# DiBosons at Tevatron

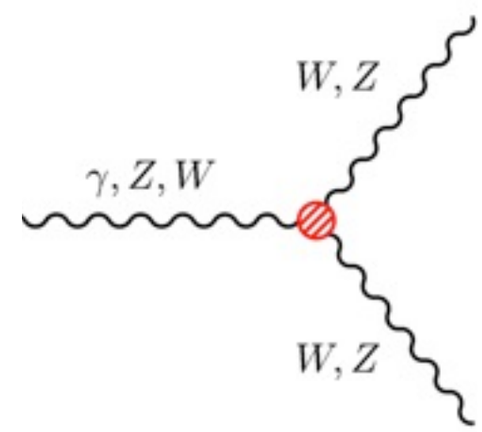
**Vadim Rusu**
Fermilab

# Dibosons

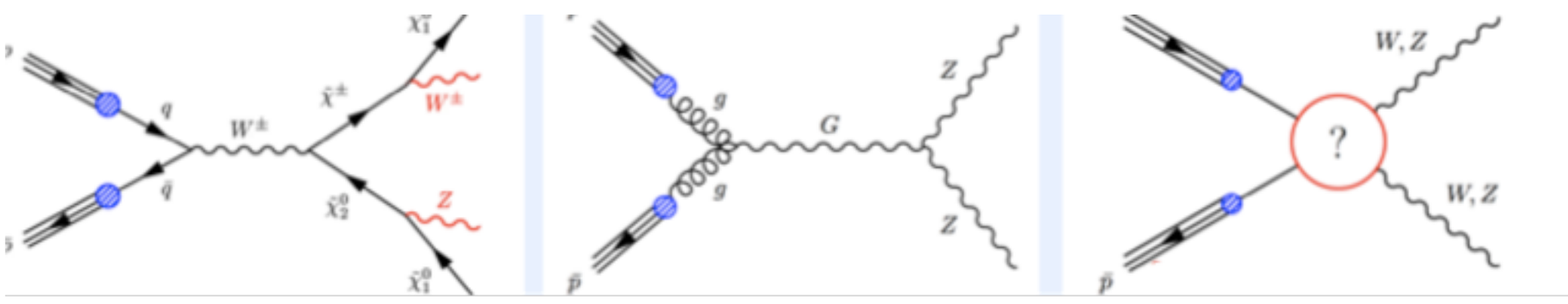
- **Direct probe into the gauge structure of the SM**
  - Rich phenomenology with well calculated predictions:
    - zero triple neutral gauge coupling
    - radiation-amplitude zero

$$-\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 - \frac{1}{2}|\partial_\mu W_\nu^+ - \partial_\nu W_\mu^+ +$$
$$-ie(W_\mu^+ A_\nu - W_\nu^+ A_\mu) + ig' c_w (W_\mu^+ Z_\nu - W_\nu^+ Z_\mu|^2 +$$
$$-\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 +$$

- **Must-do preliminary for the Higgs**
  - Benchmark for experimental capabilities
  - Dibosons final states ~ Higgs final states




- **New Physics effects**
  - new couplings



# Dibosons at Tevatron

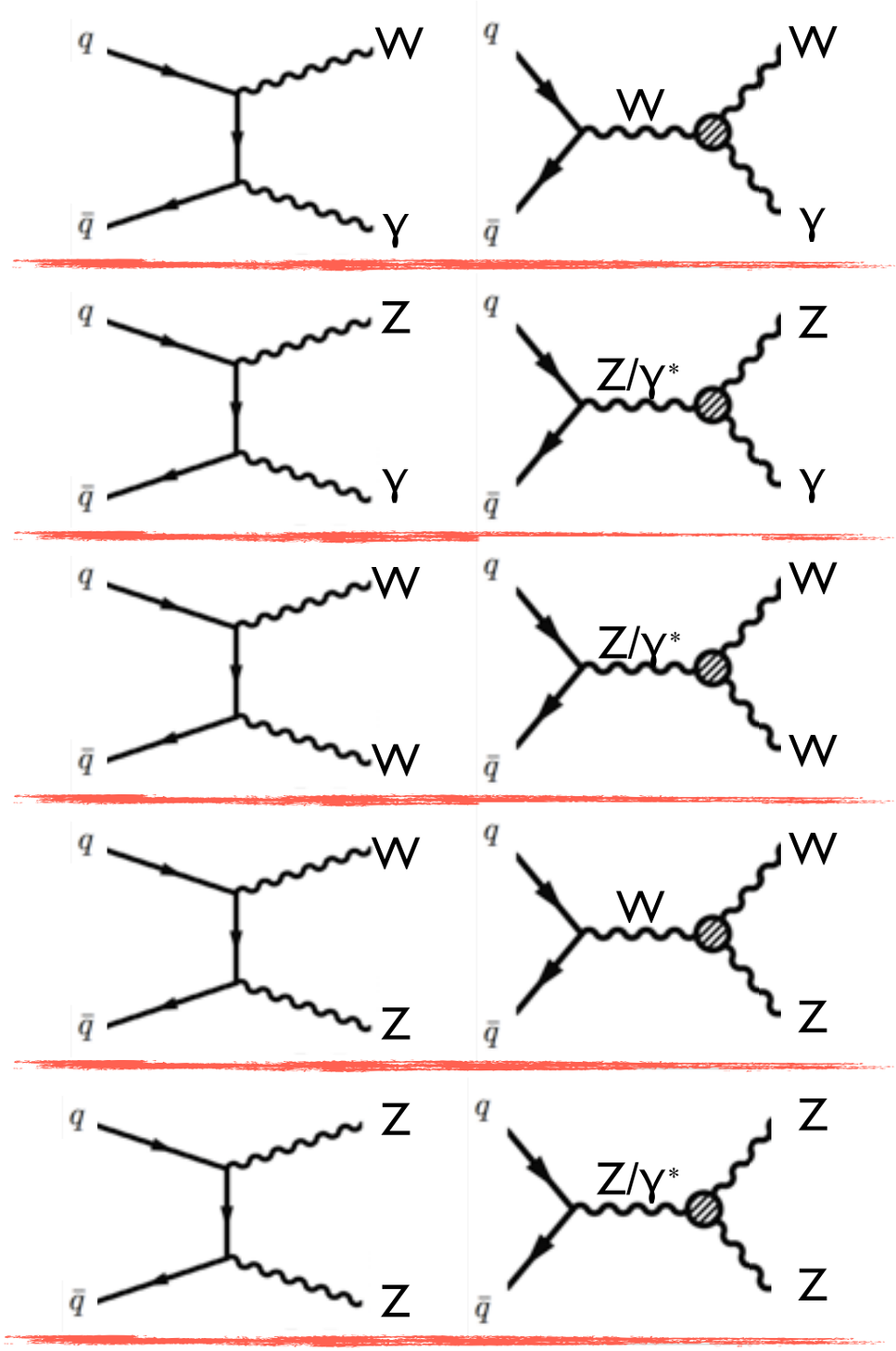
Wγ

Zγ

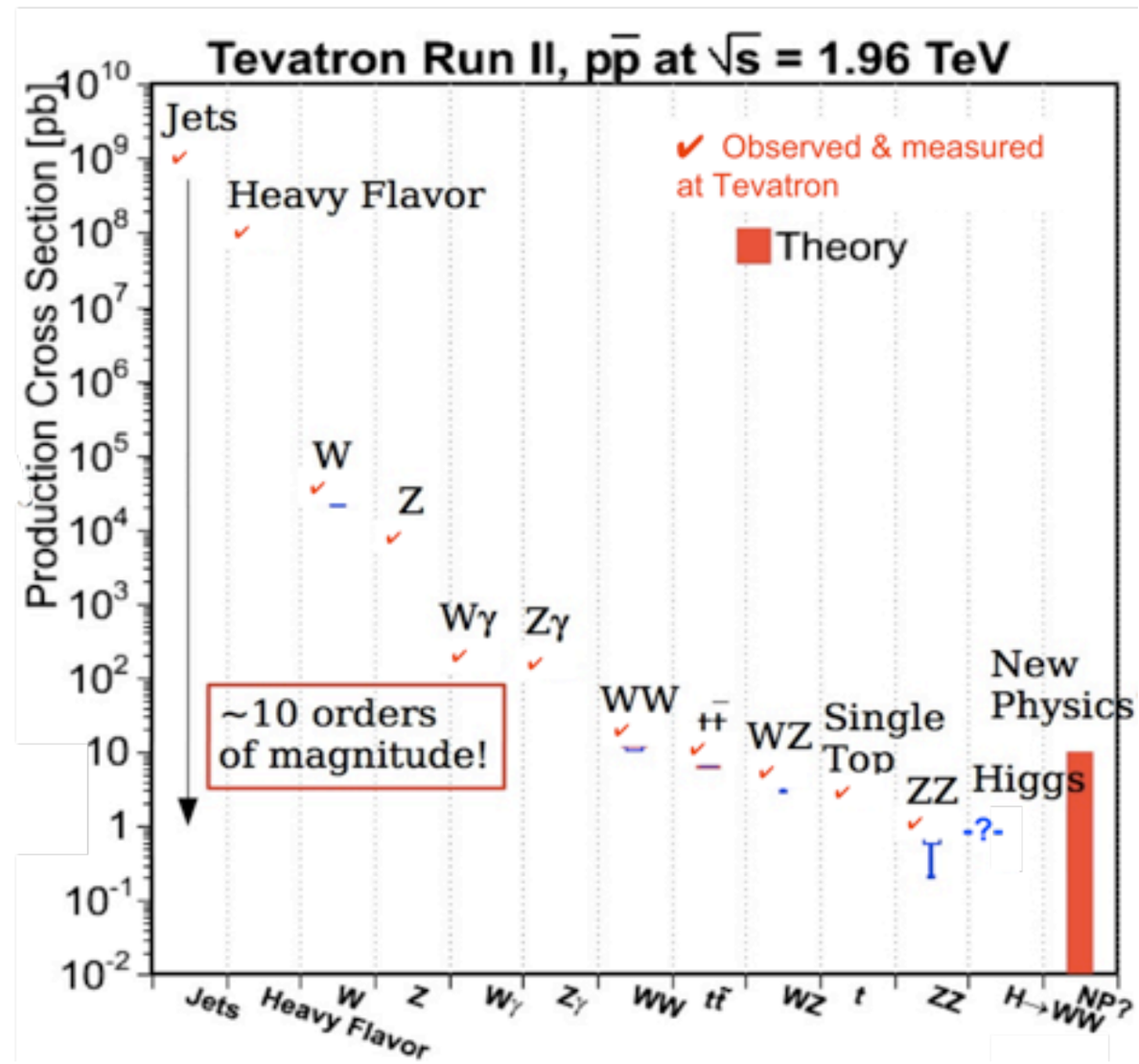
WW

WZ

ZZ




## Standard Model saga




**Higgs = the final chapter**

# Dibosons at Tevatron

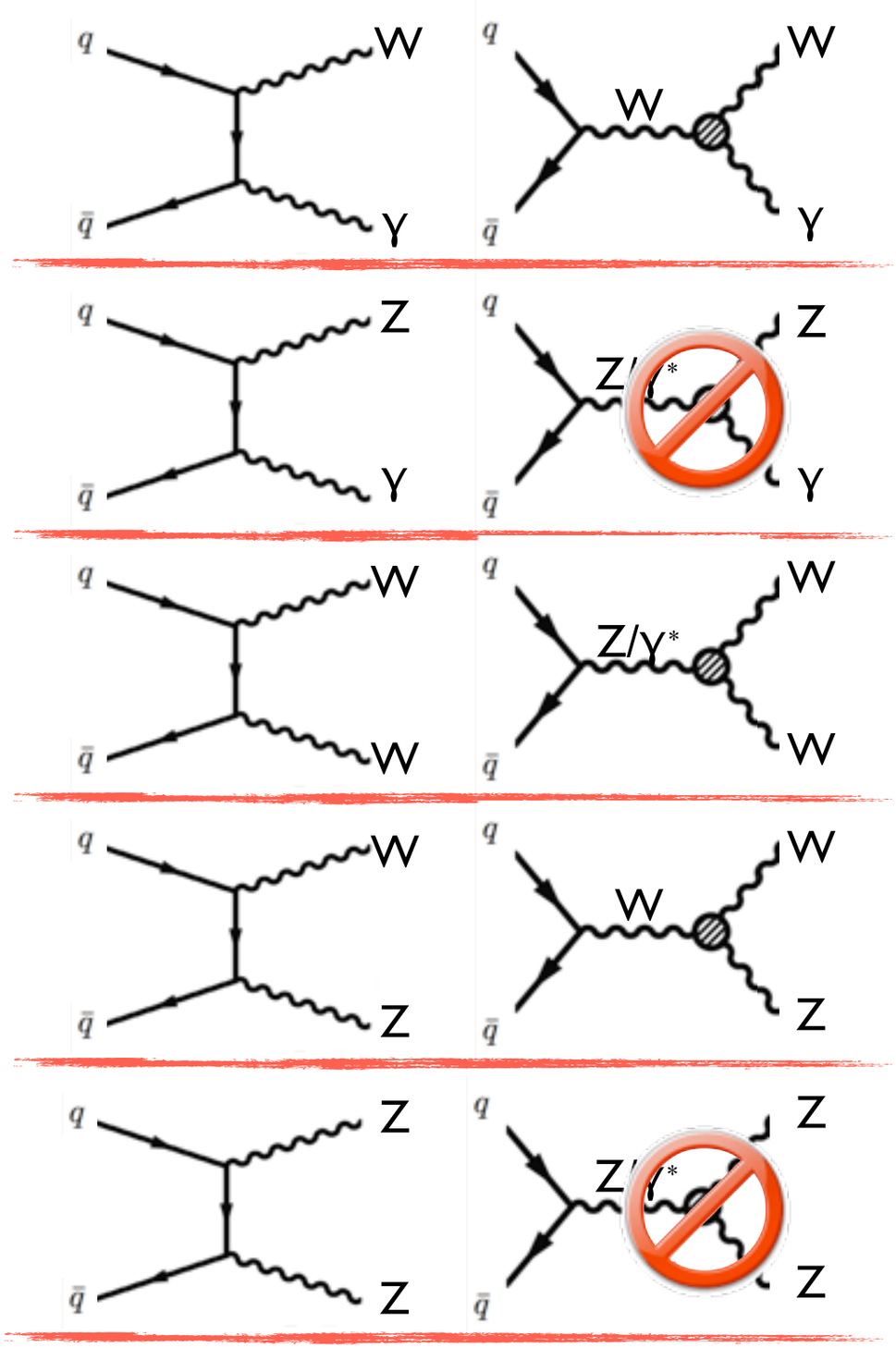
Wγ

Zγ

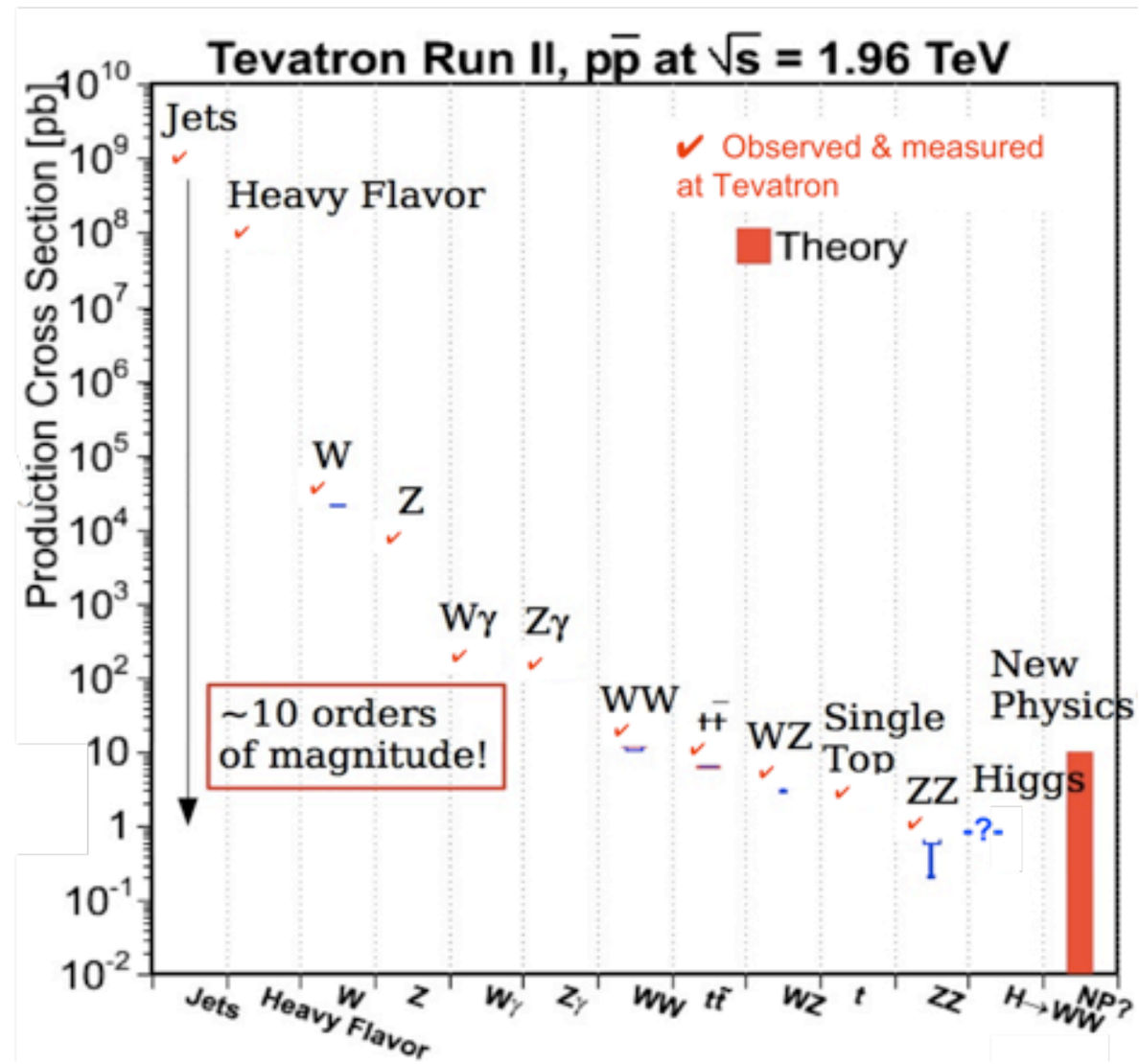
WW

WZ

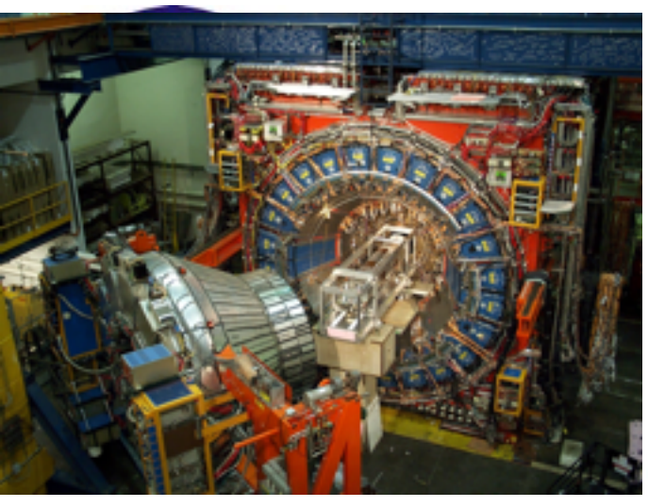
ZZ



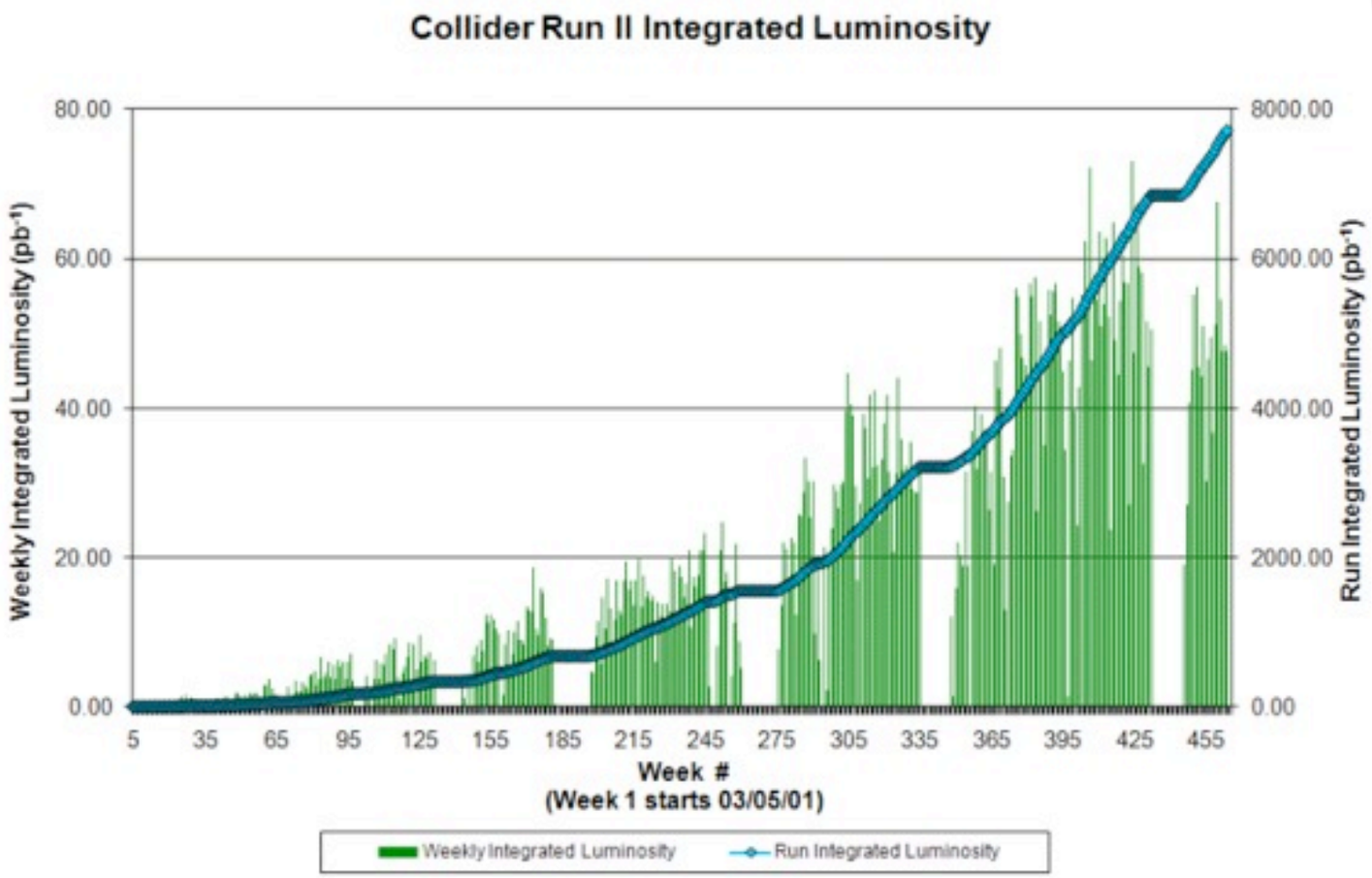

## Standard Model saga




**Higgs = the final chapter**



# Tevatron Experiments




$p\bar{p}$ collider
$\sqrt{s}$=2TeV

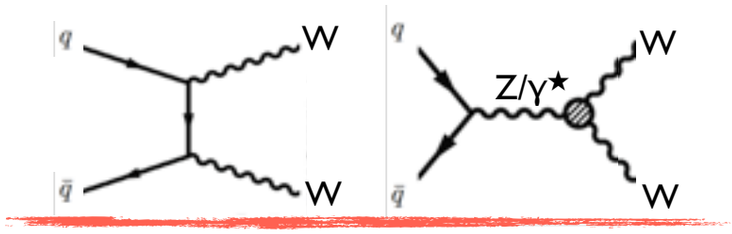
- Multipurpose HEP detectors
  - broad physics
  - 80-90% eff.

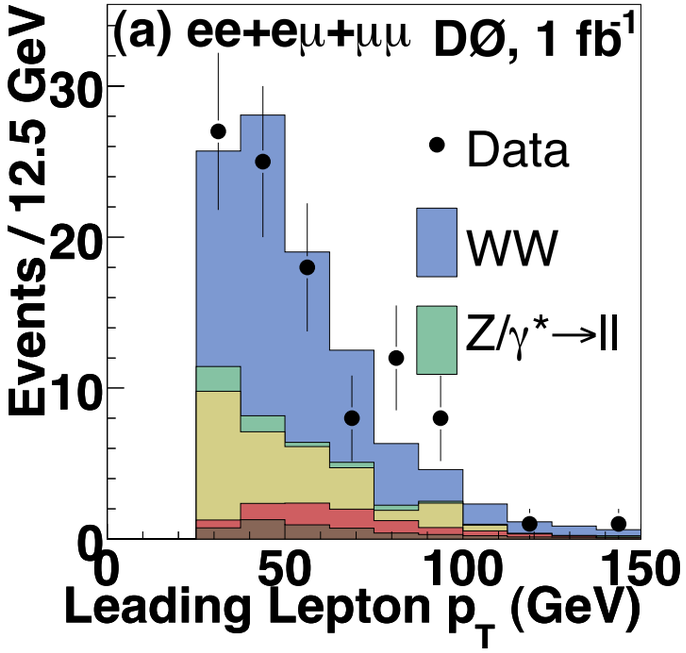
- Available analyzable data: 6fb$^{-1}$/exp
- Showing here 1-5fb$^{-1}$ analyses

| Process | Events in 5fb-1 |
|---|---|
| WW→lνlν | 2720 |
| ZZ->llll | 30 |
| Zγ->llγ | 1485 |
| WZ→lνbb | 599 |
| WH→lνbb | 158 |

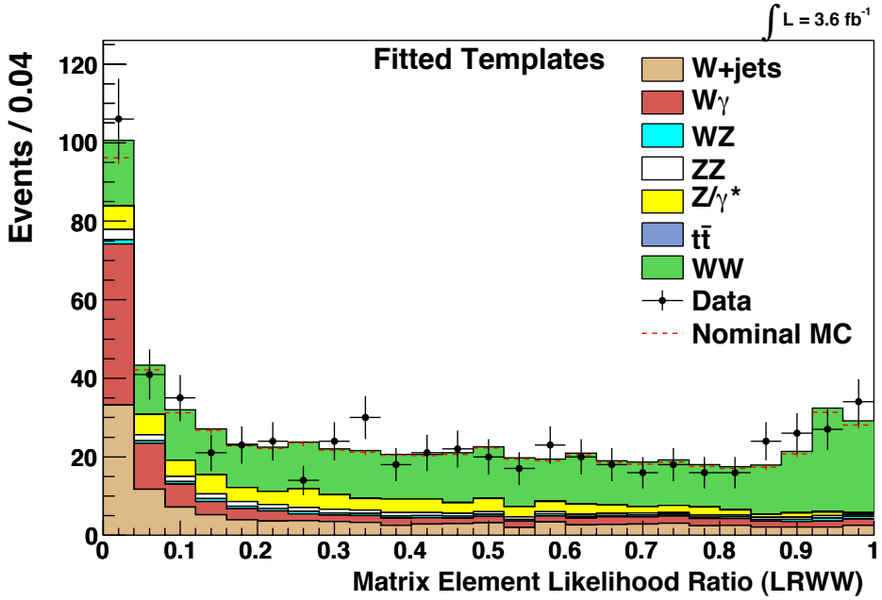
**Running in 2011 10-12fb$^{-1}$/exp.**

# WW

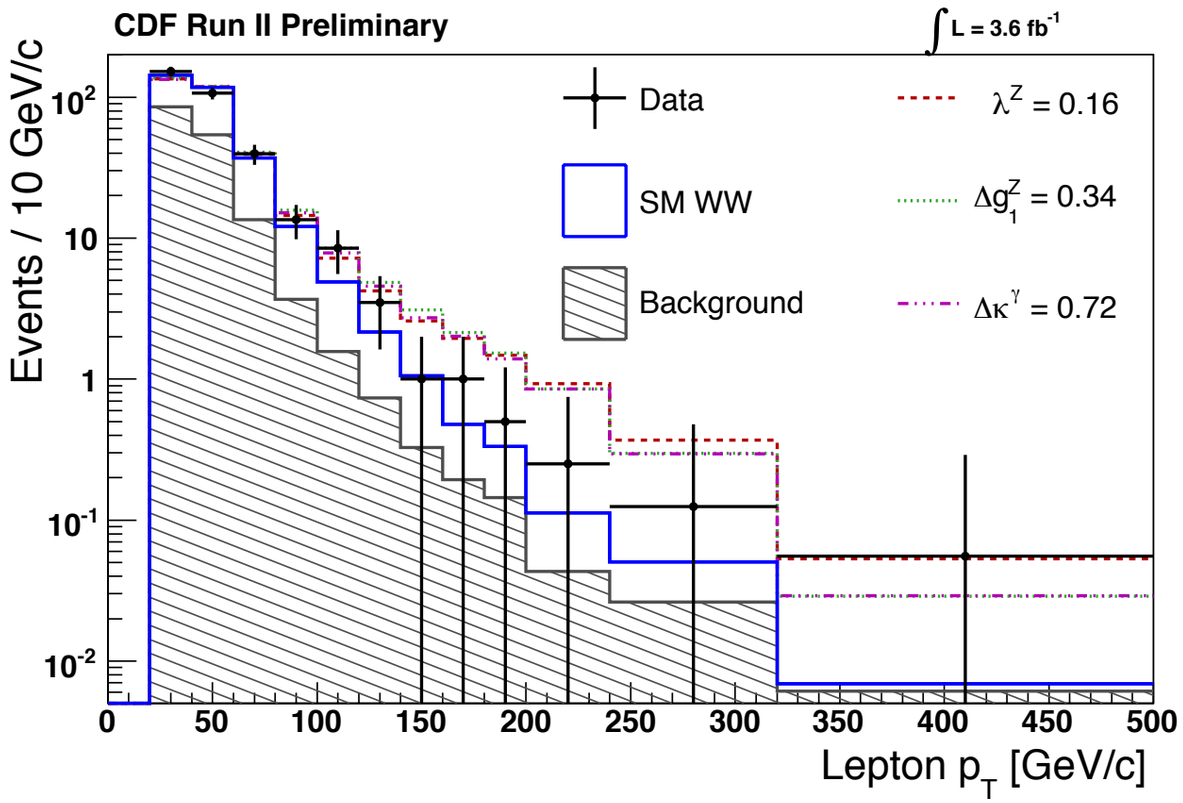


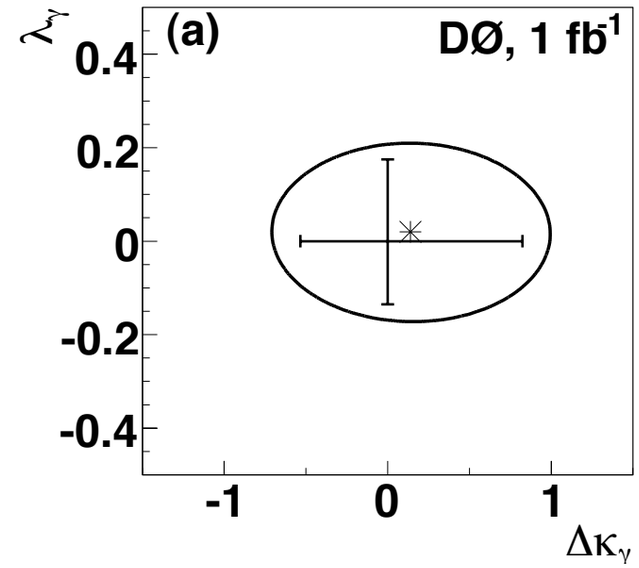




- **Two isolated leptons and large MET**
  - Easiest to observe
  - Important background for the H→WW
- **Results:**
  - CDF: 12.1±0.9(stat)±1.6±1.4(syst) pb
    - arXiv:0912:4500
  - D0: 11.5±2.1(stat+syst)±0.7 (lumi) pb
    - PRL 103, 191801 (2009)
  - NLO theory: 11.66±0.7 pb



# WW and TGC



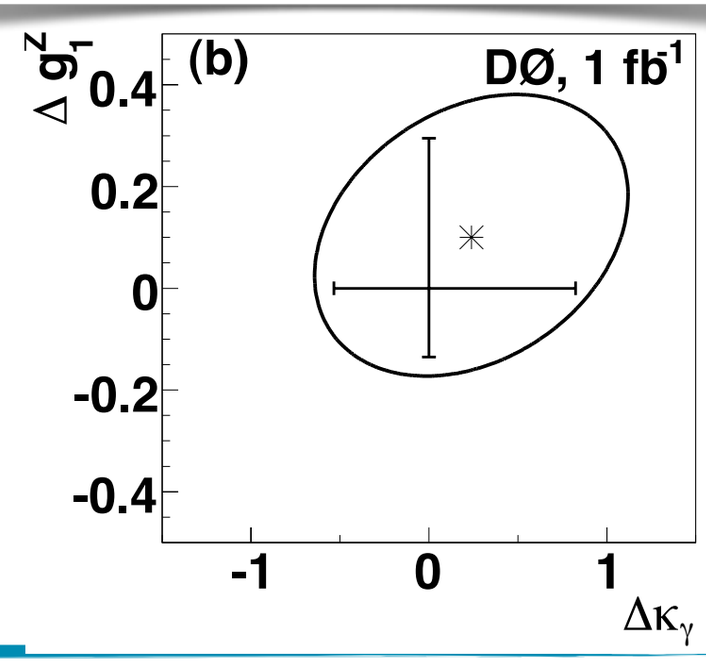

$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = ig_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\lambda_V}{M_W^2}W^\dagger_{\lambda\mu}W^\mu{}_\nu V^{\nu\lambda}$$

CDF Preliminary Results at $3.6\text{fb}^{-1}$

| $\Lambda$ | $\lambda^Z$ | $\Delta g_1^Z$ | $\Delta\kappa^\gamma$ |
|---|---|---|---|
| 2.0TeV | (-0.14,0.15) | (-0.22,0.30) | (-0.57,0.65) |
| 1.5TeV | (-0.16,0.16) | (-0.24,0.34) | (-0.63,0.72) |

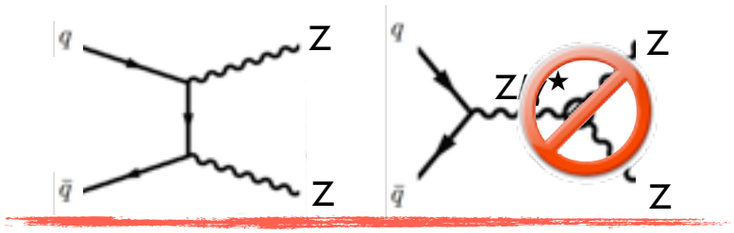
DØ Results at $1.0\text{fb}^{-1}$

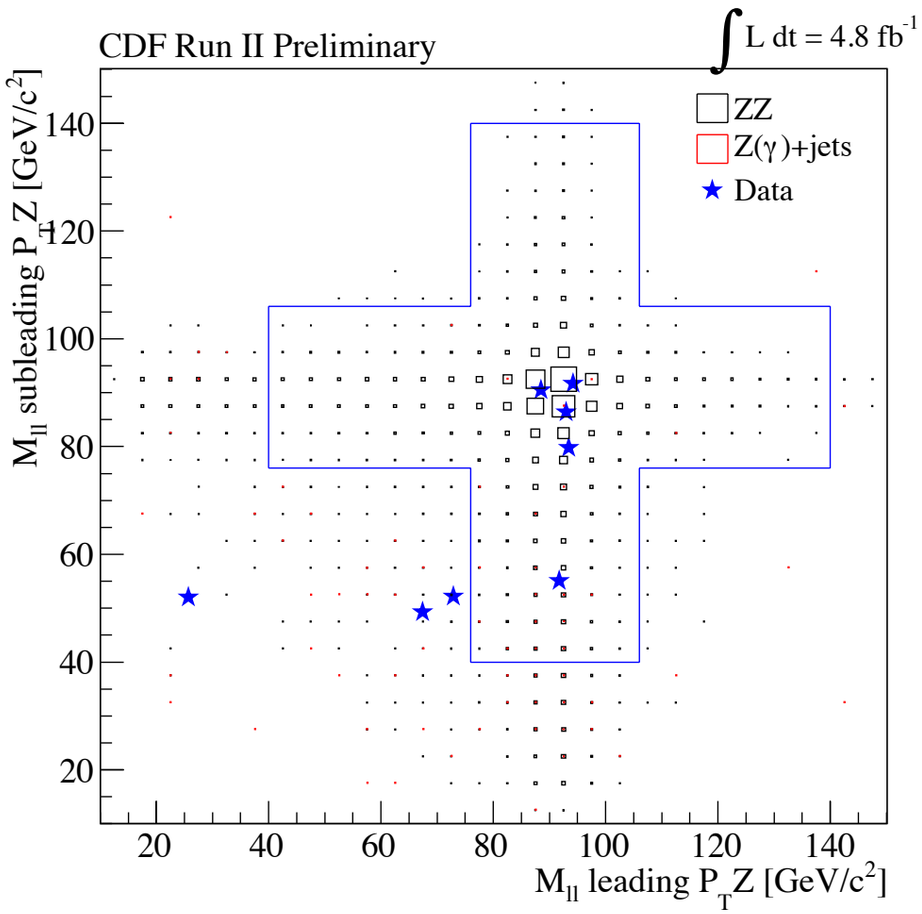
| $\Lambda$ | $\lambda^Z$ | $\Delta g_1^Z$ | $\Delta\kappa^\gamma$ |
|---|---|---|---|
| 2.0TeV | (-0.14 , 0.18) | (-0.14 , 0.30) | (-0.54 , 0.83) |




Parameterization from Hagiwara et al
PRD 48 2182

# ZZ



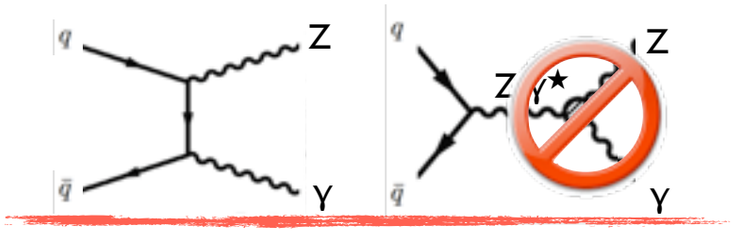

- **Four leptons final state**

| Events in $\mathcal{L} = 4.8$ fb$^{-1}$ | |
|---|---|
| Signal | $4.68 \pm 0.02$(stat.) $\pm 0.76$(syst.) |
| Z($\gamma$)+jets | $0.041 \pm 0.016$(stat.) $\pm 0.029$(syst.) |
| Total expected | $4.72 \pm 0.03$(stat.) $\pm 0.76$(syst.) |
| **Observed** | **5** |

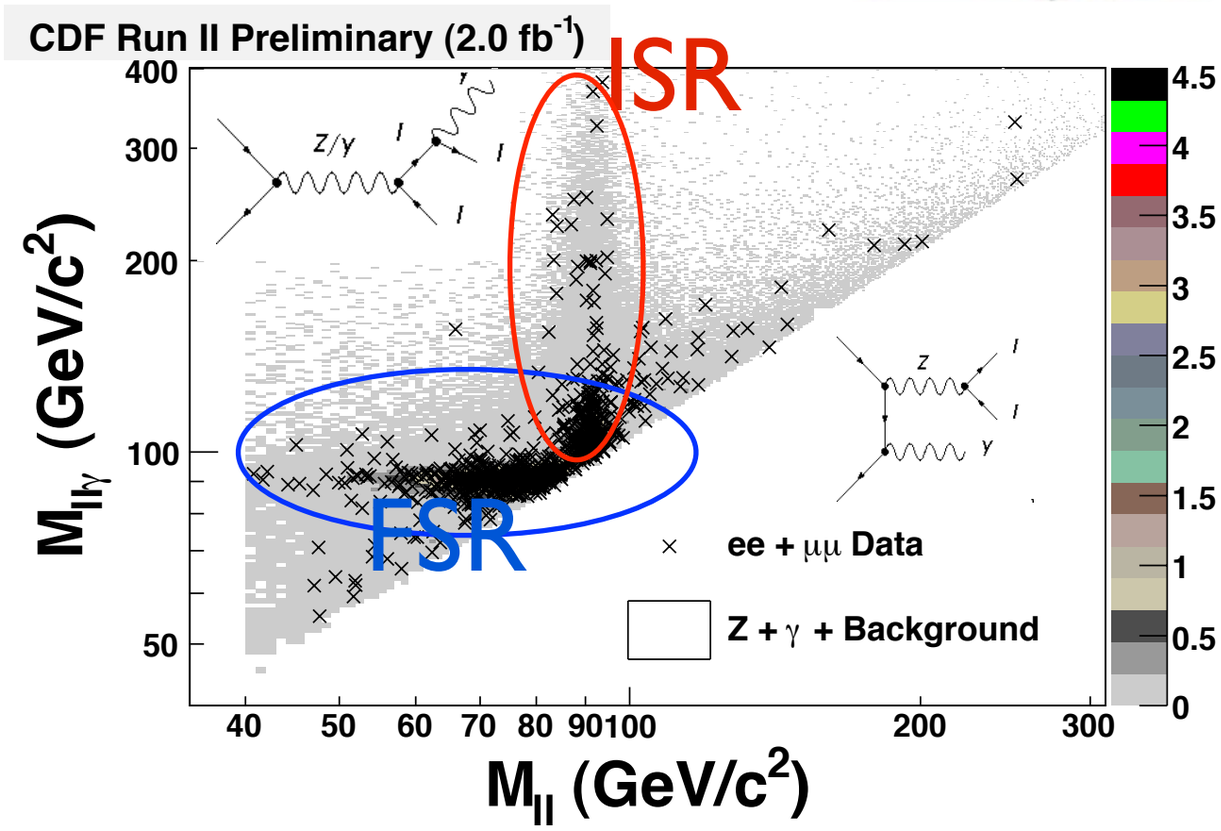
$$\sigma_{ZZ} = 1.56^{+0.80}_{-0.63}(stat.) \pm 0.25(syst.)$$

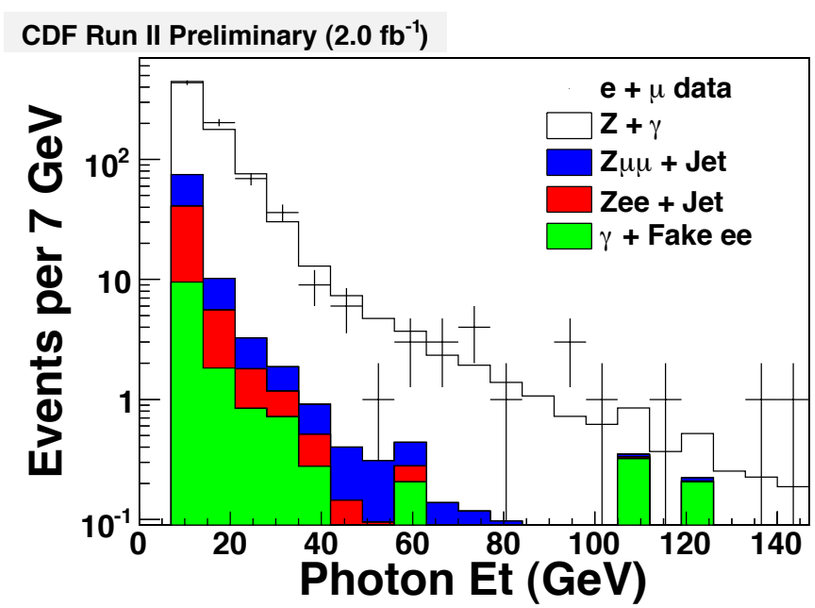
NLO: 1.4±0.1pb

# Z+γ

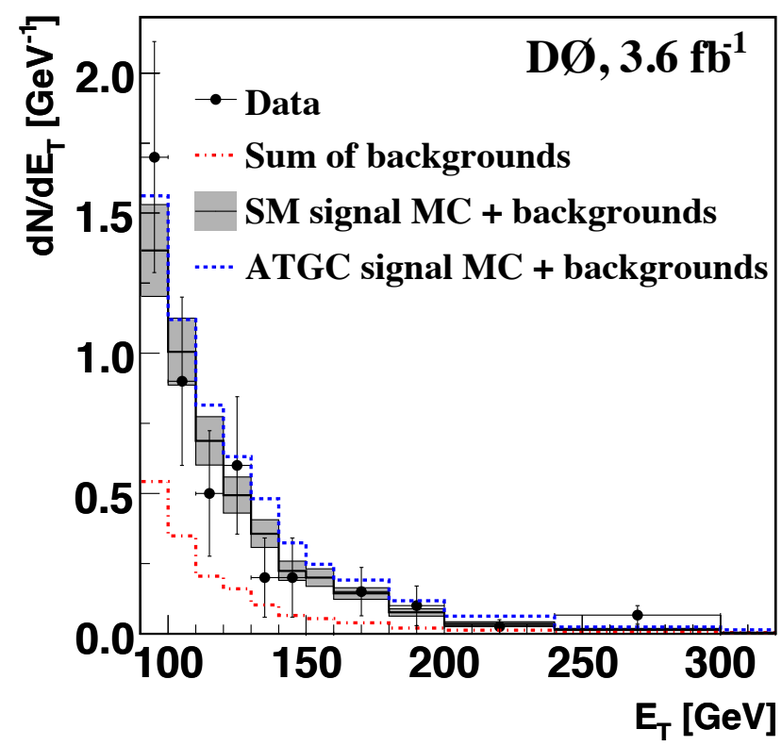



- Two leptons and a high ET photon
- FSR and ISR only
  - New physics can contribute
  - H→Zγ
- σ=4.6±0.2(stat)±0.3(syst)±0.3(lumi)pb
- NLO = 4.5±0.4pb



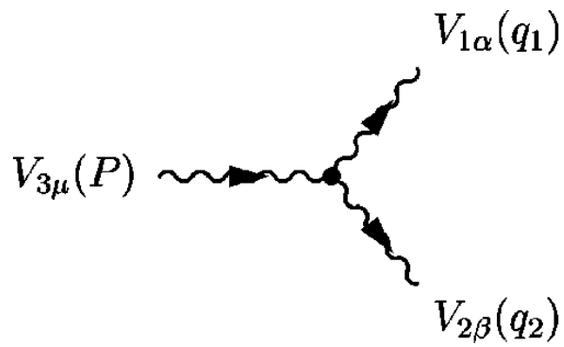




- Add MET channel
  - Z→νν+photon
  - MET+photon final state
- TGC in high Et photons



# TGC with Z+γ

- ~~CP~~: $h_1$, $h_2$
- CP: $h_3$, $h_4$

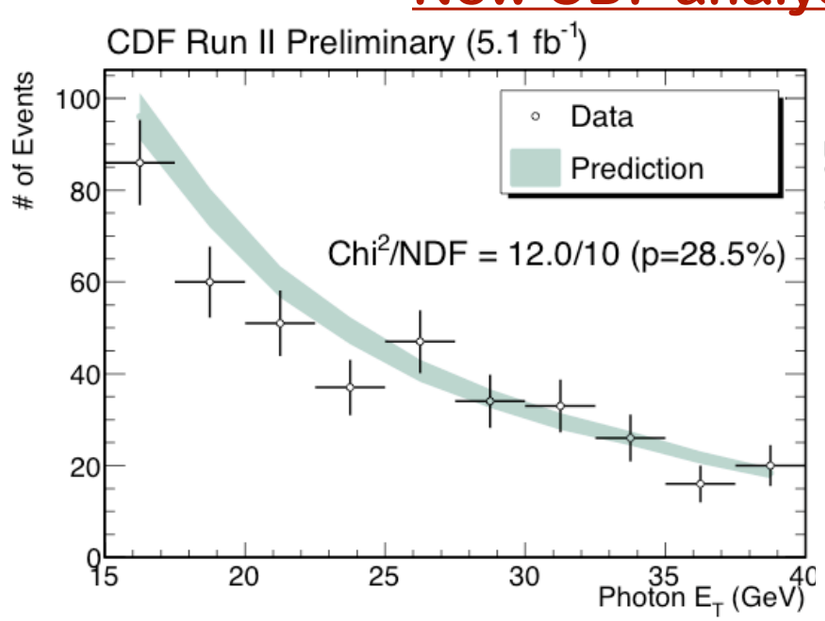


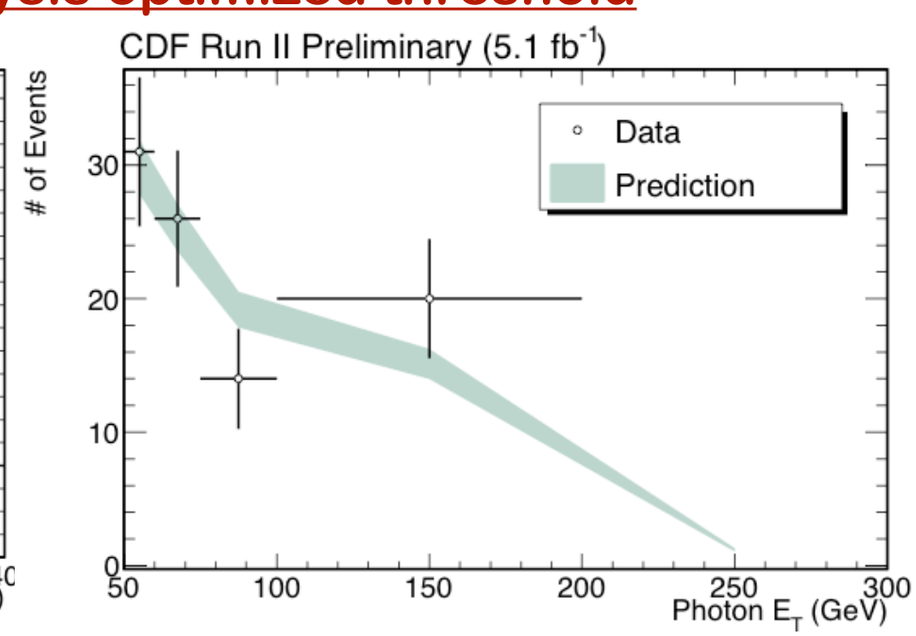

$$= ie\ \Gamma^{\alpha,\beta,\mu}_{V_1V_2V_3}(q_1,q_2,P)$$

Parameterization from Gounaris et al PRD 62 073012

| Experiment<br>Luminosity($fb^{-1}$) | LEP II<br>0.7 | D0<br>1.1 | CDF (+MET)<br>1.5 | D0(+MET)<br>3.6 |
|---|---|---|---|---|
| $h_3^Z$<br>$h_4^Z$ | -0.20, 0.07<br>-0.05, 0.12 | -0.083, 0.082<br>-0.005, 0.005 | -0.05, 0.05<br>-0.0034, 0.0034 | -0.033, 0.033<br>-0.0017, 0.0017 |
| $h_3^\gamma$<br>$h_4^\gamma$ | -0.049, 0.008<br>-0.02, 0.034 | -0.085, 0.084<br>-0.005, 0.005 | -0.051,0.051<br>-0.0034, 0.0034 | -0.033, 0.033<br>-0.0017, 0.0017 |

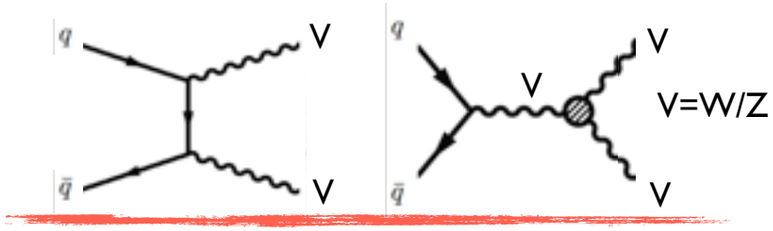
## New CDF analysis optimized threshold



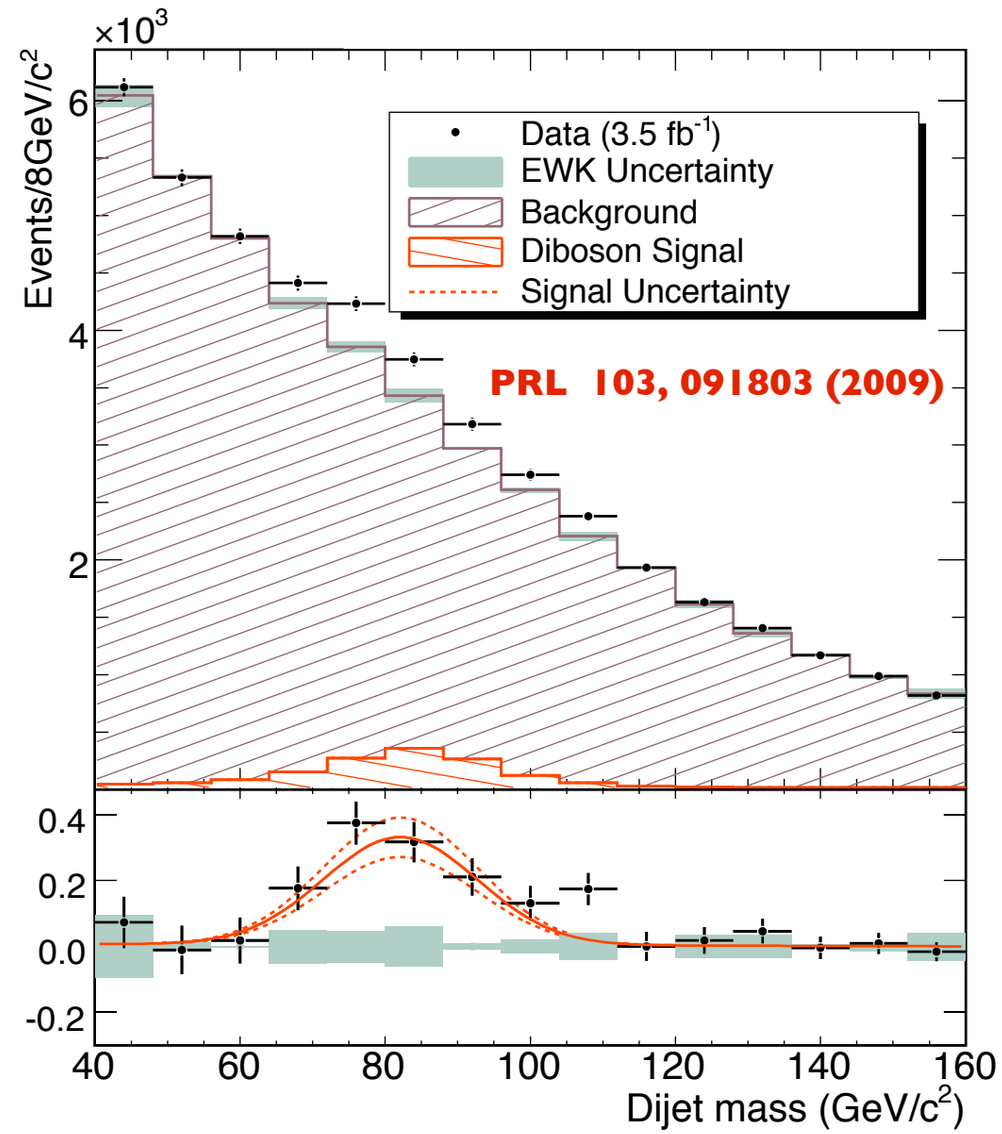




| Variable | Measured Limits |
|---|---|
| $h_3^Z$ | -0.037,0.038 |
| $h_4^Z$ | -0.0017,0.0017 |
| $h_3^\gamma$ | -0.038,0.040 |
| $h_4^\gamma$ | -0.0017,0.0017 |

# WW+WZ+ZZ

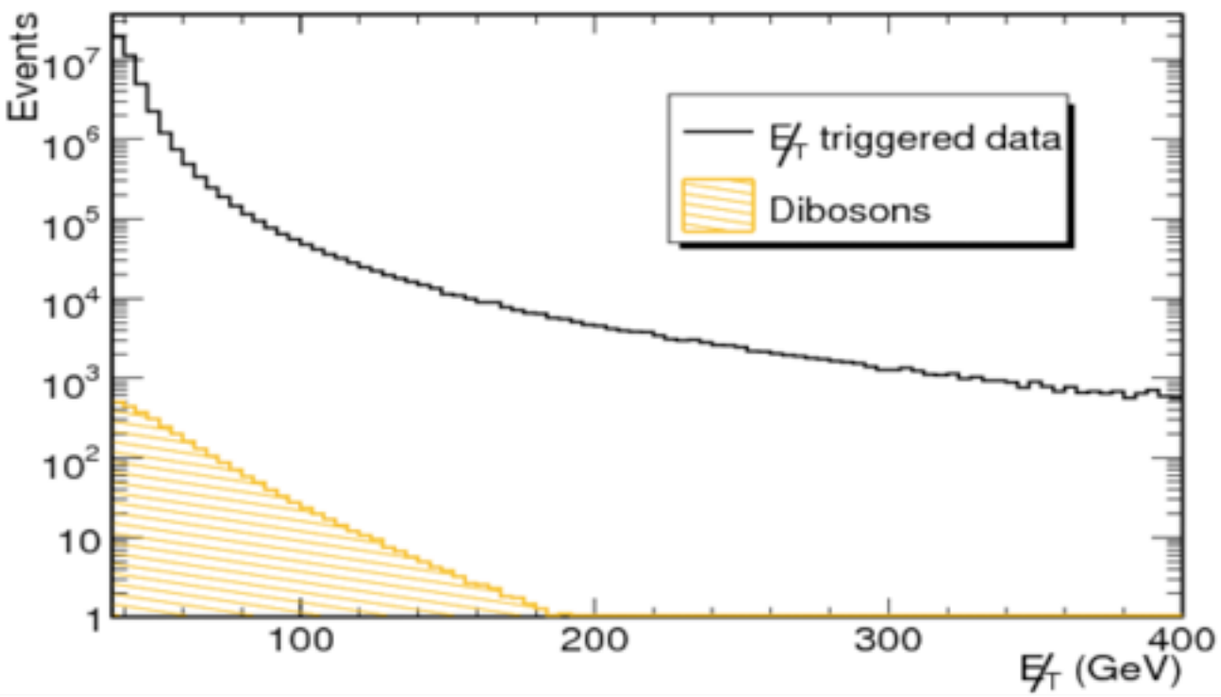


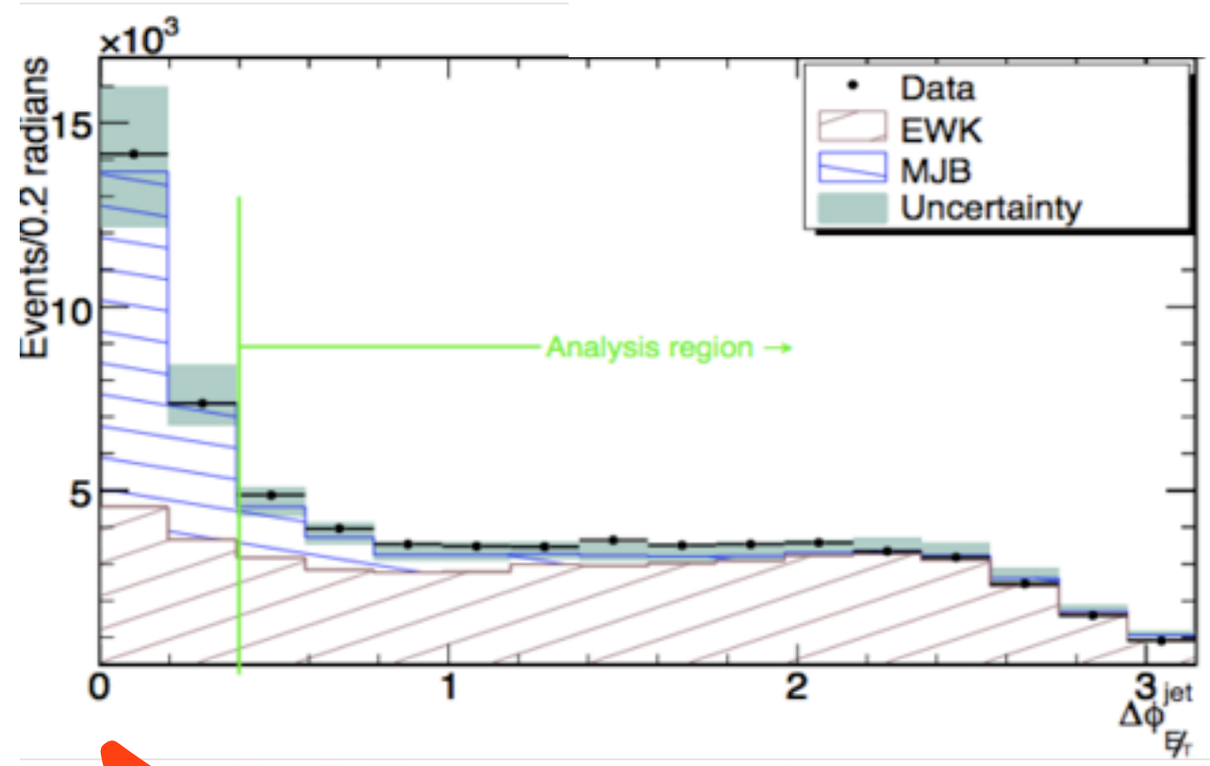

- Jet final states are more difficult
  - Resolution much worse
  - Backgrounds much higher
- More telling for Higgs
  - Similar final states
- Results in 3.5 $fb^{-1}$
  - N=1516±239(stat)±144(syst)
  - 5.3σ significance
- σ = 18.0±2.8(stat)±2.4(syst)±1.1(lumi) pb
  - NLO=16.8±0.5 pb




**Large MET + 2JETS**

# First observation of VV->MET+jj

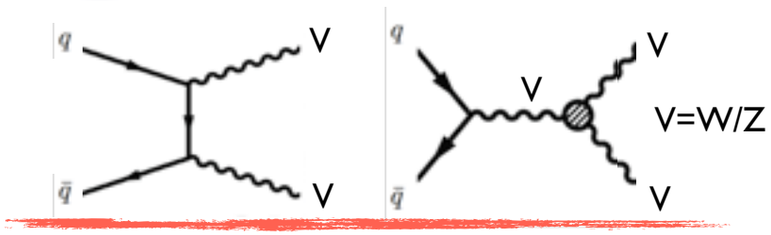



**QCD rejection**

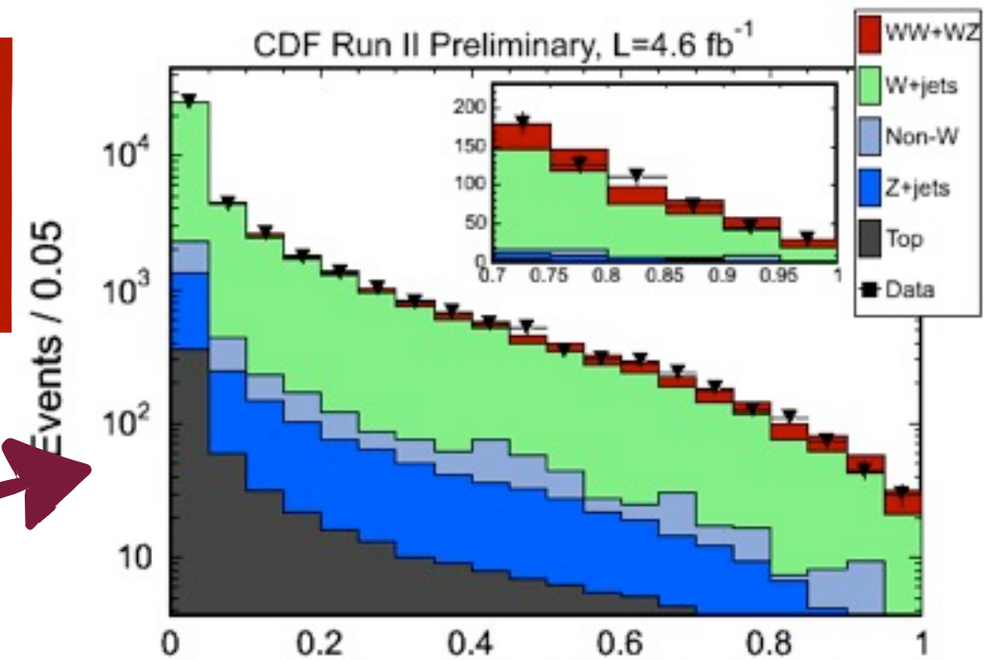
- **Challenging analysis**
  - **After the trigger the S/B=$10^{-4}$**
  - **use sophisticated techniques for QCD rejection**

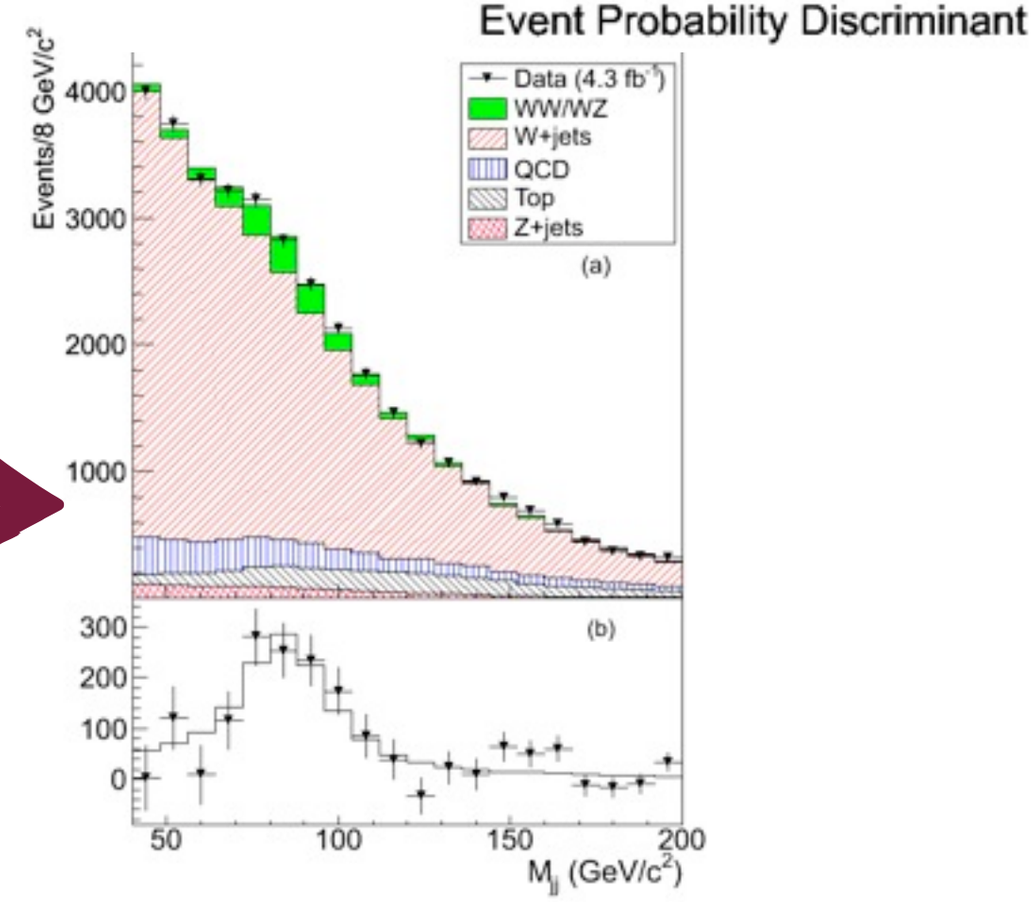
# WW+WZ




**Lepton+MET +2JETS**

- First evidence from D0
  - PRL 102, 161801 (2009)
- Two CDF analyses
  - Matrix Element (ME) method
    - 4.6 $fb^{-1}$ of data
    - Fit event probability discriminant
      - Based on ME calculation
    - $16.5^{+3.3}_{-3.0}$(stat.+syst) pb
      - 5.4σ signal significance
  - $M_{jj}$ fit
    - 4.3 $fb^{-1}$ of data
    - 18.1±3.3(stat)±2.5(syst)pb
  - NLO: 16.1±0.9pb



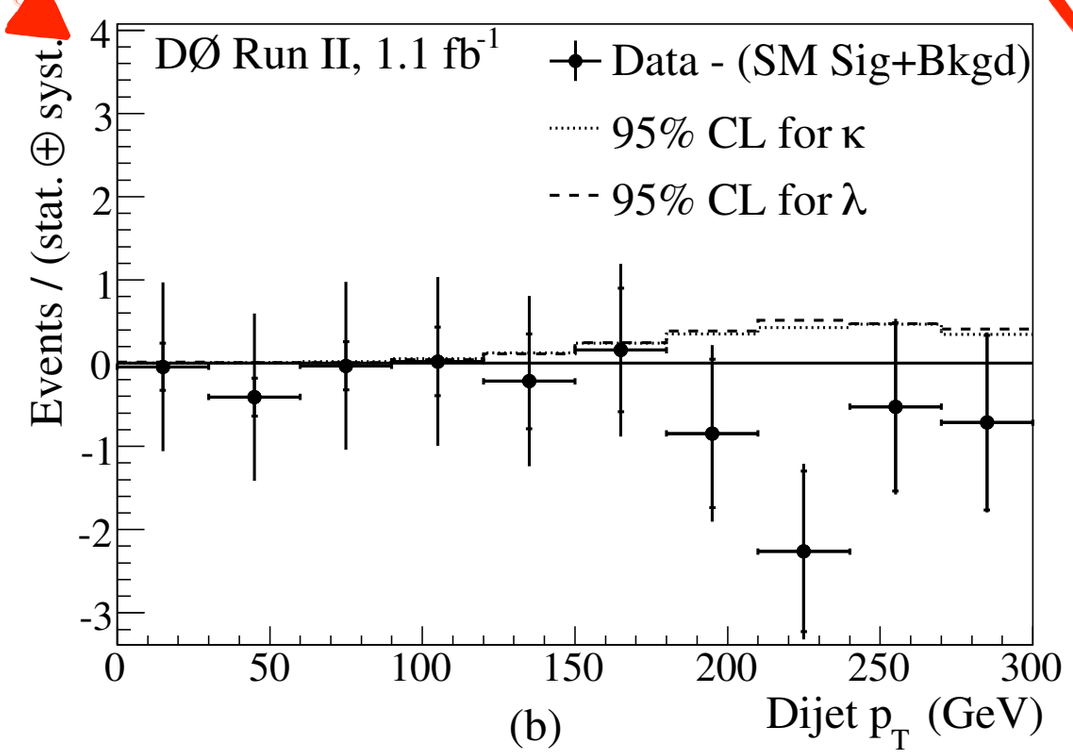



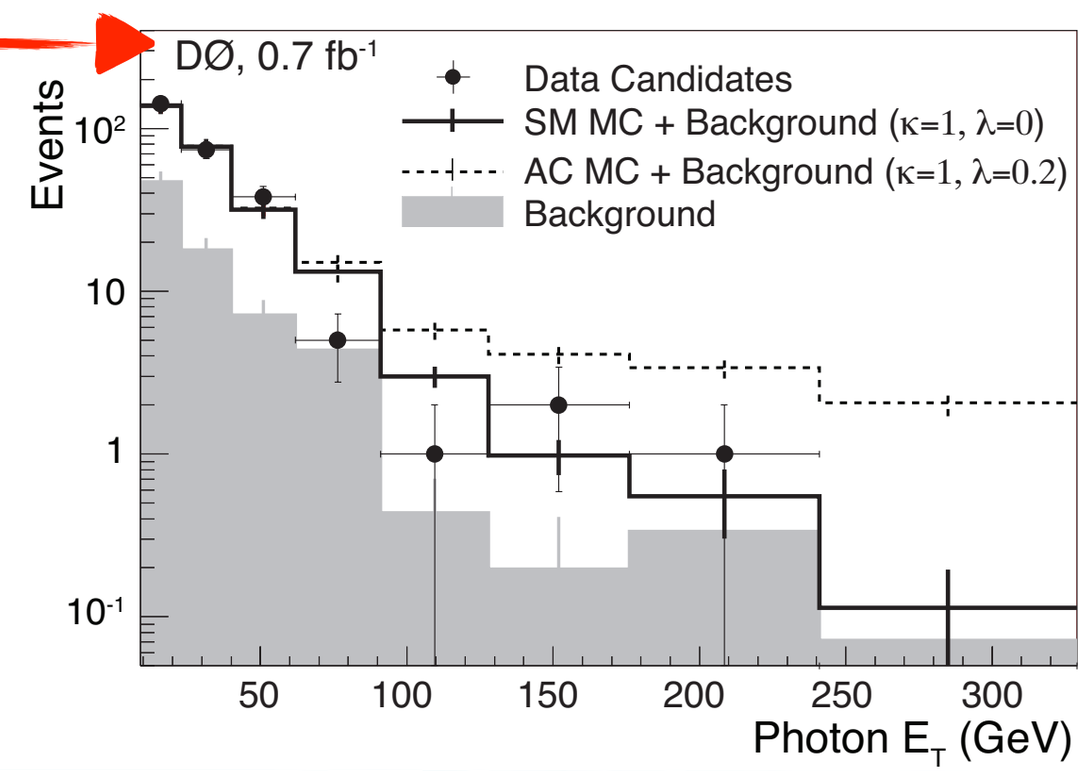
# Combined ZWW and γWW TGC

- Four channel combined:
  - WW+WZ→lν+jj - PRL 102, 161801 (2009)
  - WZ→lνl'l' - PRD 76, 111104 (2007)
  - WW→lνl'ν - arVix:0904.0673[hep-ex]
  - Wγ→lνγ - PRL 100, 241805 (2008)
- 0.7-1.1fb-1 data

arXiv:0907.4952 hep-ex

| | $SU(2)_L \otimes U(1)_Y$ | | ZWW=γWW | |
|---|---|---|---|---|
| | minimum | 95%CL | minimum | 95%CL |
| $\Delta k_\gamma$ | 0.07 | -0.29, 0.38 | 0.03 | -0.11, 0.18 |
| $g1_Z$ | 0.05 | -0.07, 0.16 | N/A | N/A |
| $\lambda$ | 0.0 | -0.08, 0.08 | 0.0 | -0.08,0.08 |
| $\mu_W$ | 2.02 | 1.86, 2.16 | 2.02 | 1.88, 2.15 |
| $q_W$ | -1.02 | -1.09, -0.91 | -1.02 | -1.16, -0.87 |



# Conclusions

- Diboson physics a rich and interesting place
  - SM tests
  - Higgs benchmarks
  - New physics searches
- Larger Tevatron datasets allows for more targeted searches
  - New final states uncovered
- $1fb^{-1}$ at 7TeV ~ $3.5\text{-}5.5fb^{-1}$ at 2TeV
  - Tevatron still the place for SM dibosons in the coming years