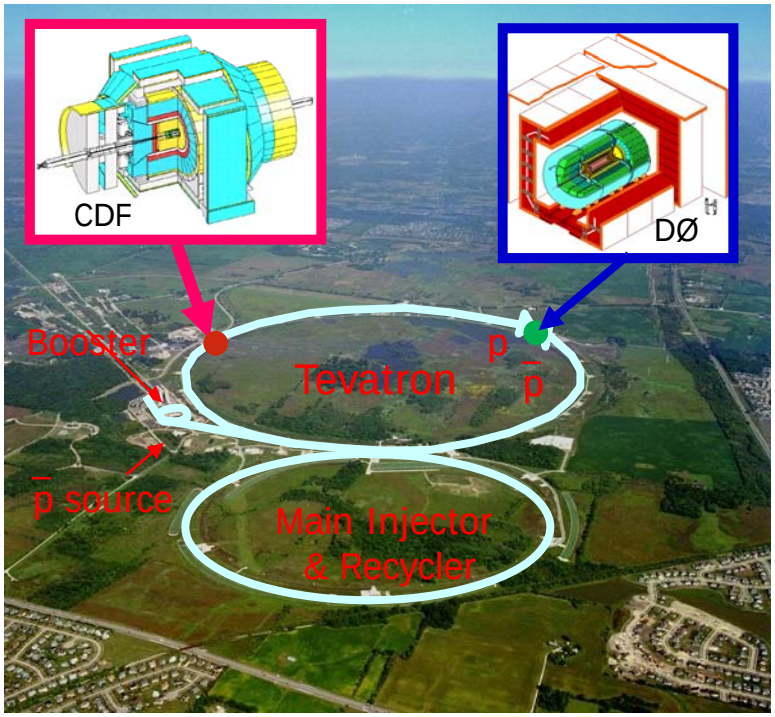
On behalf of the 

& 
Collaborations

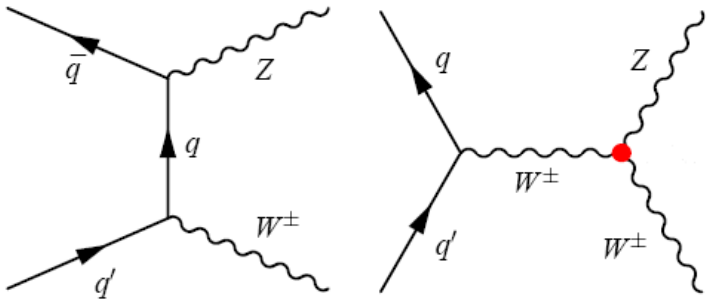


- P-Pbar @1.96 TeV, 2×10^{32} $cm^{-2}s^{-1}$
- Vector Boson factory
  - ✓ ~ 0.7 million W
  - ✓ ~ 0.15 million Z
  - ✓ ~ 400 WW, ~ 120 WZ, ~50 ZZ

at $L\sim$ 30 pb^{-1}/week

- Precise test of non-Abelian $SU(2)_L \times U(1)_Y$
  -- complementary to LEP : higher c.m. energy, new couplings of charged currents
- Probe *TGC* (trilinear gauge couplings)
  -- sensitive to "*low*" energy remnants of new physics @ high scale
- Background to hunting Higgs, top and SUSY
- Topology : ≥2 isolated high pT(>15 GeV) lepton(l=e,μ)/γ, MET(>20 GeV) for W

WZ production @ Tevatron



SM NLO : 3.68 ± 0.25 pb

[***PRD 60, 113006 (1999)***]

- Unique measurement on WWZ TGC

$$L/g_{WWV} = ig_1^V (W^*_{\mu\nu} W^\mu W^\nu - W_{\mu\nu} W^{*\mu} V^\nu) + i\kappa^V W^*_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2} W^*_{\rho\mu} W^\mu_\nu V^{\nu\rho}$$

  -- non-SM anomalous as $\Delta g_1^Z = g_1^Z - 1$, $\Delta\kappa_Z = \kappa_Z - 1$, λ_Z with form factor as $a(\hat{s}) = \frac{a_0}{(1+\hat{s}/\Lambda^2)^2}$

  -- Enhancement on production + excess at W/Z high pT spectrum

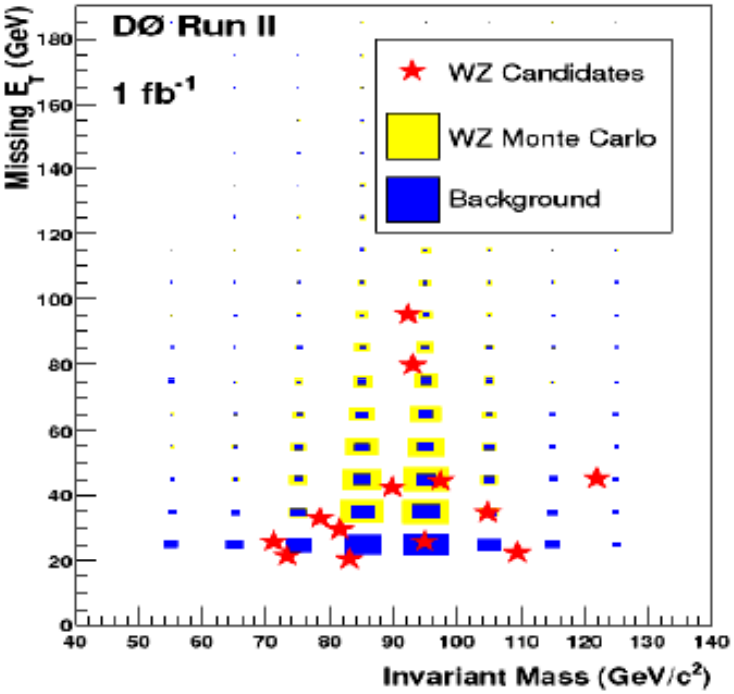
- WZ→lllν search channel :

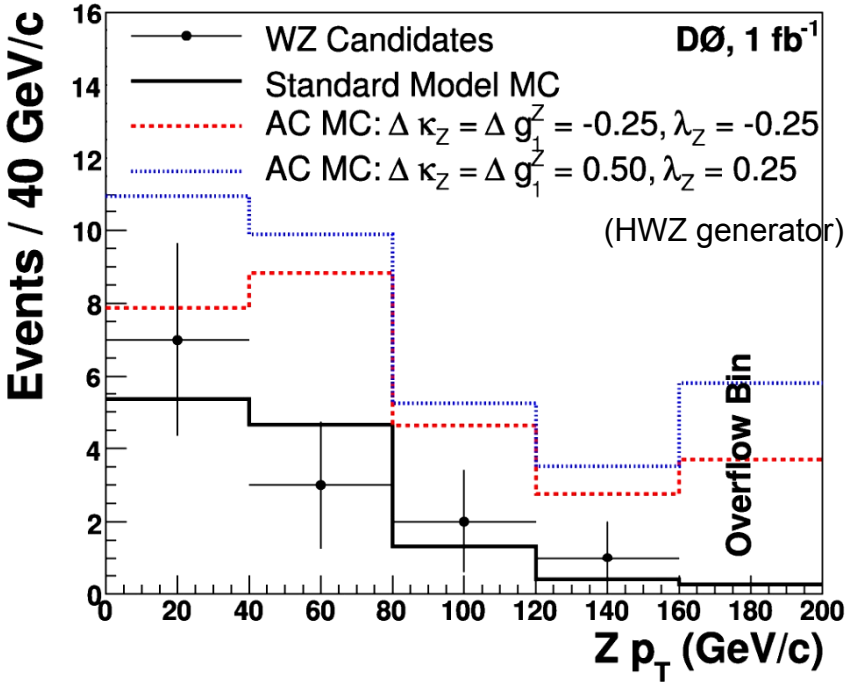
  -- eee, eeμ, eμμ and μμμ combined, Br~1.5%

  -- high pT isolated lepton + MET + di-lepton invariant mass around Z

Evidence of WZ→3l @ DØ 1fb^{-1}

- 13 candidates with 4.5 background ~ 3σ significance





$$\sigma(P\bar{P}@1.96\text{TeV} \rightarrow WZ) = 2.7^{+1.7}_{-1.3}\ \text{pb}$$

[***PRD 76, 111104(R) (2007)***]

- Anomalous WWZ TGC

Λ=1.5 TeV	Λ=2.0 TeV
$-0.18<\lambda_Z<0.22$	$-0.17<\lambda_Z<0.21$
$-0.15<\Delta g_1^Z<0.35$	$-0.14<\Delta g_1^Z<0.34$
$-0.14<\Delta\kappa_Z=\Delta g_1^Z<0.31$	$-0.12<\Delta\kappa_Z=\Delta g_1^Z<0.29$

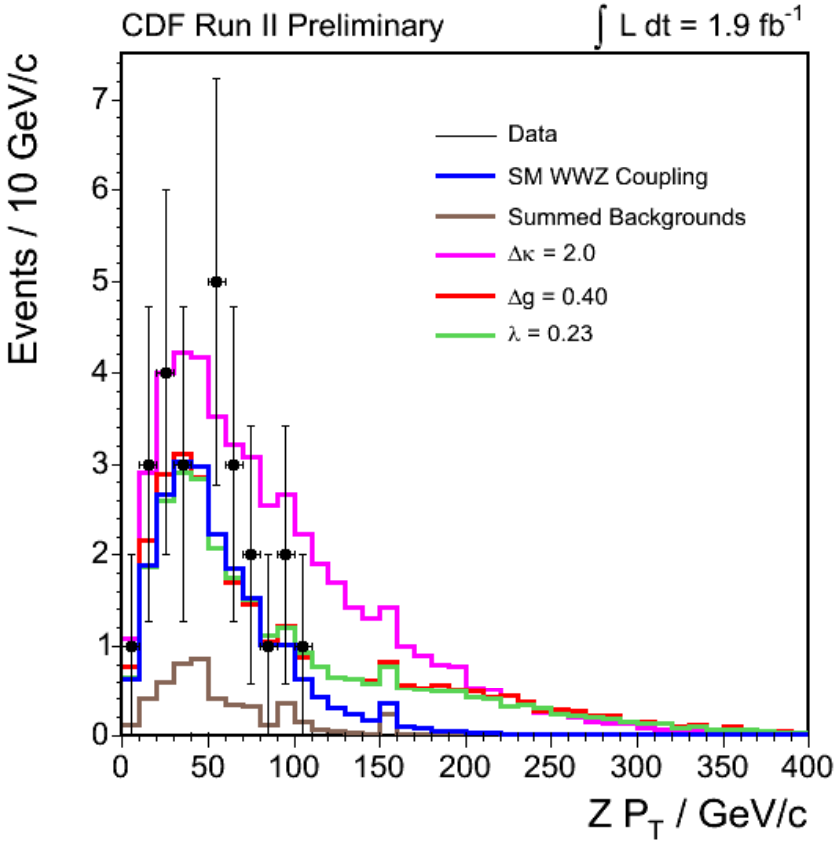
Observation of WZ→3l @ CDF 2fb^{-1}

- Cross-section measurement: 25 candidates

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**

$$\sigma = 4.3^{+1.3}_{-1.0}(\text{stat}) \pm 0.4(\text{syst} + \text{lumi})\text{pb}$$

[***PRL 98, 161801***]

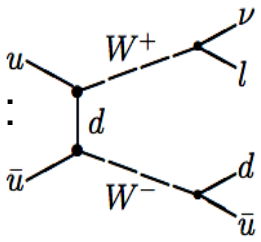


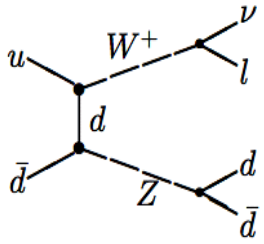
- Constraint on anomalous WWZ

Λ=1.5 TeV	Λ=2.0 TeV
$-0.14<\lambda_Z<0.16$	$-0.13<\lambda_Z<0.14$
$-0.17<\Delta g_1^Z<0.27$	$-0.15<\Delta g_1^Z<0.24$
$-0.86<\Delta\kappa_Z<1.36$	$-0.82<\Delta\kappa_Z<1.27$

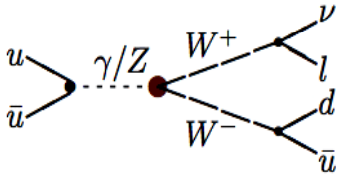
WW/WZ→lνjj @ CDF 1.2fb^{-1}

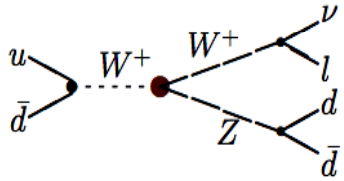
- First measurement of (l+MET+2jets) @Tevatron :
  - ✓ more statistic→ sensitive to TGC
  - ✓ similar to WH→lνbb
  - ✓ huge background from W+jets, ~300pb





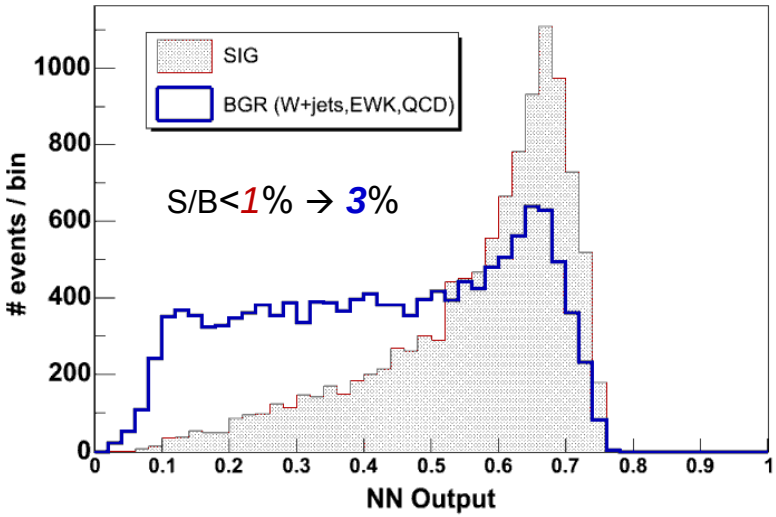
σ(WW+WZ)×Br = 2.09±0.14 pb



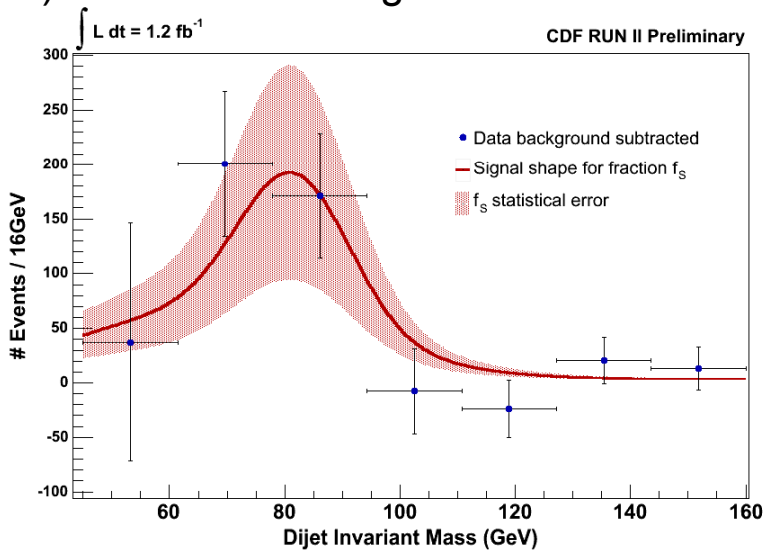


- Analysis strategy :

1) NN to increase S/B significance

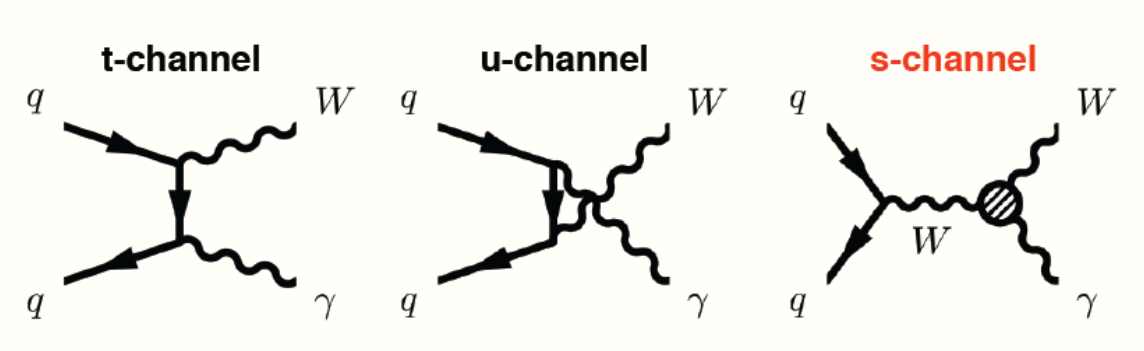


2) likelihood fit → signal fraction

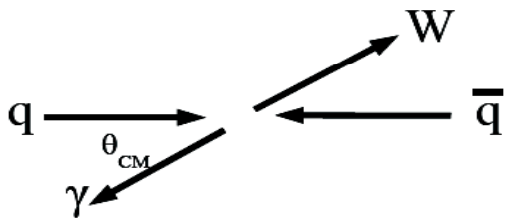


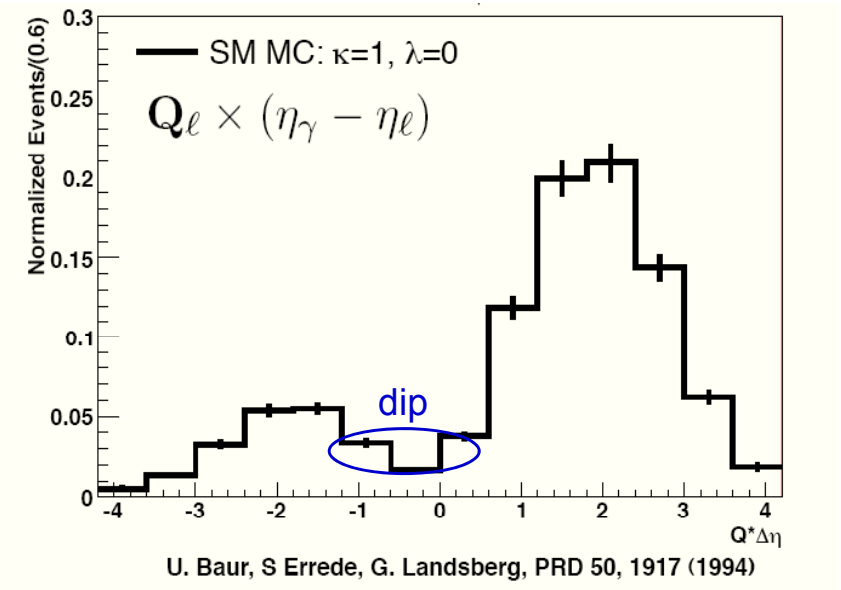
σxBr < ***2.88*** pb@95%C.L.

Radiation-Amplitude Zero in Wγ



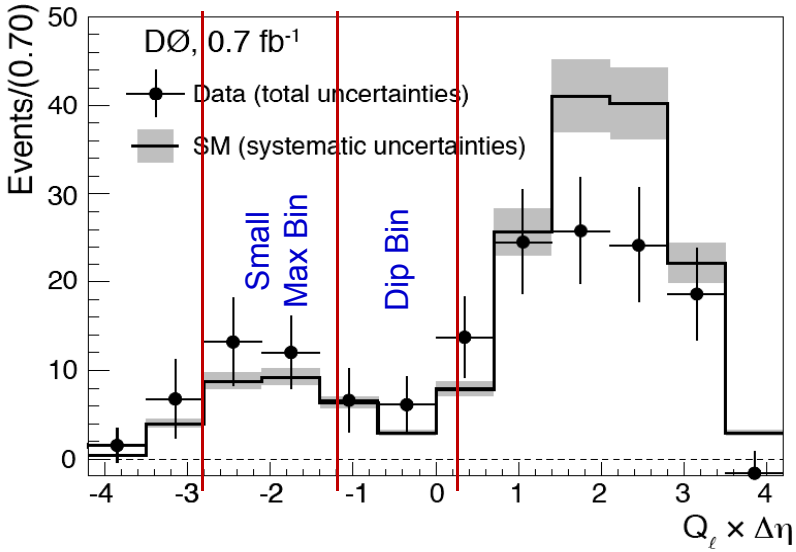
- SM : **RAZ** (Radiation Amplitude Zero)
  - Predicted at $\cos(\theta^*) = \pm 1/3$
  - Measured as Charge-Sign photon-lepton Rapidity Difference $Q \times [\eta(\gamma) - \eta(l)]$





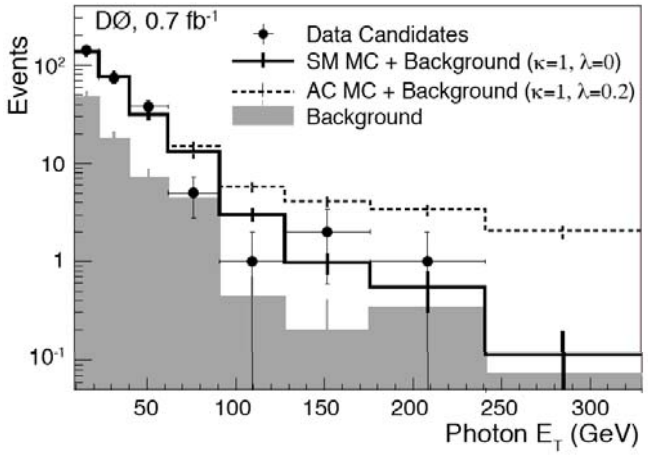
Study of W(lν)γ RAZ @ DØ 0.7fb^{-1}

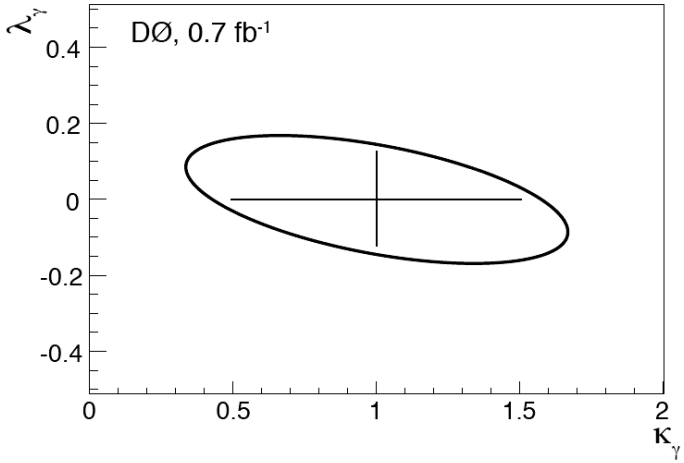
- First indication of RAZ : $E_T(\gamma)$>**7**GeV, $\Delta R(l\gamma)$>**0.7**, $M_T(l\gamma\nu)$>**90**GeV



- ✓ Full covariance matrix χ^2/dof=17.0/12
- ✓ 2-Bin Statistical analysis : unimodal hypothesis ruled out @ 2.6 σ

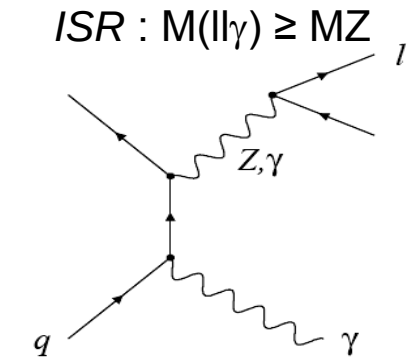
- Photon pT spectrum → anomalous WWγ TGC

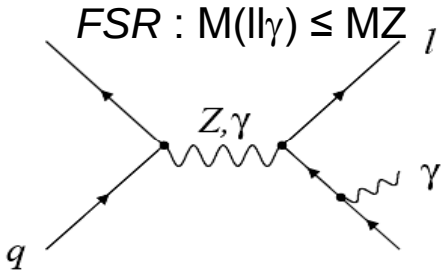


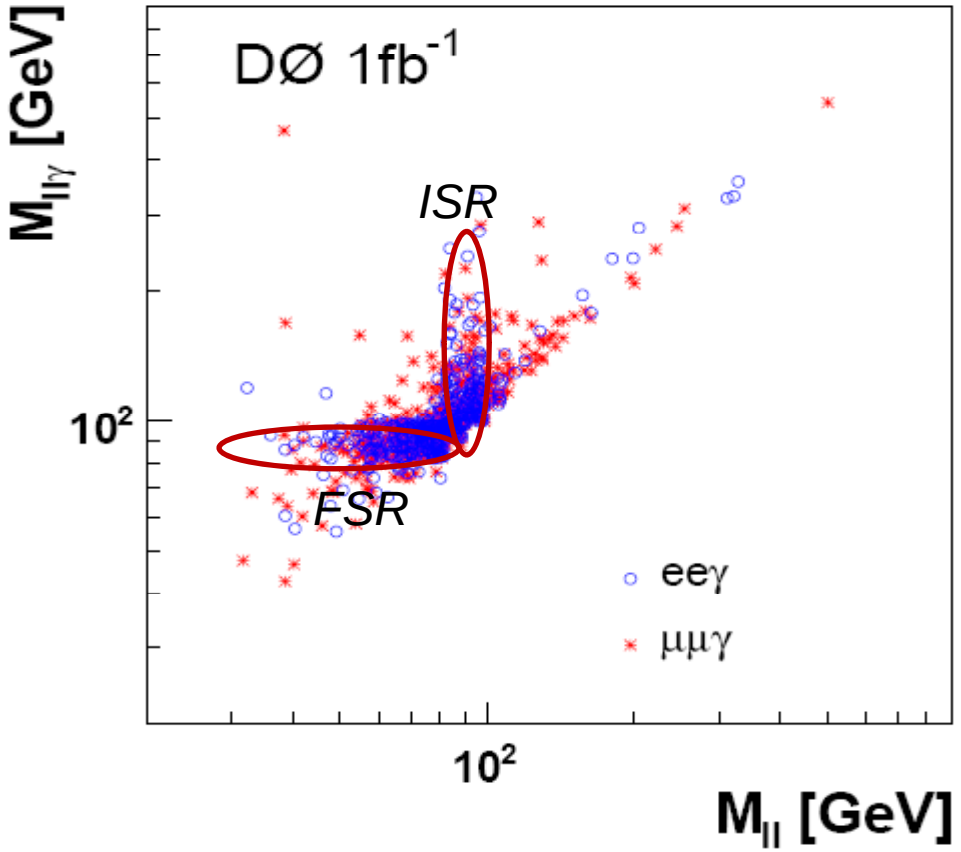


Precise Z(ll)γ measurement @ DØ 1fb^{-1}

- Event selections: $E_T(\gamma)$>**7**GeV, $\Delta R(l\gamma)$>**0.9**, $M(ll)$>**30**GeV





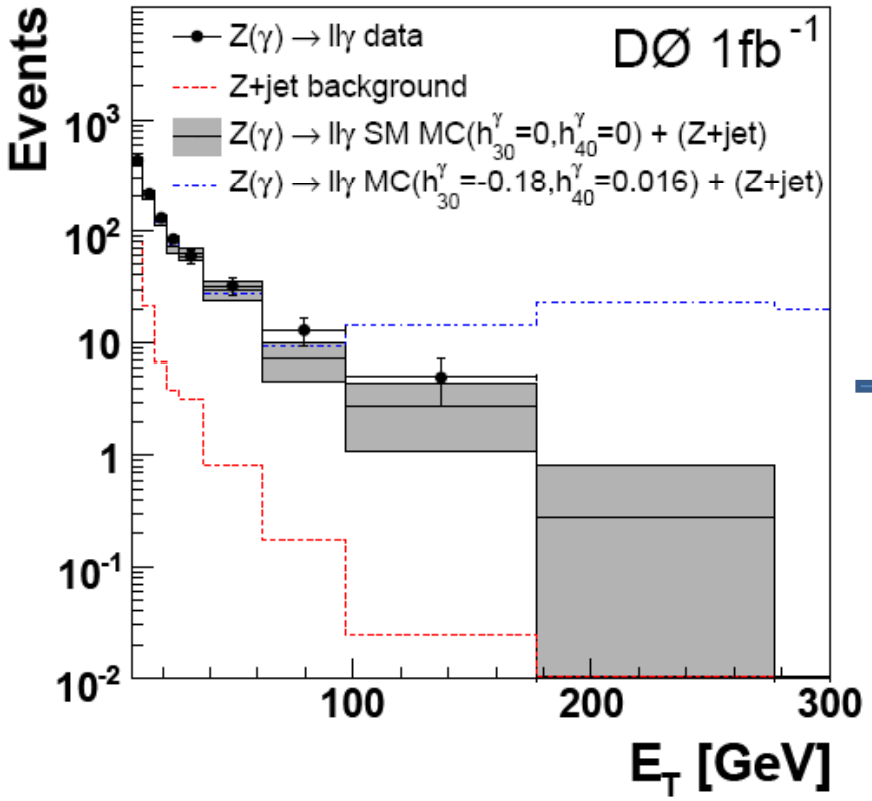


$\sigma(\ Z\gamma \rightarrow ll\gamma\ ) = 4.96 \pm 0.30(\text{stat+syst}) \pm 0.30(\text{lumi})$ pb.

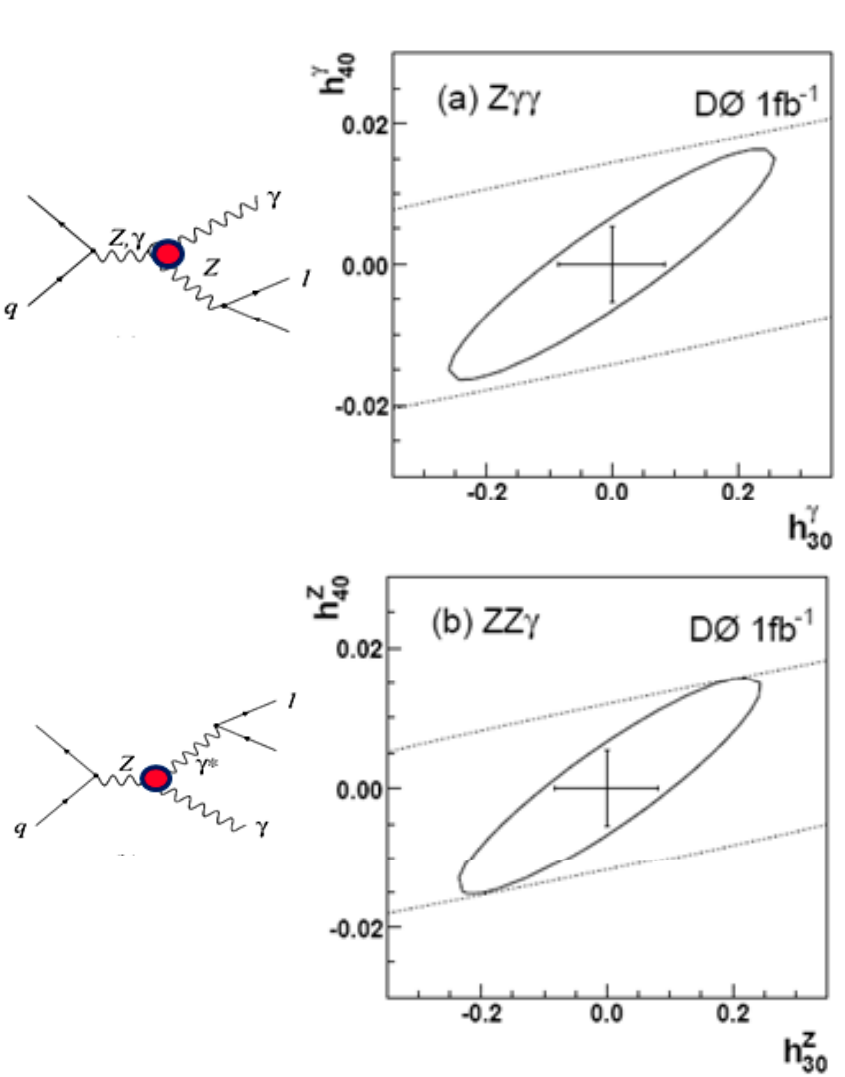
SM NLO : 4.74 ± 0.22 pb. [***PRD 57, 2823 (1998)***]

Anomalous ZZγ/ Zγγ TGC@ DØ 1fb^{-1}

- Photon E_T spectrum of selected events :



[*PLB 653, 378 (2007)*]

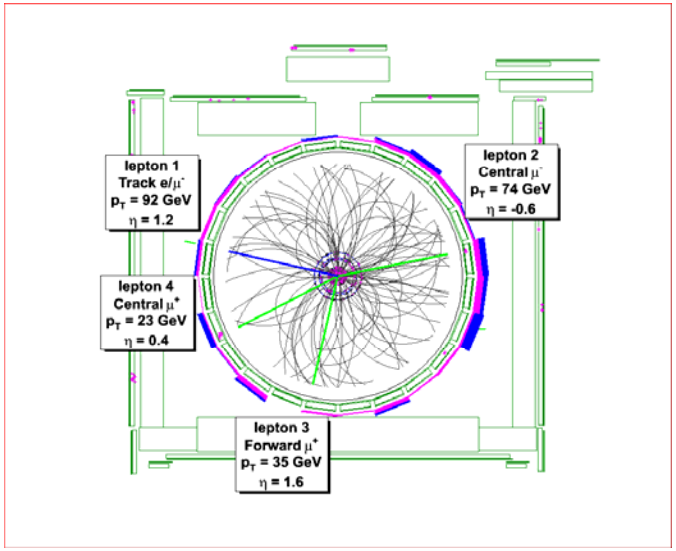


First measurement of ZZ @ CDF 2fb^{-1}

- Charged *4l* channel:

  3 events with 0.1 background → **4.2** σ significance

Category	Candidates without a trackless electron	Candidates with a trackless electron
ZZ	$1.990 \pm 0.013 \pm 0.210$	$0.278 \pm 0.005 \pm 0.029$
Z+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**



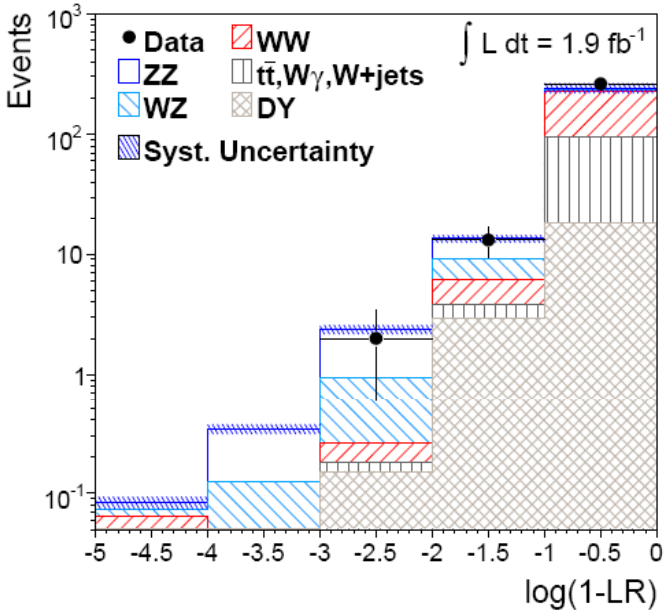
m_{ll1}=90.94 GeV $\quad |\not\!\!E_T|$=9.5 GeV

m_{ll2}=82.20 GeV $\quad N_{jets} = 0$

M_{lll}=311.9 GeV/c^2

- Adding the $ll\nu\nu$ channel:

leading order Elemental Matrix → likelihood ration $\mathrm{LR} = \dfrac{\boldsymbol{P}(ZZ)}{\boldsymbol{P}(ZZ)+\boldsymbol{P}(WW)}$



- Combined $4l$ + $ll\nu\nu$ result : **4.4** σ significance

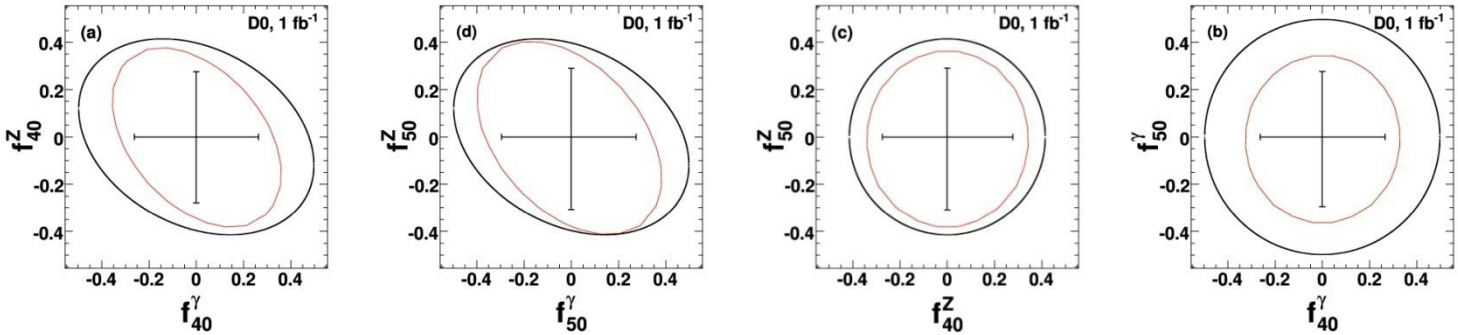
$$\sigma(ZZ@\mathrm{Tevatron}) = 1.\ 4^{+0.7}_{-0.6}\ \mathrm{pb}$$

SM NLO :1.4 ± 0.1 pb. [***PRD 60, 113006 (1999)***]

Search for ZZ @ DØ

- SM NLO :
  --1.6 ± 0.1pb [***PRD 62, 113011; PRD 60, 072002***]
  -- t-channel only, no tri-linear TGC

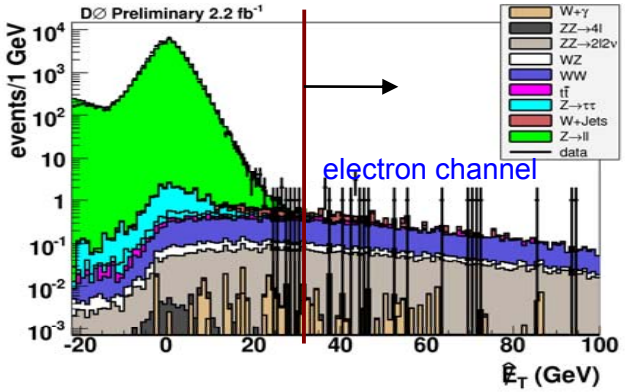
- Charged ***4l*** channel @**1** fb^{-1} : *M(ll)* > 30 GeV for eeee, ee$\mu\mu$, $\mu\mu\mu\mu$
  - ✓ 1 event observed with 0.13 ± 0.03 background expected
  - ✓ Cross section $\sigma(ZZ/Z\gamma^*) < 4.4$ pb @95%C.L.
  - ✓ The first bounds on $ZZZ/ZZ\gamma^*$ anomalous couplings from Tevatron



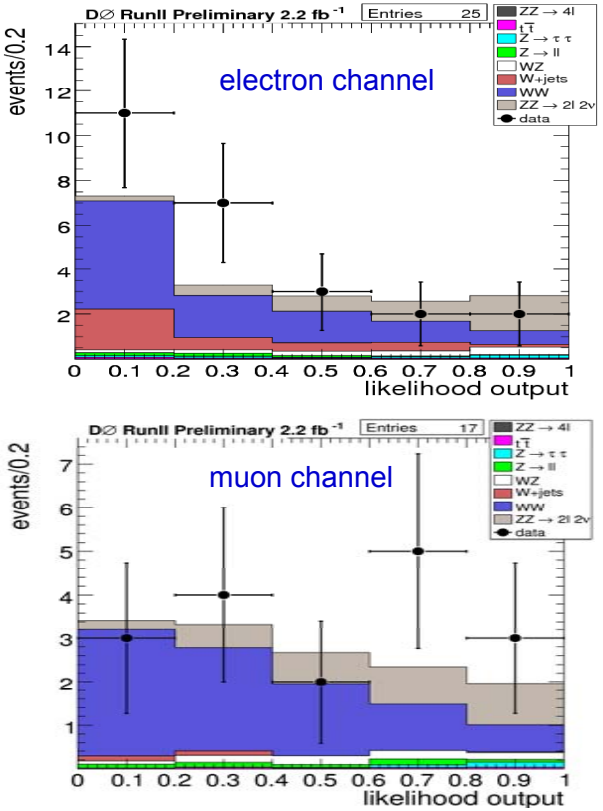
[***hep-ex/0712.0599***]

- Combined e and μ channel of $ll\nu\nu$ @ **2.2** fb^{-1} :

  - Recoil of $Z+X$ → discriminating variable $\hat{\not{E}}_T$



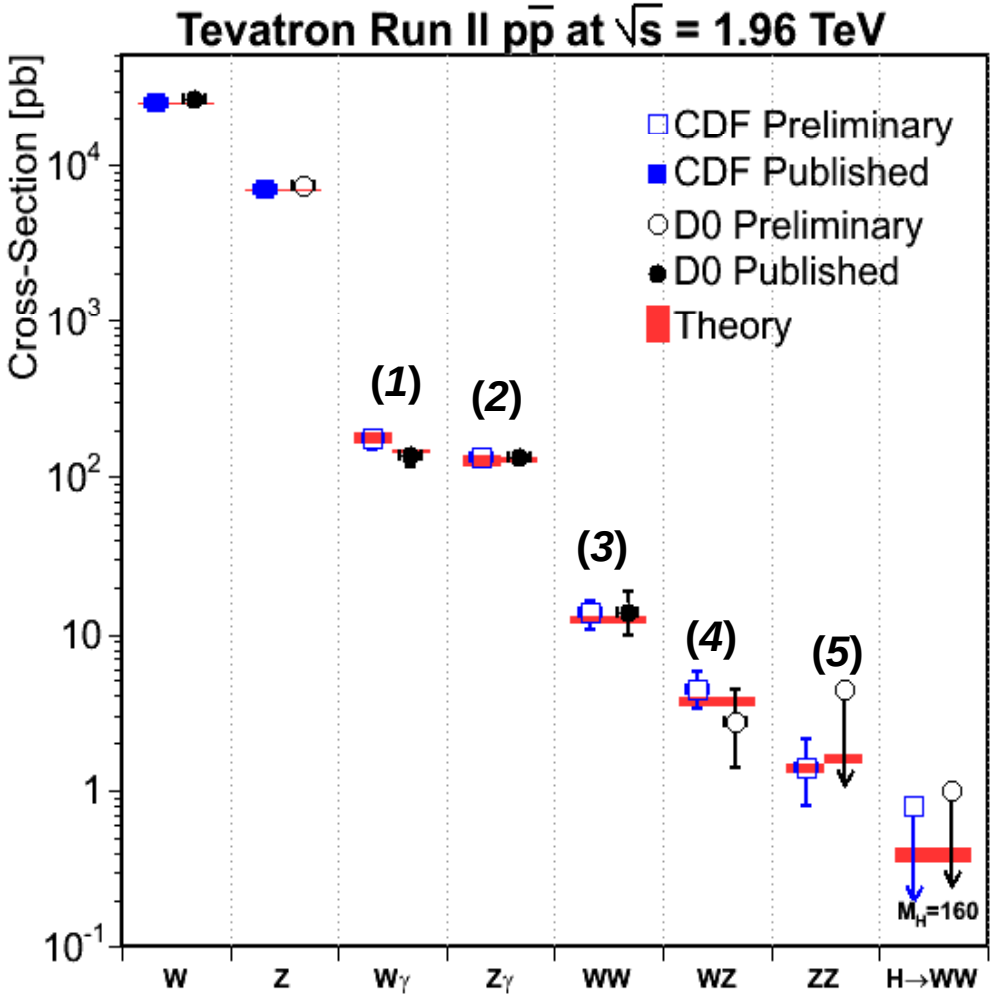
  - Physics background → likelihood



- ✓ Statistic test : 1.77 σ significance predicted → 2.4 σ significance observed
- ✓ Cross section measurement :

$$\sigma(p\bar{p} \to ZZ) = 2.1 \pm 1.1(stat.) \pm 0.4(sys.)\text{pb}$$

Di-Boson Physics @ Tevatron



- Precise measurement from O(**10^2**)pb down to O(**1**)pb @ up to 2fb^{-1}, precise agreement to SM is observed
  - (*1*) First evidence of Wγ RAZ
  - (*2*) Zγ cross-section measurement
  - (*3*) WW/WZ→lνjj semi-leptonic
  - (*4*) WWZ TGC
  - (*5*) First evidence of ZZ

✓ *CDF results*
http://www-cdf.fnal.gov/physics/ewk/

✓ *D0 results*
http://www-d0.fnal.gov/Run2Physics/WWW/results/ew.htm

- More data coming, and digging hard for Higgs

Backup Slides

To reduce the contribution of fake MET, no direct cut on MET → build a variable sensitive to "true MET"

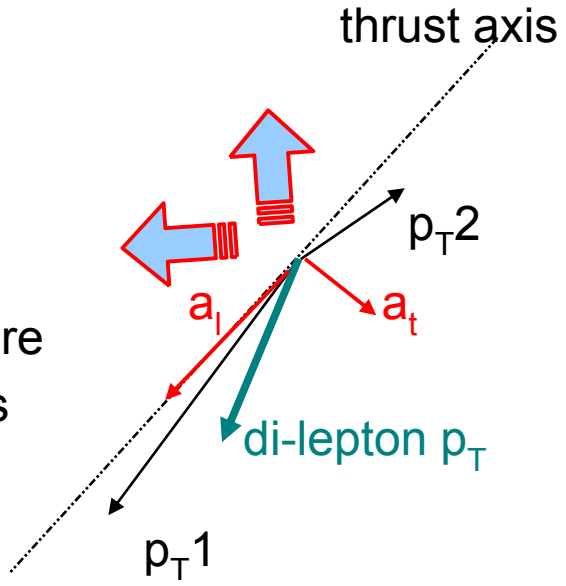
- decompose di-lepton p_T in 2 components with respect to thrust axis:

  a_l: sensible to p_T mis-measurement

  a_t: sensible to recoil activity mis-measurment

- build a variable which gives more weight to a_t (add in quadrature with different weights) → $\not\!\!E_T$

- balance against activity in the opposite hemisphere and correct using the corresponding uncertainties



Result:

- <u>by construction</u> all uncertainties and mis-reconstruction can ONLY reduce the value of $\not\!\!E_T$