Diboson Production at DØ

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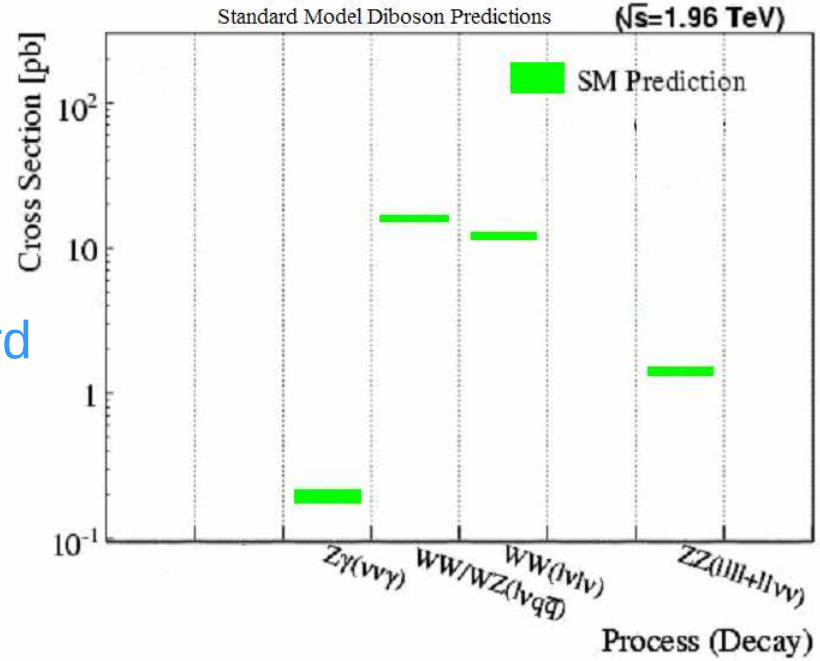
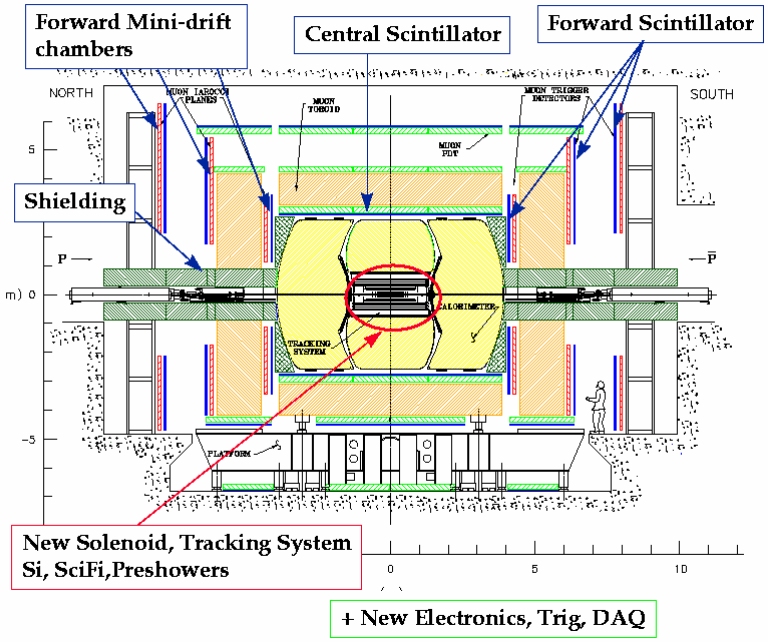
Diboson Physics at DØ

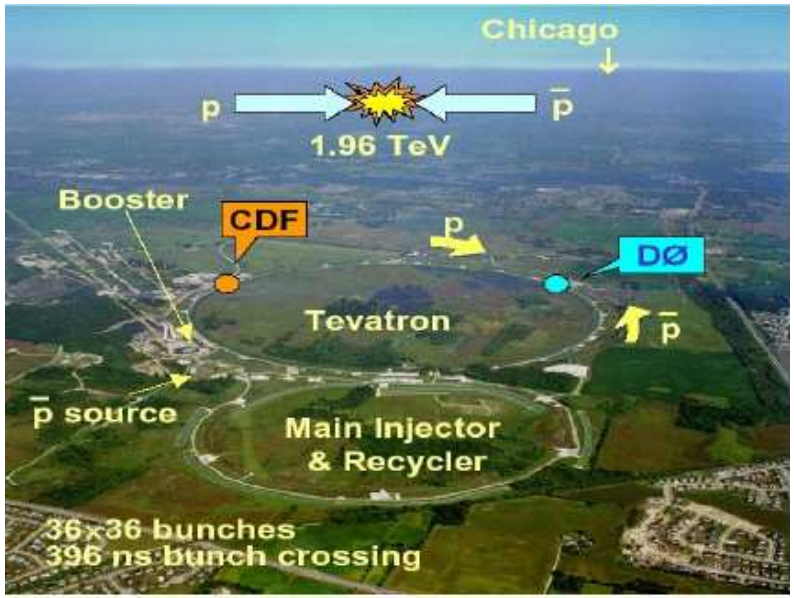
- Diboson processes have low cross sections
  - Provide natural series of goals for detector sensitivity
  - Probe fundamental details of standard model EW sector directly
  - Search at Tevatron explores higher energies than LEP and provides access to some channels (e.g., WZ) not available there
  - New physics would be reflected in increased cross sections

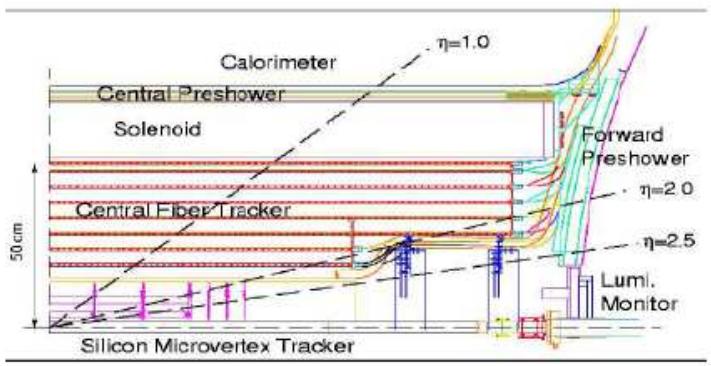


- Motivated by Higgs and SUSY searches
  - Share same or similar final states
    - Vital to understand diboson background
  - Share similar analysis techniques that can be used at the LHC

The DØ Detector







- Silicon micro-strip vertex detector
- Scintillating fiber tracker
- 2 T solenoid magnet
- Uranium Liquid Argon calorimeter
- 1.8 T toroid magnet
- Wire tracking / scintillation counter muon detector
- $|\eta|$ coverage:
  - electrons < 3.2
  - muons < 2.0

$ZZ \rightarrow llll$

- Selected events from 1.7 fb^{-1} of RunIIb data
  - Four isolated leptons

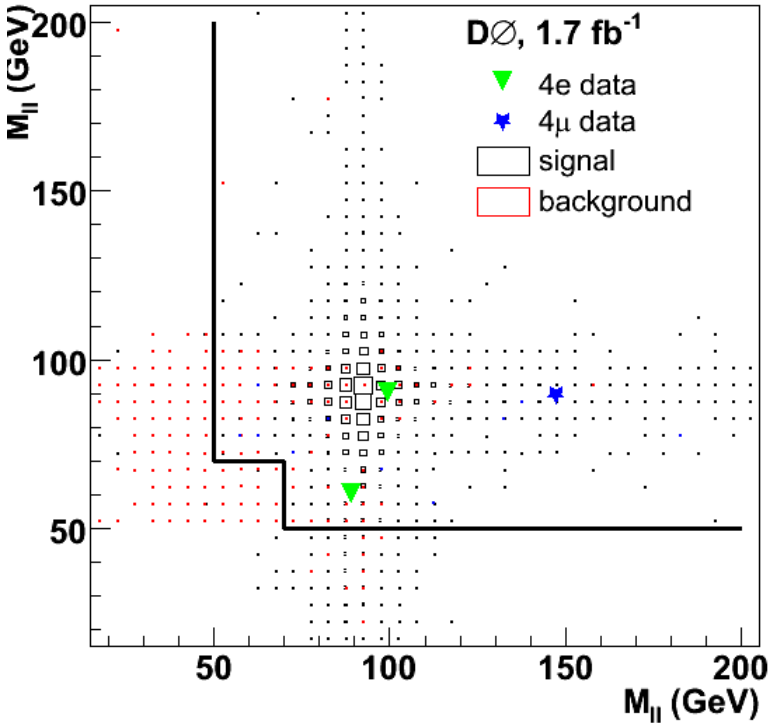
    4*e* channel: Four electrons with p_T > 30, 25, 15, 15 GeV sorted by number of electrons with $|\eta| < 1.1$

    4μ channel: Four muons with p_T > 30, 25, 15, 15 GeV

    2*e*2μ channel: Two electrons and two muons with p_T > 25, 15 GeV sorted by number of electrons with $|\eta| < 1.1$
  - That come from a pair of Z bosons

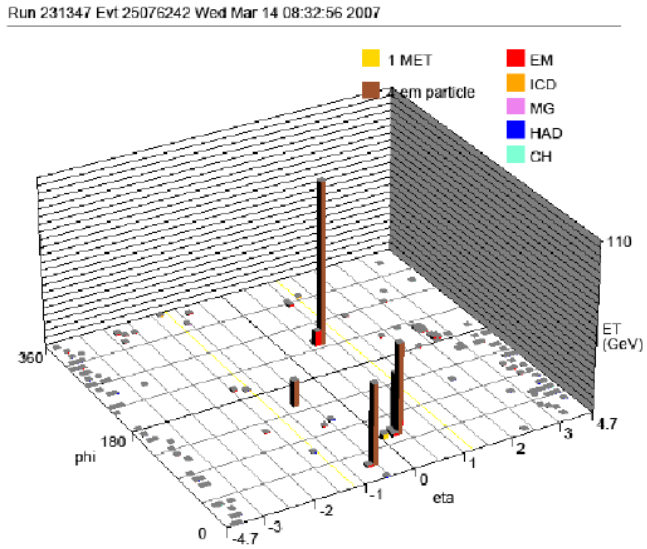
    Dilepton mass M_{ll} > 70, 50 GeV

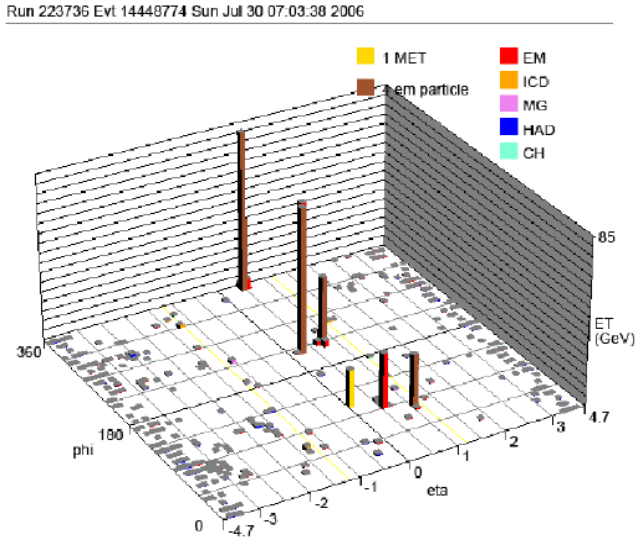
    (one combo of opposite-charge, like flavor lepton pairings)
- Clean Signature
  - No SM background with 4 leptons
  - Small number of expected events means understanding background is important
  - Small Z(γ)+jets background
    - Jets reconstructed as leptons
    - Varies depending upon number of electrons in central calorimeter

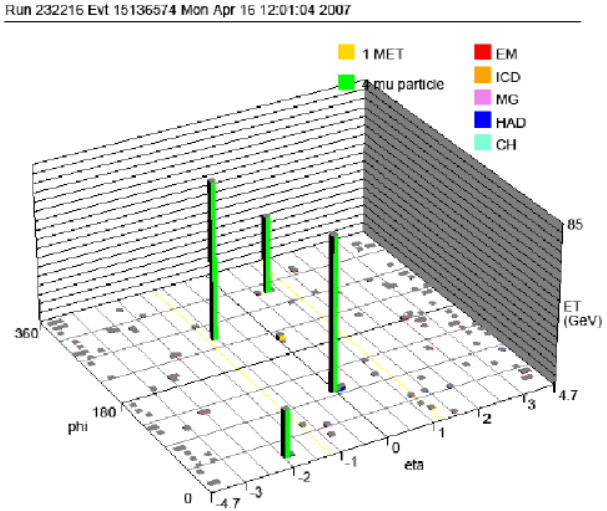


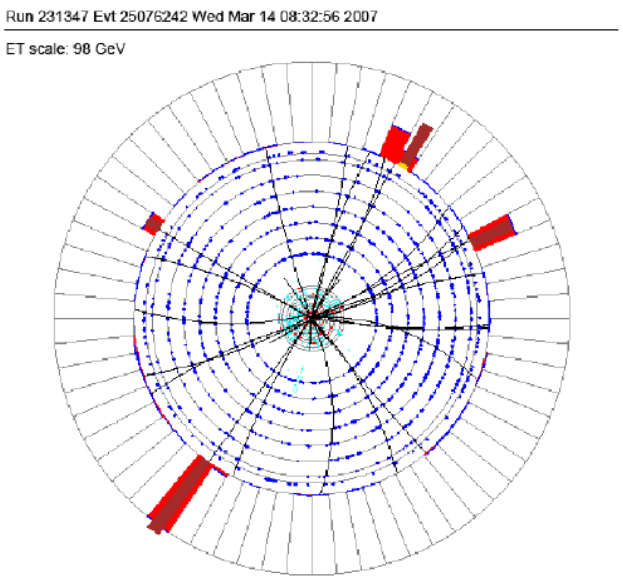
- Predicted background: $0.14^{+0.03}_{-0.02}$
- Predicted signal: 1.89 ± 0.08
- Observe 3 candidate events

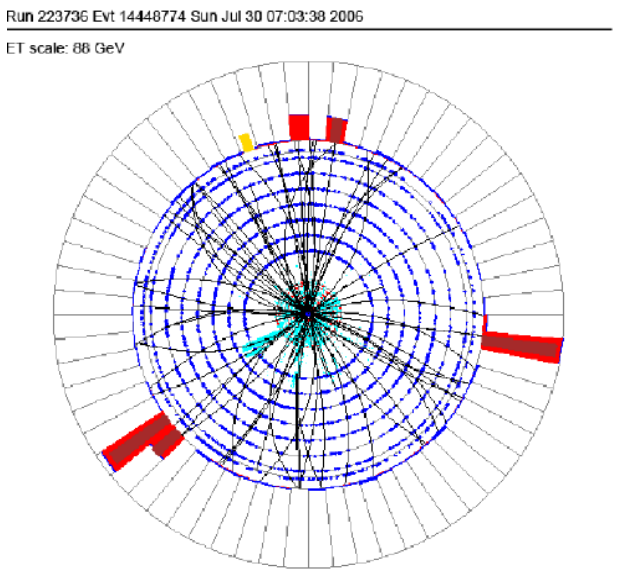
$ZZ \rightarrow llll$

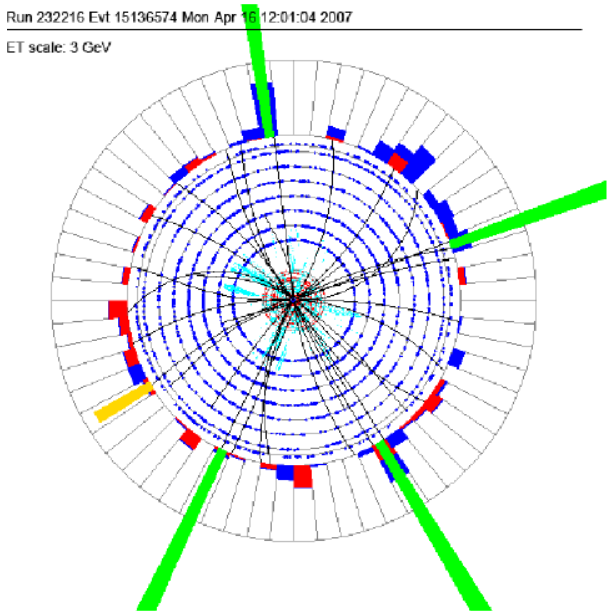








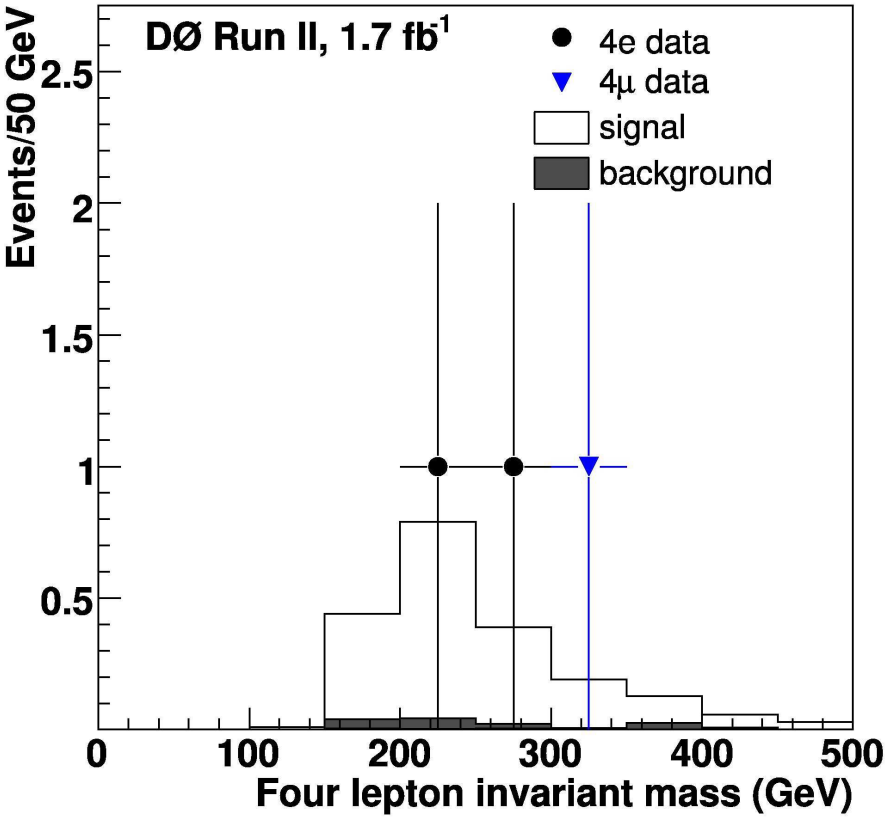




$ZZ \rightarrow llll + ll\nu\nu$

- Production results
  - Measured cross section:
    $1.75^{+1.27}_{-0.86}$ (stat.) $\pm$ 0.13 (syst.) pb
  - Expected significance of 3.7σ
  - Observed significance of 5.3σ

- Combined with previous ZZ $\rightarrow$ *llll* analysis (1 fb^{-1} RunIIa) and ZZ $\rightarrow$ $ll\nu\nu$ (2.7 fb^{-1})
  - Measured cross section:
    1.60 ± 0.63 (stat.)$^{+0.16}_{-0.17}$ (syst.) pb
  - Expected significance of 4.8σ
  - Observed significance of 5.7σ
    - First Tevatron Observation



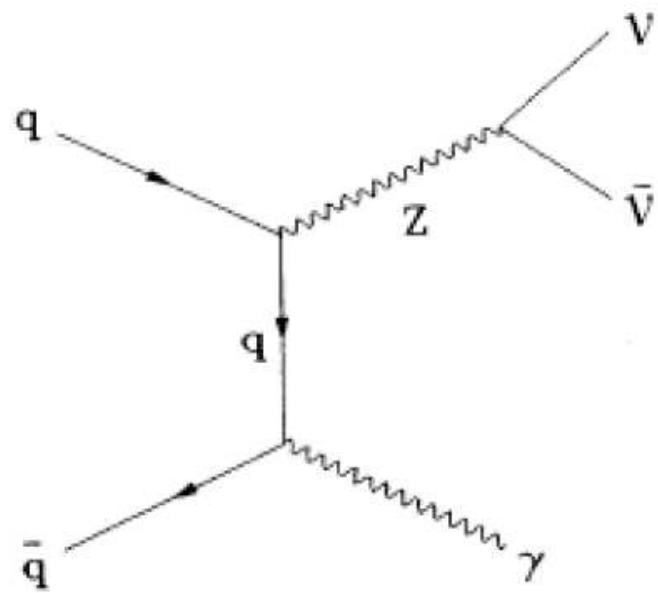
SM NLO: $\sigma(ZZ) = 1.4 \pm 0.1$ pb

PRL 101, 171803 (2008)

$Z\gamma \rightarrow \nu\nu\gamma$

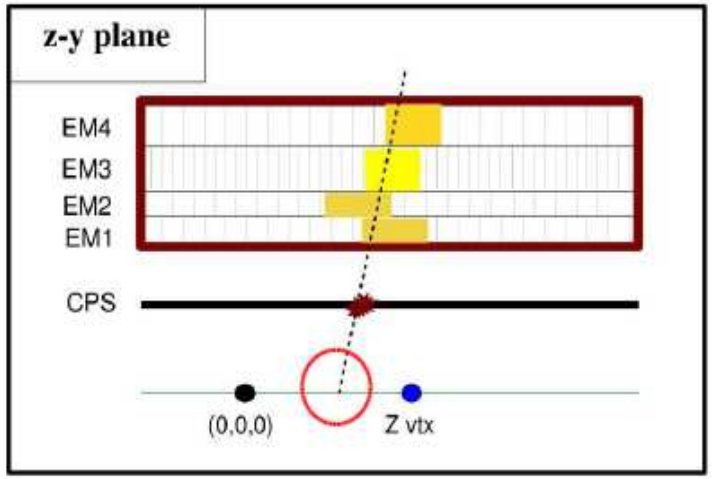
- Selected events from 3.6 fb^{-1} of RunII data
  - Single high E_T photon with p_T > 90 GeV and $|\eta|$ < 1.1
  - Large missing transverse energy mE_T > 70 GeV
    - Suppresses multijet background

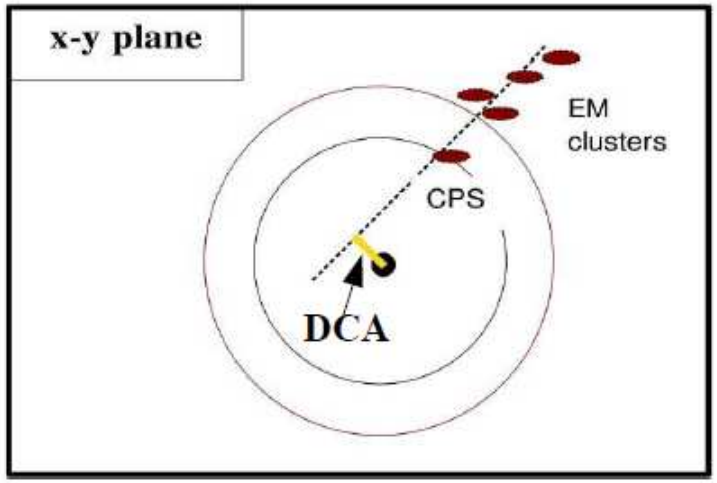
- Reduce backgrounds
  - Mis-measured mE_T
    - Reject events with jets with p_T > 15 GeV
  - $W \rightarrow l\nu$ and $Z \rightarrow ll$
    - Veto muons
    - Isolated tracks
    - Additional EM objects with p_T > 15 GeV

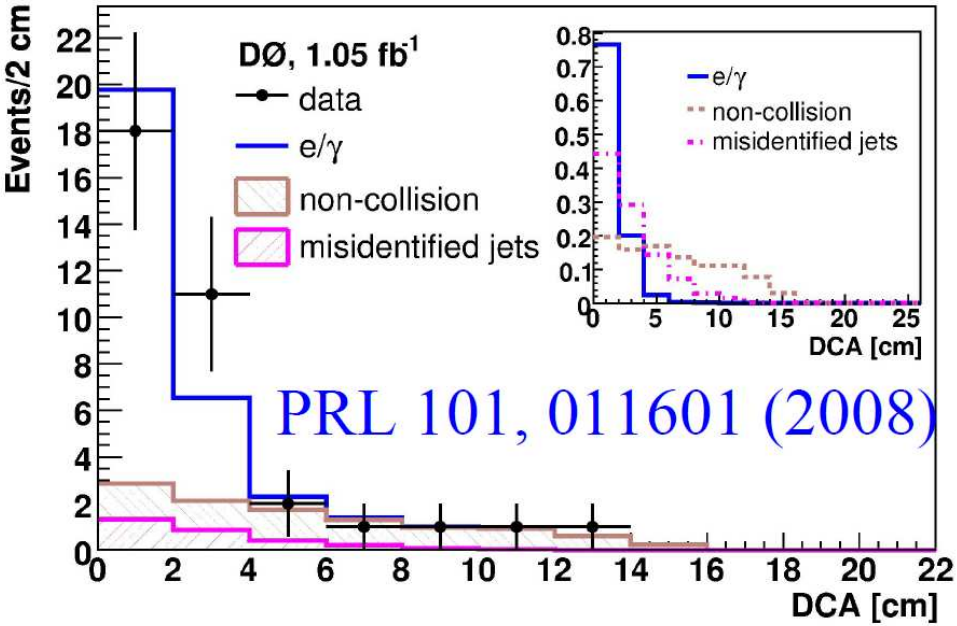


$Z\gamma \rightarrow \nu\nu\gamma$

- Reduce backgrounds
  - Non-collision background (*e.g.*, muon from halo or cosmics undergoing bremsstrahlung)
    - Pointing algorithm (assume EM shower initiated by photons)
      - → require $|z_{em} - z_{vtx}| < 10$ cm
      - → require DCA < 4 cm





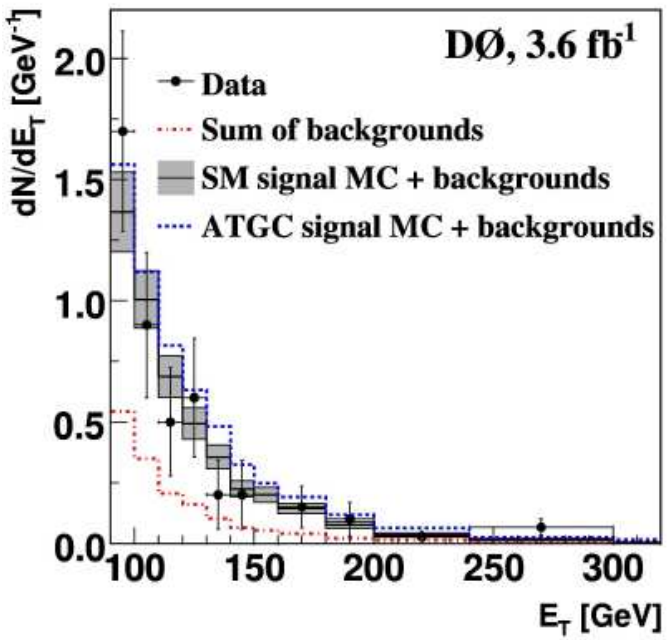


$Z\gamma \rightarrow \nu\nu\gamma$

- Predicted background: 17.3 ± 2.4
- Predicted Signal: 33.7 ± 3.4
- Observe 51 candidate events

- Production results
  - Measured cross section

    $\sigma(Z\gamma)\cdot BR(Z\rightarrow\nu\nu) = 32.9 \pm 9(\text{stat+syst}) \pm 2(\text{lumi})$ fb
  - Observed significance of 5.1σ
    - First Tevatron observation in this channel

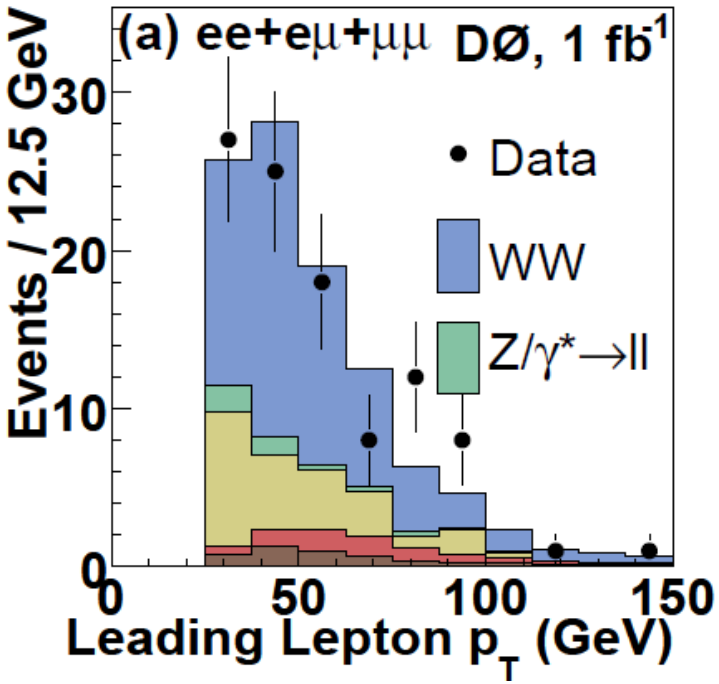


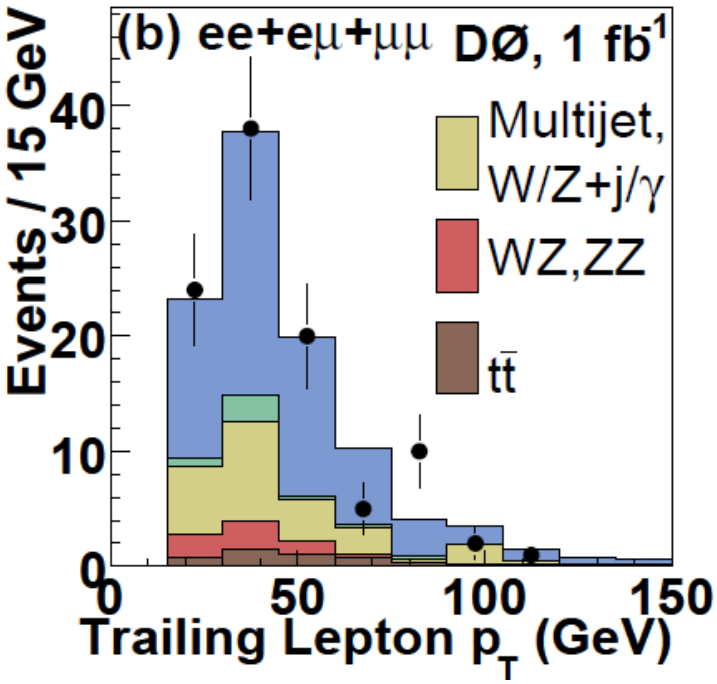
SM NLO: $\sigma(Z\gamma)\cdot BR(Z\rightarrow\nu\nu) = 39 \pm 4$ fb

PRL 102, 201802 (2009)

$WW \rightarrow l\nu l\nu$

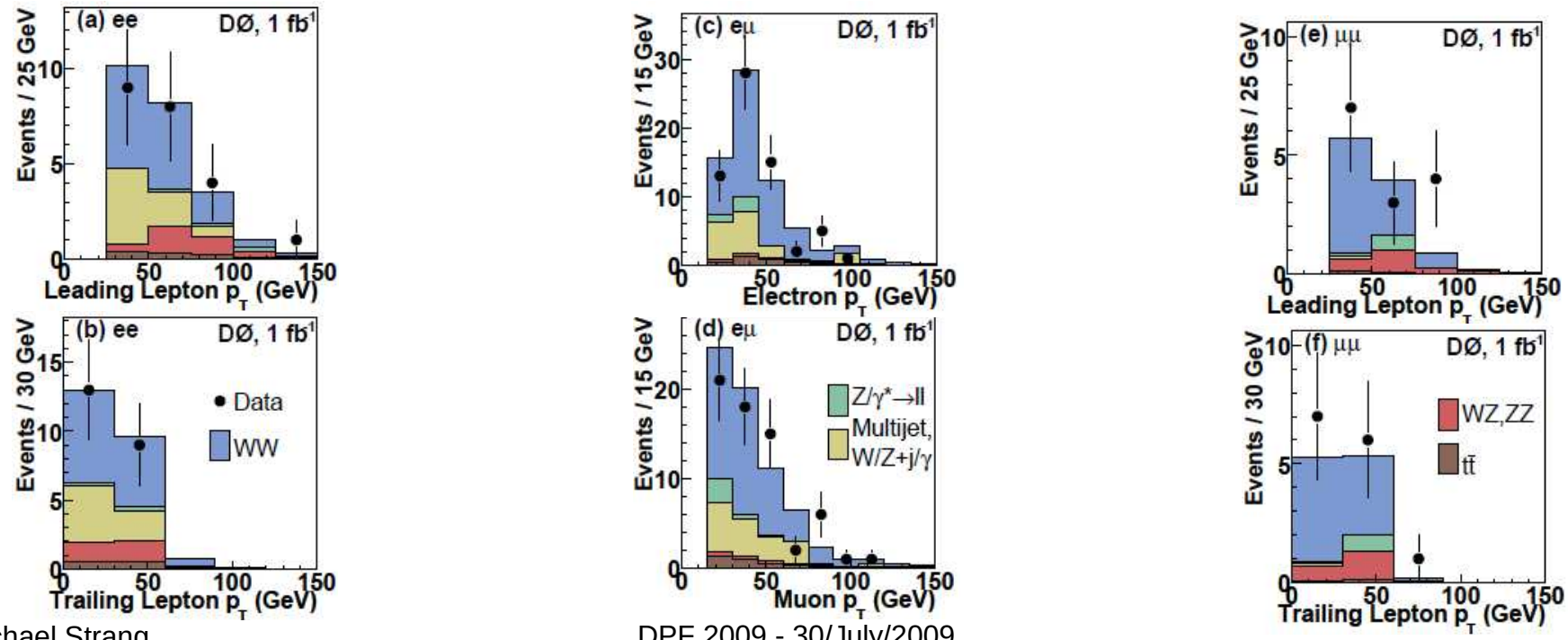
- Selected events from 1 fb^{-1} of RunII data
  - Two isolated leptons from same vertex
    - ee, eμ or μμ of opposite charge
      - → At least one electron in central calorimeter
    - Leading lepton pT > 25 GeV
    - Trailing lepton pT > 15 GeV





$WW \rightarrow l\nu l\nu$

- Reduce backgrounds
  - $Z \rightarrow ll$
    - Optimized mE_T cuts for each channel
      $\rightarrow$ mET > 45 (ee), 20 (eμ), 35 (μμ) GeV
  - *tt* and *W*+jets
    - Require balanced event:
      $|p_T l1 + p_T l2 + mE_T| < 20$ (ee), 25 (eμ), 16 ($\mu\mu$) GeV



$WW \rightarrow l\nu l\nu$

Process	ee	$e\mu$	$\mu\mu$
Signal	12.38 ± 0.62	44.43 ± 0.86	7.89 ± 0.35
Background	11.08 ± 1.80	24.21 ± 3.78	2.91 ± 0.46
Total expected	23.46 ± 1.90	68.64 ± 3.88	10.79 ± 0.58
Data	22	64	14

- Production results
  - Measured cross section

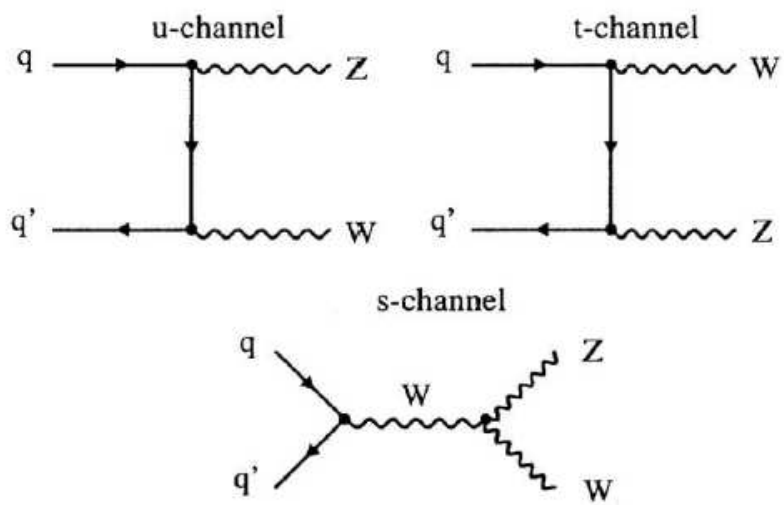
$$\sigma(WW) = 11.5 \pm 2.1(\text{stat+syst}) \pm 0.7(\text{lumi})\ \text{pb}$$

SM NLO: $\sigma(WW) = 12.0 \pm 0.7$ pb

arXiv: 0904.0673

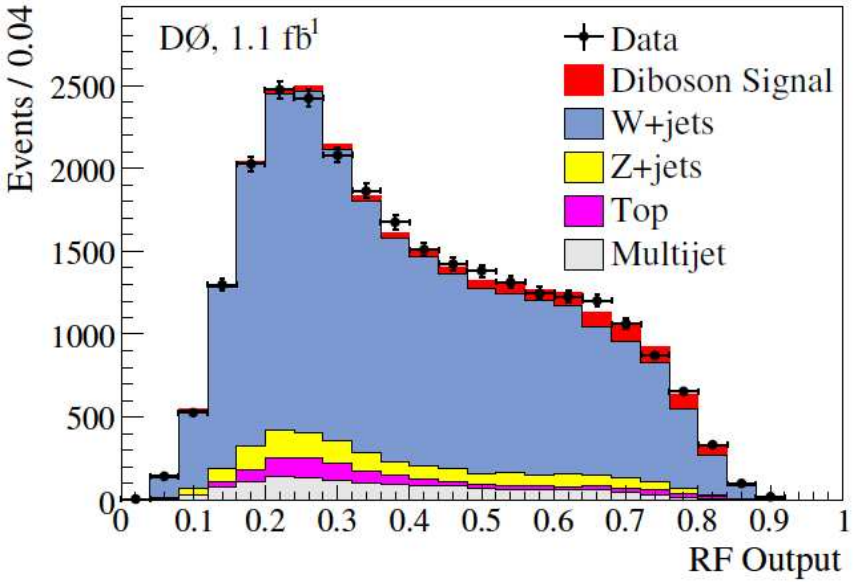
$WW/WZ \rightarrow l\nu jj$

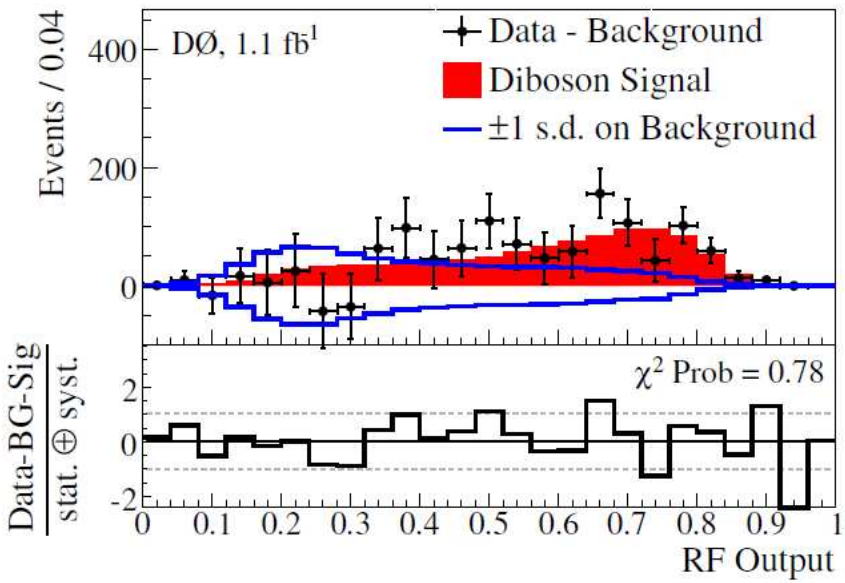
- Selected events from 1.1 fb^{-1} of RunII data
  - One isolated lepton with $p_T > 20$ GeV and $|\eta| < 1.1$ (2.0) for electrons (muons)
  - $mE_T > 20$ GeV
  - Two jets with $p_T > 30$, 20 GeV and $|\eta| < 2.5$



$WW/WZ \rightarrow l\nu jj$

- Reduce backgrounds
  - Multijet backgrounds
    - "Transverse" *W* mass > 35 GeV
  - *W*+jets (*Z*+jets, top)
    - "Random Forest" multivariate discriminant

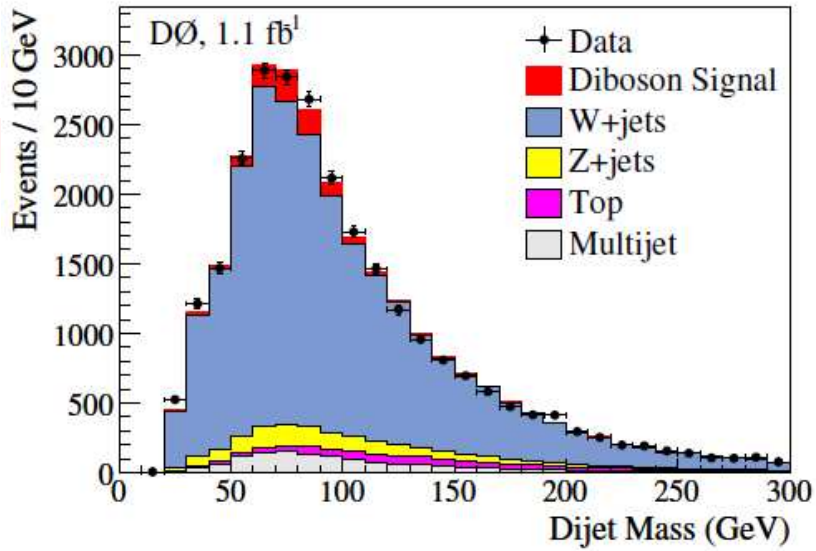




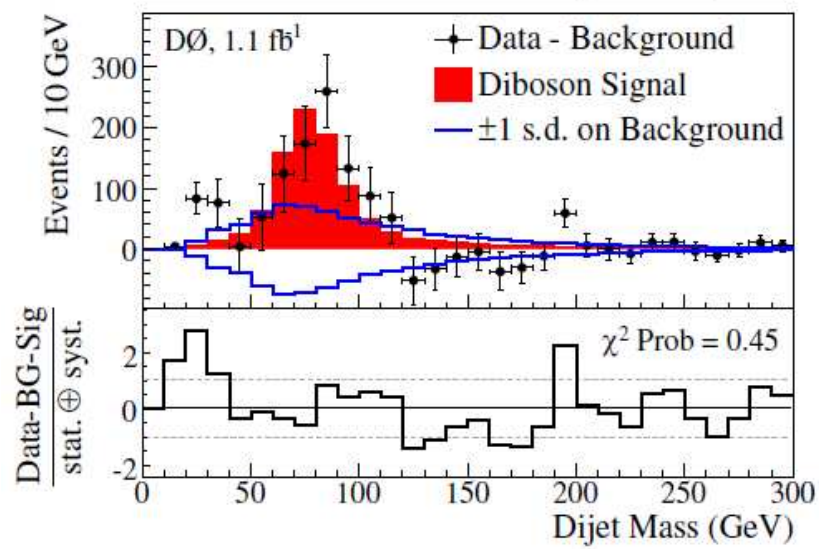
$WW/WZ \rightarrow l\nu jj$

- Production results
  - Measured cross section

    $\sigma(WW+WZ) = 20.2 \pm 4.4(\text{stat+syst}) \pm 1.2(\text{lumi})$ pb
  - Expected significance of 3.6σ
  - Observed significance of 4.4σ



SM NLO: $\sigma(WW+WZ) = 16.1 \pm 0.9$ pb



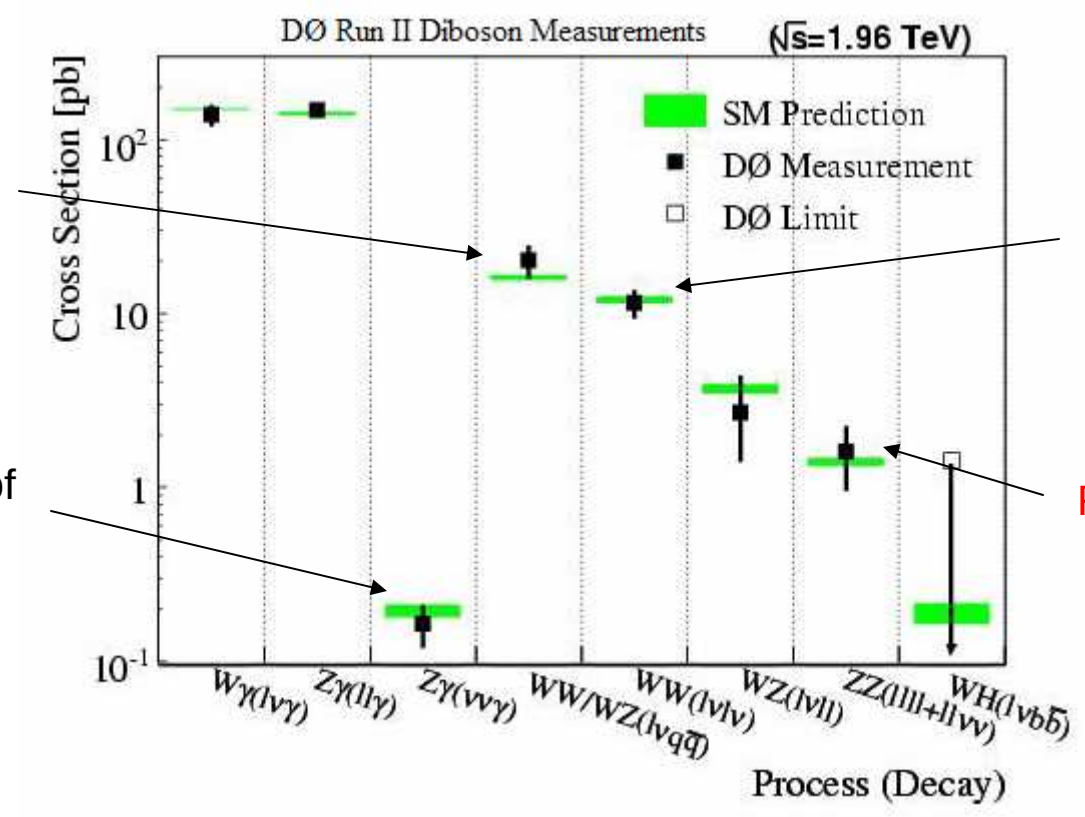
PRL 102, 161801 (2009)

Conclusions

- So far, everything agrees with the standard model

Evidence of $WW/WZ \rightarrow l\nu jj$

First observation of $Z\gamma \rightarrow \nu\nu\gamma$



Measurement of $\sigma(WW)$

First observation of ZZ

- Now have over 6 fb^{-1} of reconstructed data
  - Much more diboson physics to come from DØ

Backup

Calculation of Significance

- Performed using a semi-frequentist approach
  - Assume data is drawn randomly from a Poisson parent distribution
- Input is the information in channels (binned)
  - s is expected signal, b is expected background, d is data
  - Generate pseudo-experiments via random Poisson with mean value from expected b and s+b
  - Systematic uncertainties treated using a Bayesian model
    - Treated as Gaussian-distributed, randomly sampled for each pseudo-experiment
    - Nominal background prediction varied according to smeared values of systematics, changing the mean of the random Poisson with each pseudo-experiment
- Use a negative log-likelihood ratio (LLR) test statistic:

$$LLR(\vec{s},\vec{b},\vec{d}) = \sum_{i=0}^{N_{bins}} s_i - d_i \ln(1+\frac{s_i}{b_i})$$