Study of the Dijet Invariant Mass in W + 2 jet events

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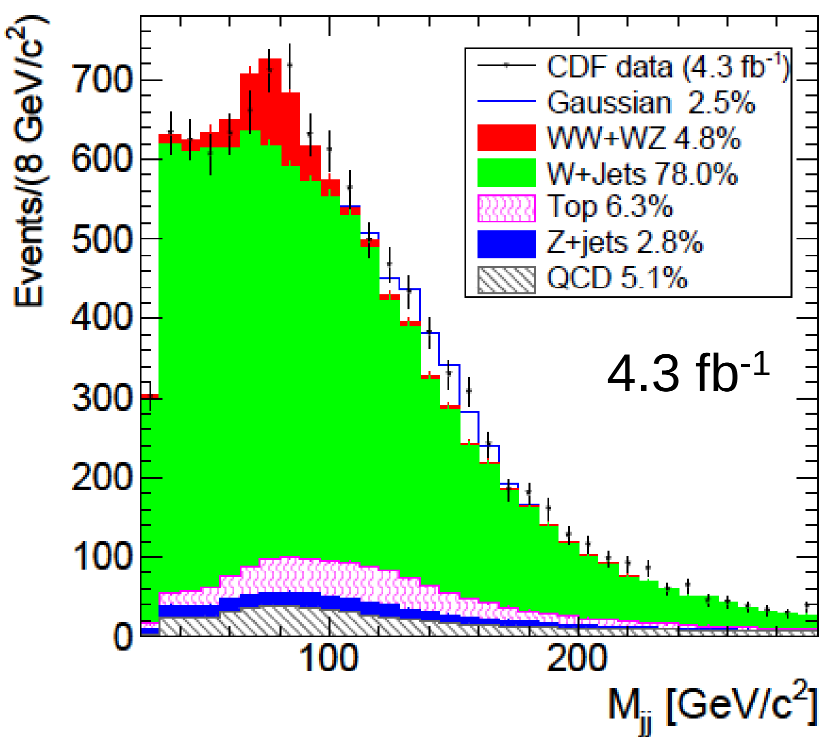
Results from the CDF Experiment

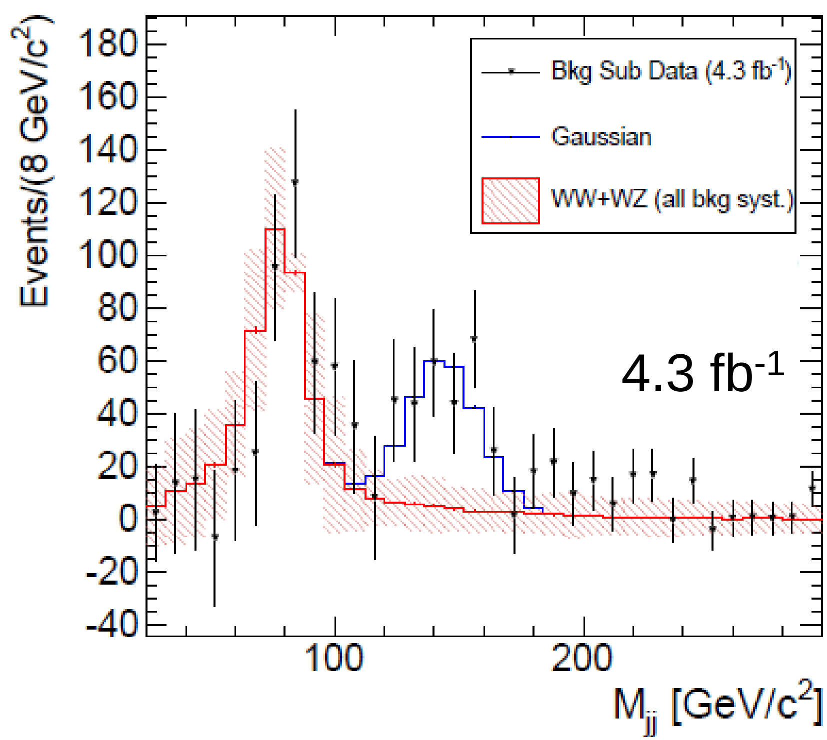
Significant excess of events in the dijet mass distribution at M_{JJ} ~145 GeV (3.2σ)

- Excess modeled with a Gaussian with a width expected from the dijet mass resolution
- Efficiency from MC WH with m_H@150 GeV→lνbb
- If a new particle X, with BR(X→jj) = 1: **σ(pp→WX) ≈ 4 pb**

used as a benchmark cross section in the DØ study

PRL 106, 171801 (2011)

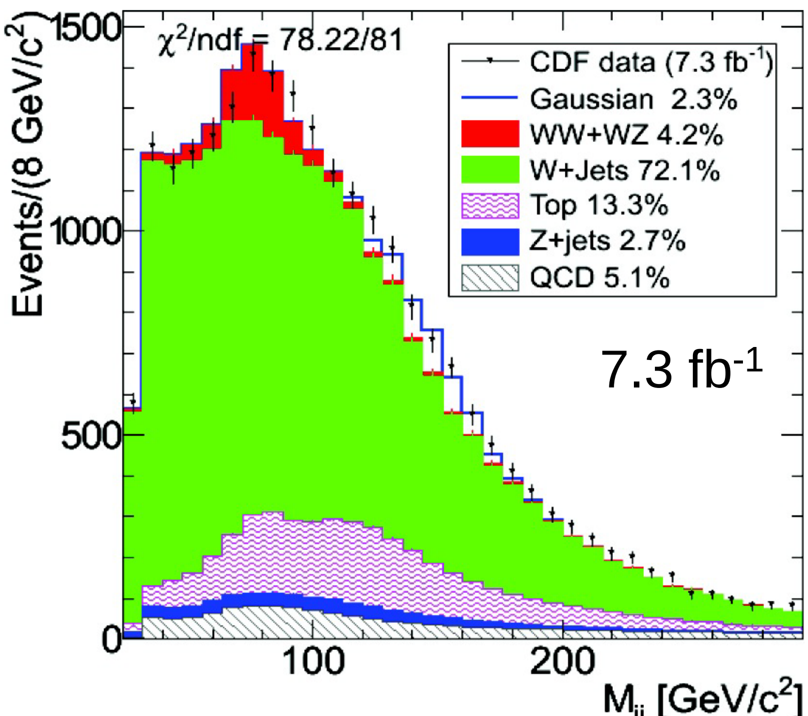


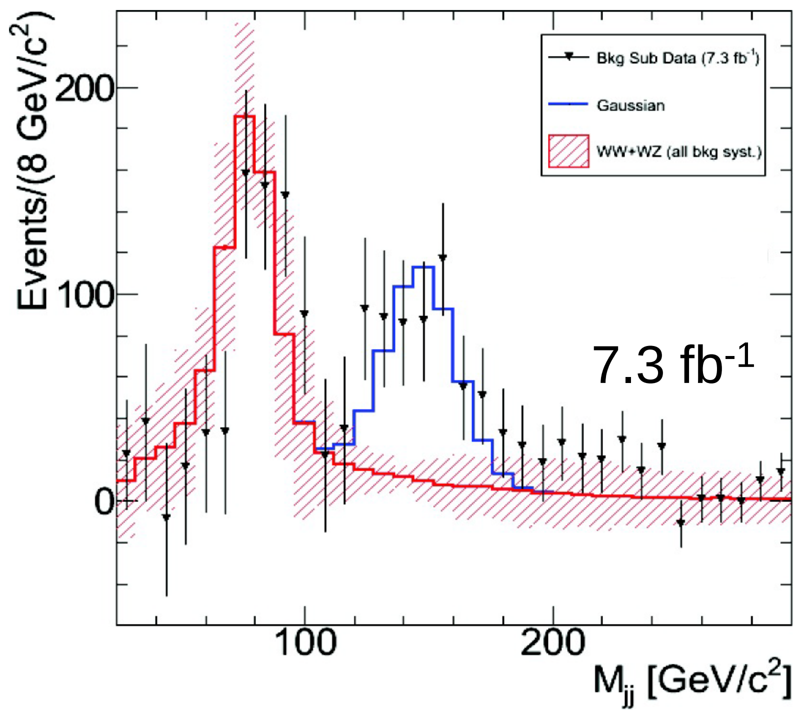


Results from the CDF Experiment

Significant excess of events in the dijet mass distribution at M_{JJ} ~145 GeV (4.3σ)

www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html





Analysis at the DØ Experiment

Do the DØ data show a similar excess at M_{JJ} ~145 GeV?

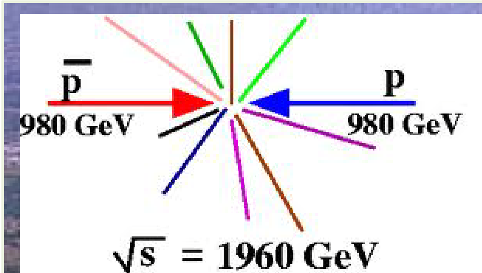
Same event selection as in the CDF analysis
Detailed treatment of systematic uncertainties

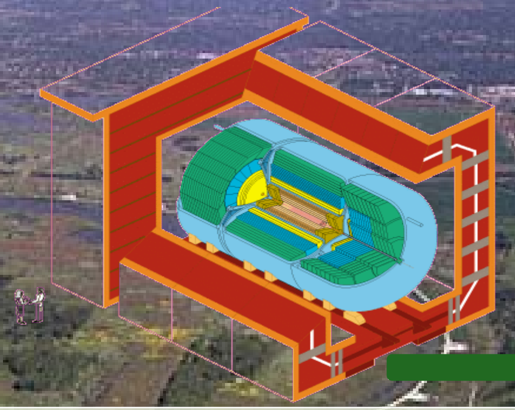
• Fit SM processes to data
$\Rightarrow$ Is there an excess of events similar to that in CDF data?

• Include a model “a la CDF” for $WX \rightarrow l\nu jj$ in the fit
$\Rightarrow$ How large excess do the DØ data support?

Cross checks with signal-injected data

The DØ Experiment (Fermilab, US)





Multipurpose detector
operates with efficiency > 90%

- **Silicon Tracker**
- **Central Fiber Tracker**
- **Solenoid**
- **Calorimeter**
- **Muon System**

- **Integrated Luminosity**
  Recorded by DØ: 10.3 fb^{-1}
- **Peak Luminosity**
  4.2×10^{32} $cm^{-2}s^{-1}$

Event Selection

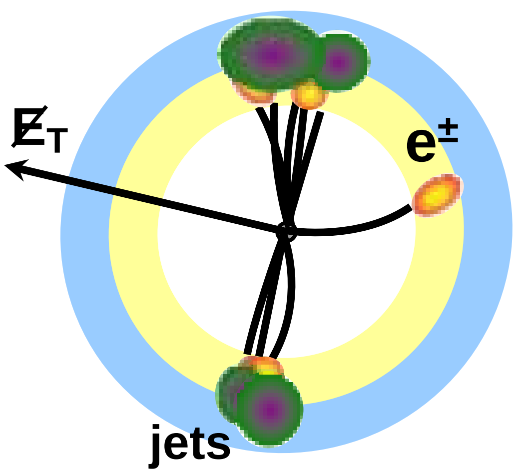
W(→lν) + 2 jets from 4.3 fb^{-1} DØ data, single lepton and lepton + jets triggers

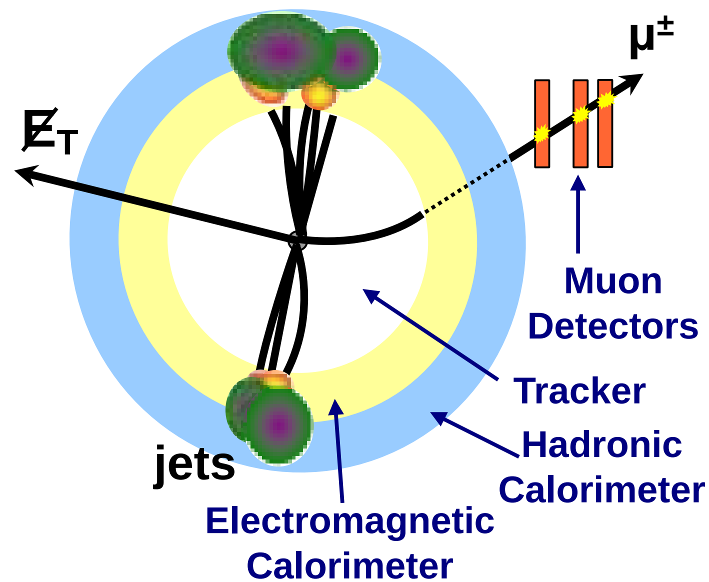
Electrons

- $p_T \geq 20$ GeV, $|\eta| \leq 1.0$
- Isolated in calorimeter/tracker
- Good EM shower shape
- Match to a track

Muons

- $p_T \geq 20$ GeV, $|\eta| \leq 1.0$
- Isolated in calorimeter/tracker
- Hits in muon system (3 layers)
- Match to a track





Global Selection

Missing E_T (MET) ≥ 25 GeV, M_T(W→lν) ≥ 30 GeV

M_T(W→lν) < 200 GeV (in the muon channel)

Veto events with more than 1 charged lepton

Event Selection

W($\to l\nu$) + 2 jets from 4.3 fb^{-1} DØ data, single lepton and lepton + jets triggers

Jets

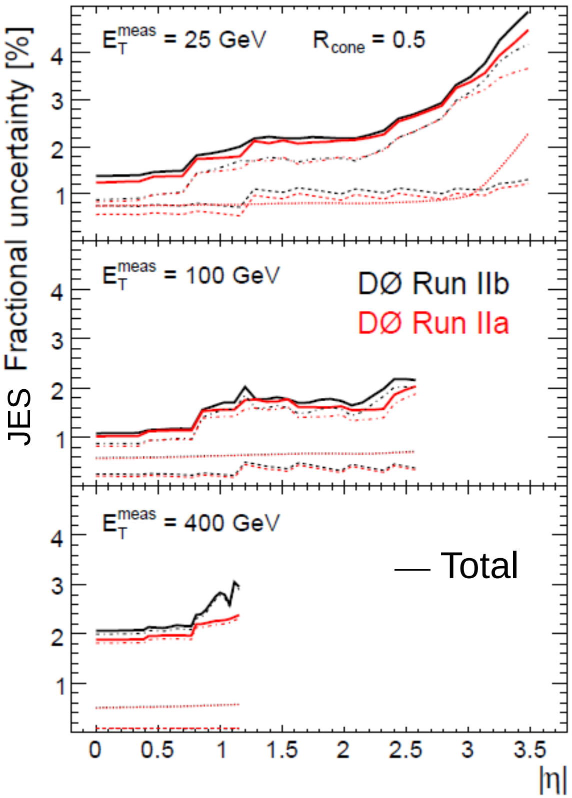
- At least two tracks originating from the primary interaction point
- Same jet selection as CDF:
  Two jets with $p_T \geq 30$ GeV (we do not veto events with extra jets with $p_T < 30$ GeV)
  Jet $|\eta_J| < 2.5$, $|\Delta\eta_{JJ}| < 2.5$, $p_T(JJ) \geq 40$ GeV, $\Delta\varphi$(leading jet, MET) > 0.4

Standard Jet Energy Scale

Measured in photon+jet and dijet events (*quark dominated*)

Correct the jet energy back to the particle-level for:

- detector energy response
- out-of-cone showering
- additional $p\bar{p}$ interaction (pileup, ZB/MB)



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Measured in photon+jet and dijet events (*quark dominated*)

Correct the jet energy back to the particle-level for:

- detector energy response
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Additional Jet Energy Calibration
(relative data/MC corrections)

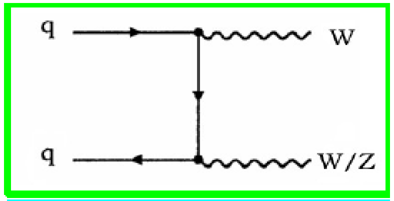
Measured in Z+jet events (MC: Alpgen) (*gluon dominated*)

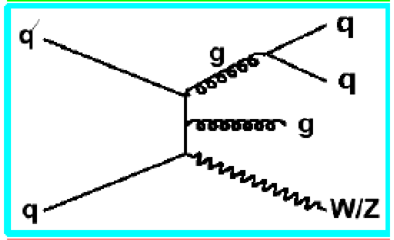
Correct p_T imbalance and energy resolution for:

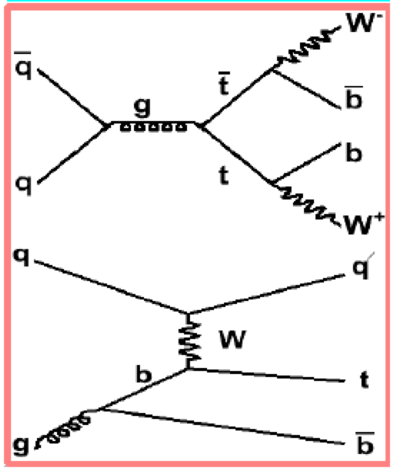
- soft out-of-cone radiation
- different quark/gluon composition (applied to Alpgen W+jet sample)

Modeling of SM processes

Event Source	Generator		σ(SM) / σ(WW) = 12.4 pb	
WW	Pythia		1.0	NLO
WZ	Pythia		0.3	NLO
ZZ	Pythia		0.1	NLO
W+light flavor jets	Alpgen	+ Pythia	800	from FIT
W+heavy flavor jets	Alpgen	+ Pythia	30	from FIT
Z+light flavor jets	Alpgen	+ Pythia	30	NNLO
Z+heavy flavor jets	Alpgen	+ Pythia	1	NNLO
Double-Top	Alpgen	+ Pythia	0.6	NNLO
Single-Top	Comphep	+ Pythia	0.2	NNLO







Multijet Background
(jet misidentified as a lepton)

- Estimated from (multijet enriched) data
- Corrected for contributions already accounted for by MC
- Normalization: template fit of $M_T(W \rightarrow l\nu)$

Modeling of SM processes

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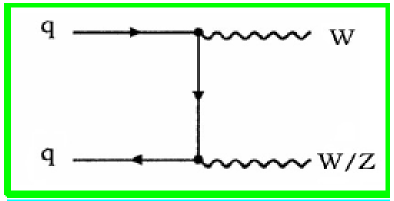

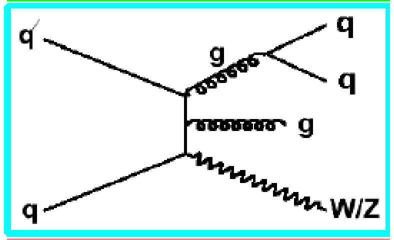

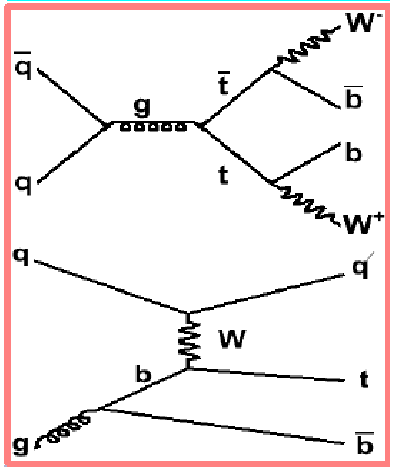

1. We do not apply data-driven corrections to Alpgen MC when comparing to the CDF result

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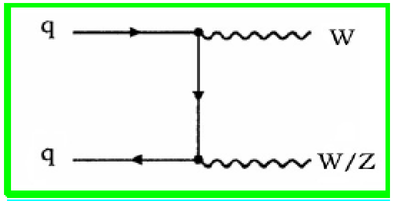
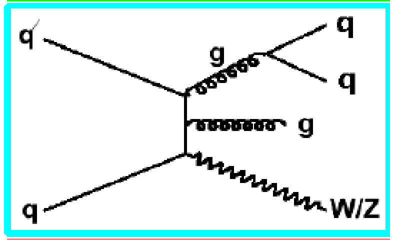
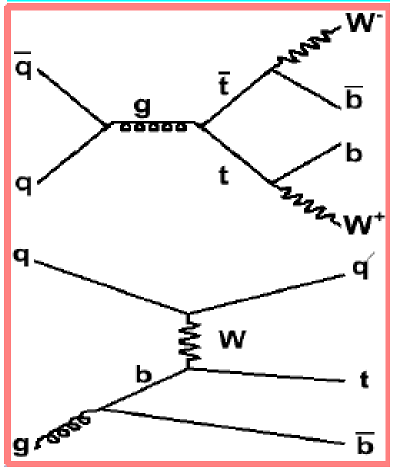






2. We include uncertainties on Alpgen MC modeling and due to tuning of Alpgen parameters when comparing to the CDF result

Systematic Uncertainties

Normalization (flat) and/or **D**ifferential (shape) of the dijet mass distribution

max. deviation in the shape/normalization of the dijet mass distribution after $\pm 1\sigma$ parameter changes

given in [%]

Source of systematic uncertainty	Diboson signal	W+jets	Z+jets	Top	Multijet	Nature	$\Delta\sigma$ (pb)
Trigger/Lepton ID efficiency	± 5	± 5	± 5	± 5		N	
Trigger correction, muon channel	± 5	± 5	± 5	± 5		D	
Jet identification	± 1	± 1	± 2	± 1		N D	
Jet energy scale	± 10	± 5	± 7	± 5		N D	
Jet energy resolution	± 6	± 1	± 3	± 6		N D	
Jet vertex confirmation	± 3	± 3	± 4	± 1		N D	
Luminosity	± 6.1	± 6.1	± 6.1	± 6.1		N	
Cross section	± 7	± 6.3	± 6.3	± 10		N	
V+hf cross section		± 20	± 20			N	
Multijet normalization					± 20	N	
Multijet shape, electron channel					± 1	D	
Multijet shape, muon channel					± 10	D	
Diboson modeling	± 8					D	
Parton distribution function	± 1	± 5	± 4	± 3		D	
Unclustered Energy correction	$\pm < 1$	± 3	± 3	$\pm < 1$		D	
ALPGEN η and $\Delta R(jet1, jet2)$ corrections		$\pm < 1$	$\pm < 1$			D	
ALPGEN W p_T corrections		$\pm < 1$				D	
ALPGEN correction Diboson bias	± 1	± 1	± 1	± 1		D	
Renormalization and factorization scales		± 1	± 1			D	
ALPGEN parton-jet matching parameters		± 1	± 1			D	
Parton shower and Underlying event correction		± 2	± 2			D	

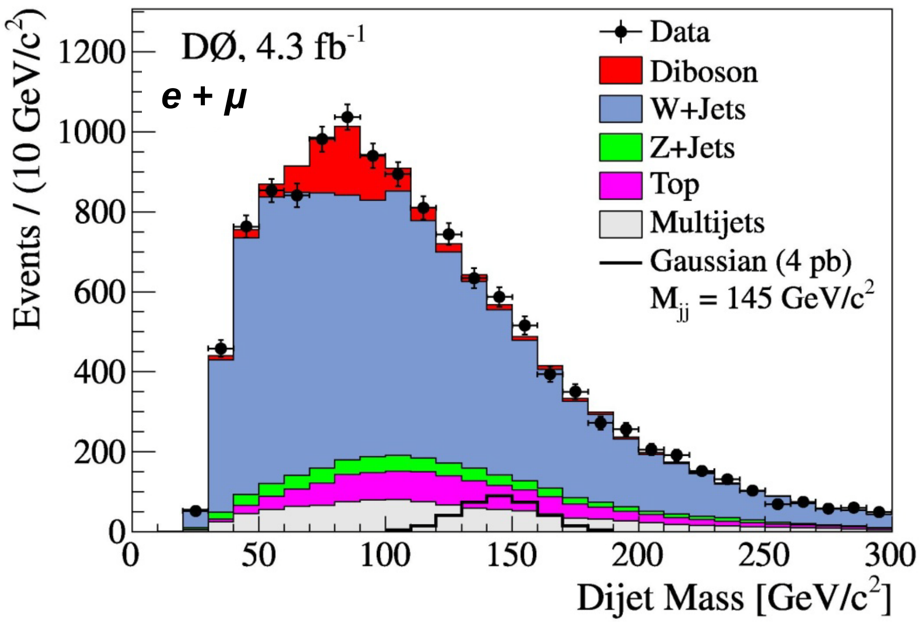
due to Alpgen modeling

due to Alpgen parameters

Poisson χ^2 fit of SM processes to data

The dijet mass distribution after fitting the SM processes to the data (normalizations for dibosons and W+jets are free parameters)

	Electron channel	Muon channel
Dibosons	434 ± 38	304 ± 25
W+jets	5620 ± 500	3850 ± 290
Z+jets	180 ± 42	350 ± 60
$t\bar{t}$ + single top	600 ± 69	363 ± 39
Multijet	932 ± 230	151 ± 69
Total predicted	7770 ± 170	5020 ± 130
Data	7763	5026



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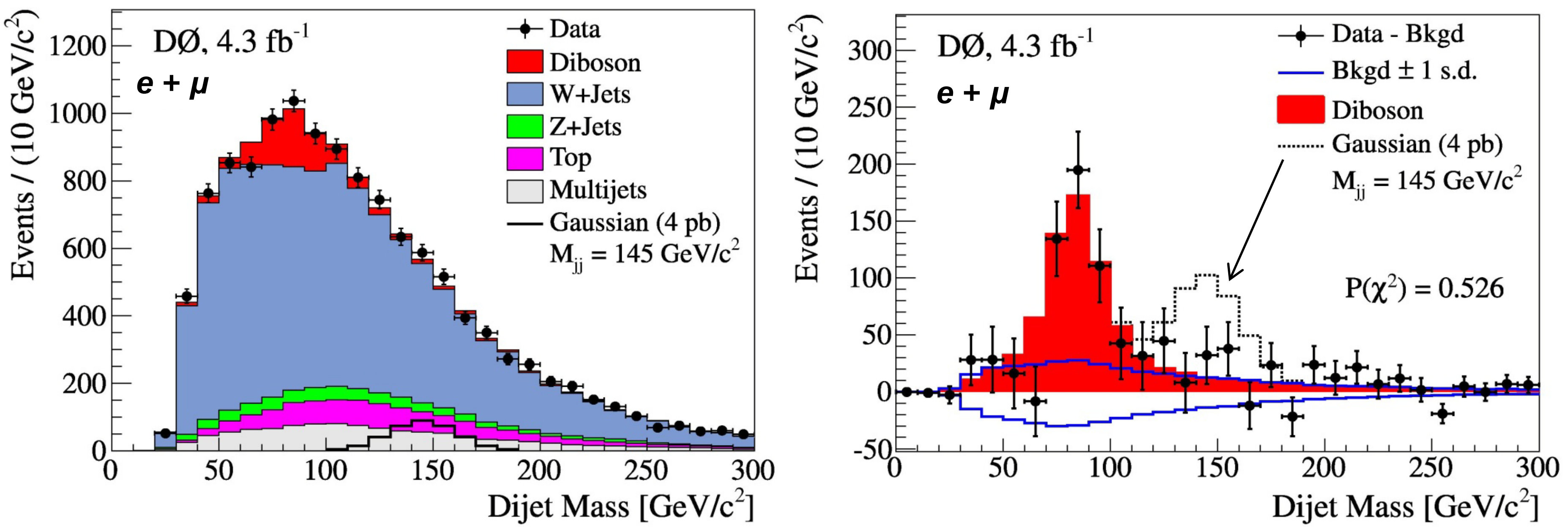

The DØ data are consistent with the SM prediction

Modeling of an Excess

- Gaussian distribution in dijet mass with a width σ_{excess} determined by the DØ experimental resolution

For $M_{JJ}^{excess} = 145\,\text{GeV}$

σ_W, M_W from $WW \to l\nu jj$ sample

$$\sigma_{excess} = \sigma_W \sqrt{\frac{M_{JJ}^{excess}}{M_W}} = 15.7\,\text{GeV}$$

- Efficiency for WX estimated with $WH \to l\nu bb$ sample (m_H@150 GeV)
- Assumption $BR(X \to jj) = 1$

Modeling of an Excess

- Gaussian distribution in dijet mass with a width σ_{excess} determined by the DØ experimental resolution

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- Efficiency for WX estimated with WH→lνbb sample (m_H@150 GeV)
- Assumption BR(X→jj) = 1
- **Systematic uncertainties** analogous to diboson samples

Modeling of an Excess

- Gaussian distribution in dijet mass with a width σ_{excess} determined by the DØ experimental resolution

For $M_{JJ}^{excess} = 145\,\text{GeV}$

σ_W, M_W from WW→lνjj sample

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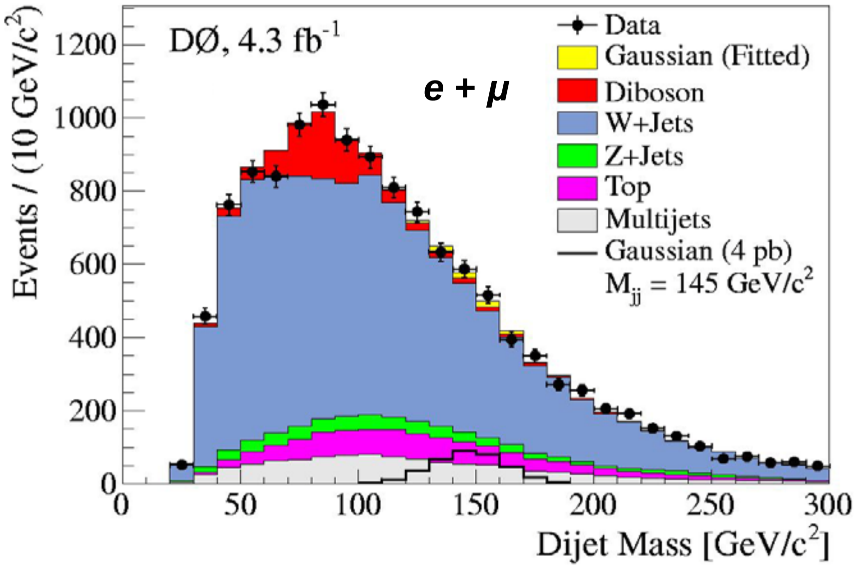
- Efficiency for WX estimated with WH→lνbb sample (m_H@150 GeV)
- Assumption BR(X→jj) = 1
- Fit ***SM processes + WX*** to data (normalizations for dibosons, W+jets, WX are free parameters)



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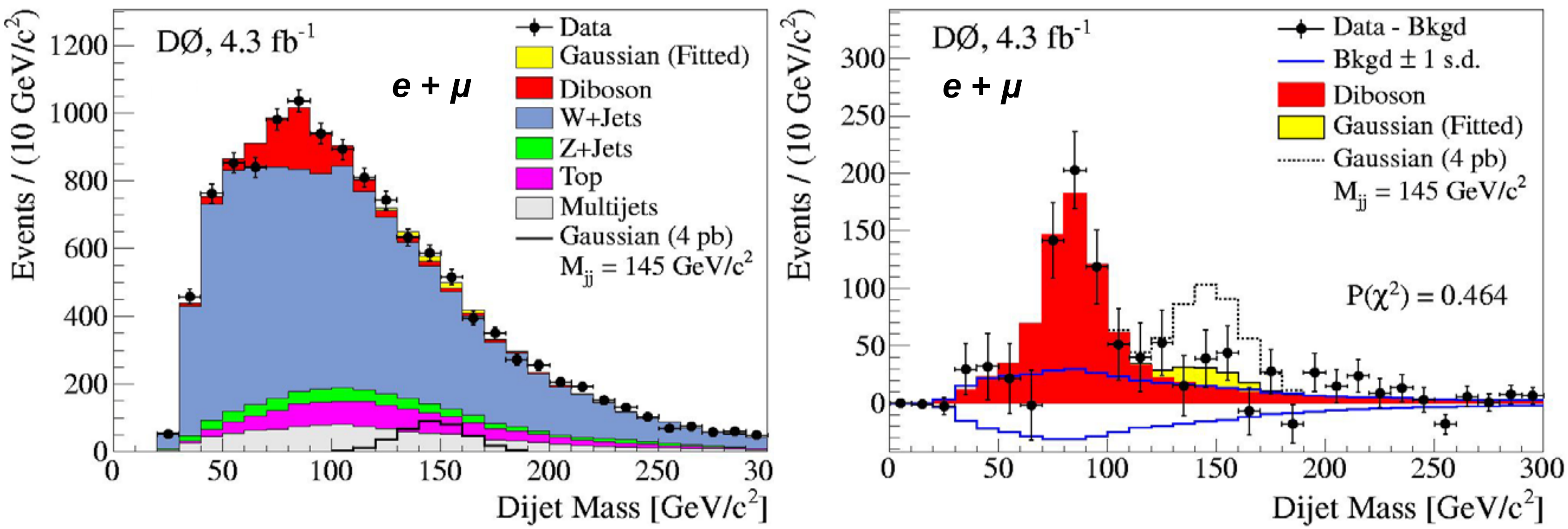

Fitted data is consistent with no excess

Modeling of an Excess

- Gaussian distribution in dijet mass with a width σ_{excess} determined by the DØ experimental resolution

For $M_{JJ}^{excess} = 145\,\text{GeV}$

σ_W, M_W from $WW \rightarrow l\nu jj$ sample

$$\sigma_{excess} = \sigma_W \sqrt{\frac{M_{JJ}^{excess}}{M_W}} = 15.7\,\text{GeV}$$

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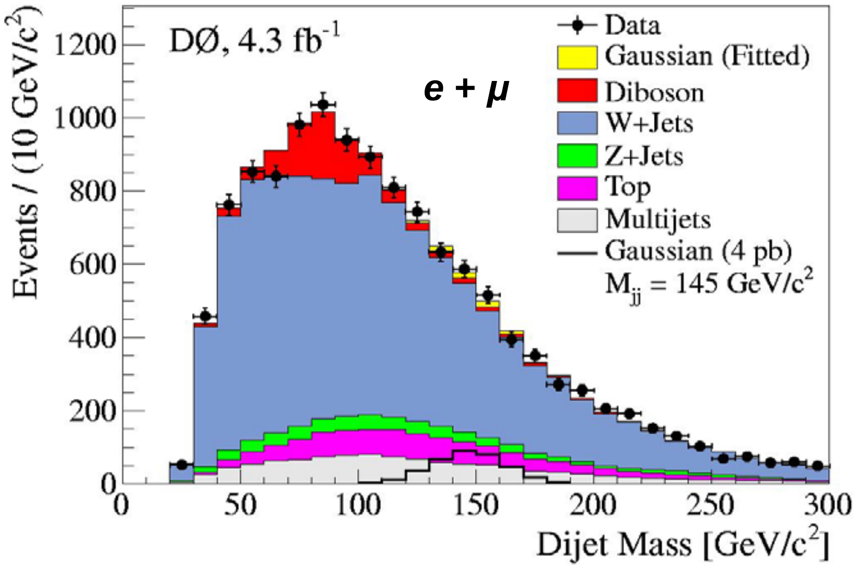


1. Measured cross section:

(normalizations for WW+WZ, W+jets, WX float)

$$\sigma(WX) \times B(X \rightarrow jj) = 0.82^{+0.83}_{-0.82}\ \text{pb}$$

Fitted cross section consistent with zero!

Modeling of an Excess

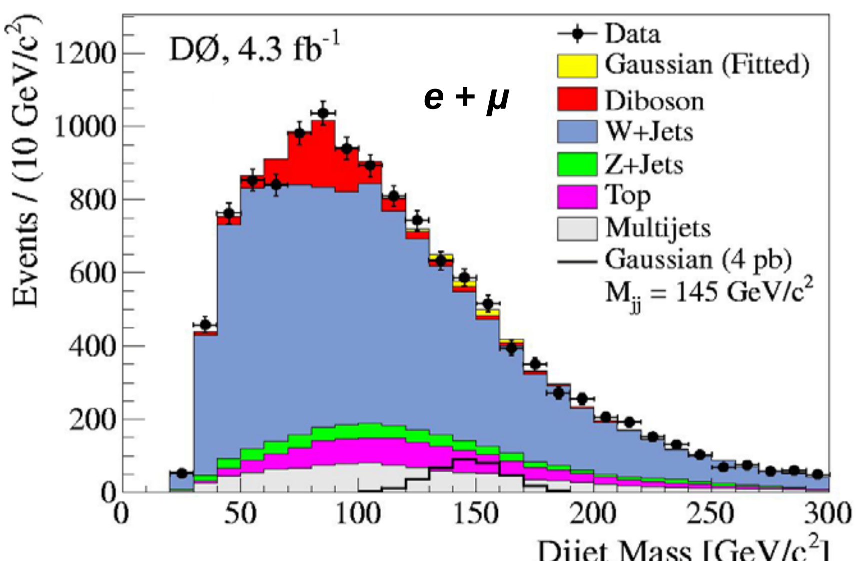
- Gaussian distribution in dijet mass with a width σ_{excess} determined by the DØ experimental resolution

For $M_{JJ}^{excess} = 145\,\text{GeV}$

σ_W, M_W from $WW \to l\nu jj$ sample

$$\sigma_{excess} = \sigma_W \sqrt{\frac{M_{JJ}^{excess}}{M_W}} = 15.7\,\text{GeV}$$

- Efficiency for WX estimated with $WH \to l\nu bb$ sample (m_H@150 GeV)
- Assumption BR($X \to jj$) = 1
- Fit **SM processes + WX** to data (normalizations for dibosons, W+jets, WX are free parameters)



1. Measured cross section:
(normalizations for WW+WZ, W+jets, WX float)

$$\sigma(WX) \times B(X \to jj) = 0.82^{+0.83}_{-0.82}\ \text{pb}$$

2. Measured cross section:
(normalizations for W+jets, WX float, a la CDF)

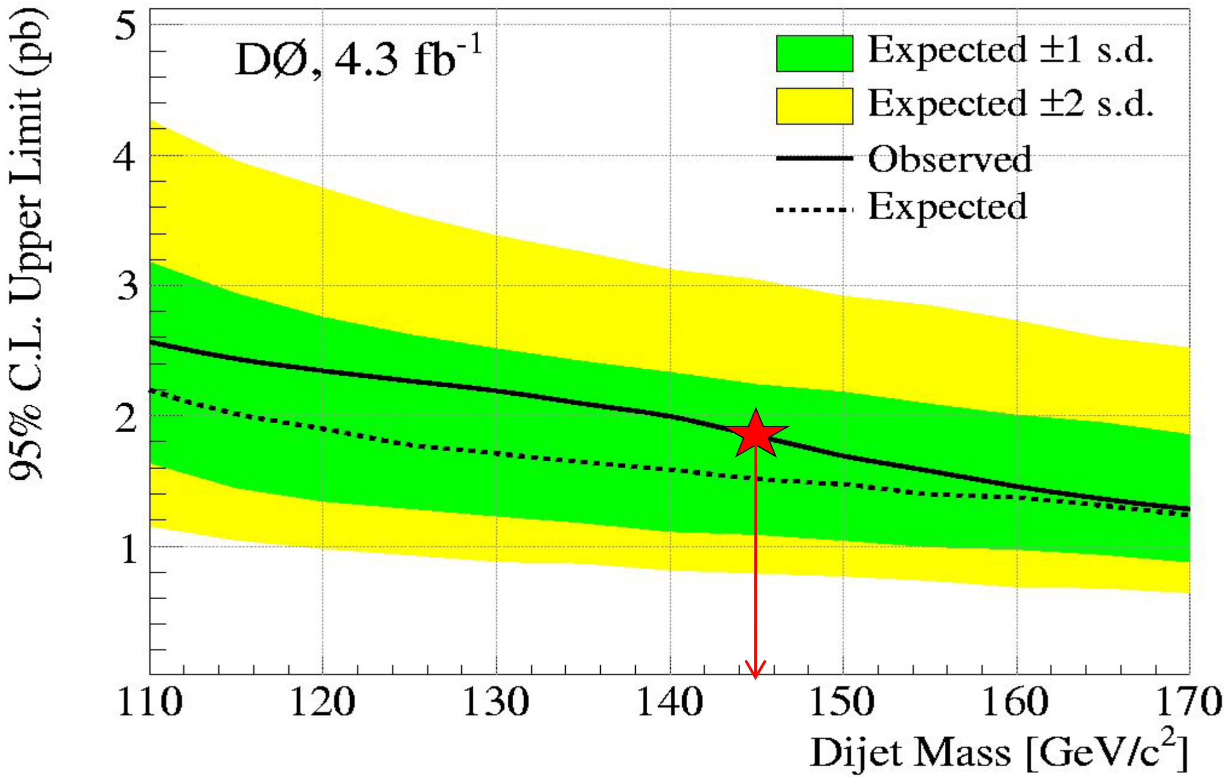
$$\sigma(WX) \times B(X \to jj) = 0.42^{+0.76}_{-0.42}\ \text{pb}$$

Fitted cross sections consistent with zero!

Setting the Limits on WX

CL_S method with Poisson Negative Log-Likelihood Test Statistics

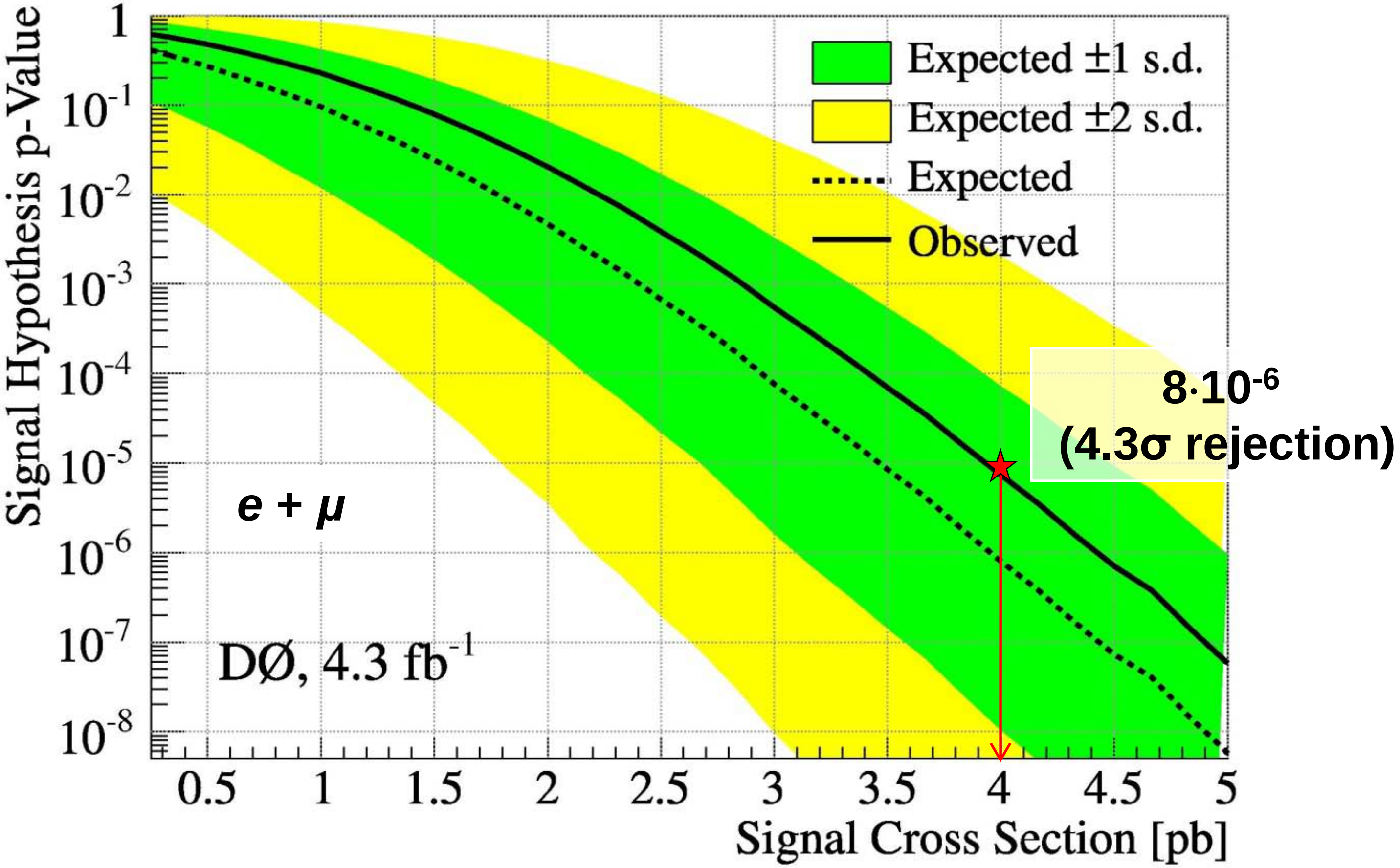
95% CL upper limits on WX→lνjj (for CDF model)



★ **1.9 pb @ M_{JJ} = 145 GeV**

Setting the Limits on WX

- Probability for S+B hypothesis to be true as a function of a cross section (for the CDF model of an excess at M_{JJ} = 145 GeV)
- Cross section of 4 pb excluded at 4.3σ

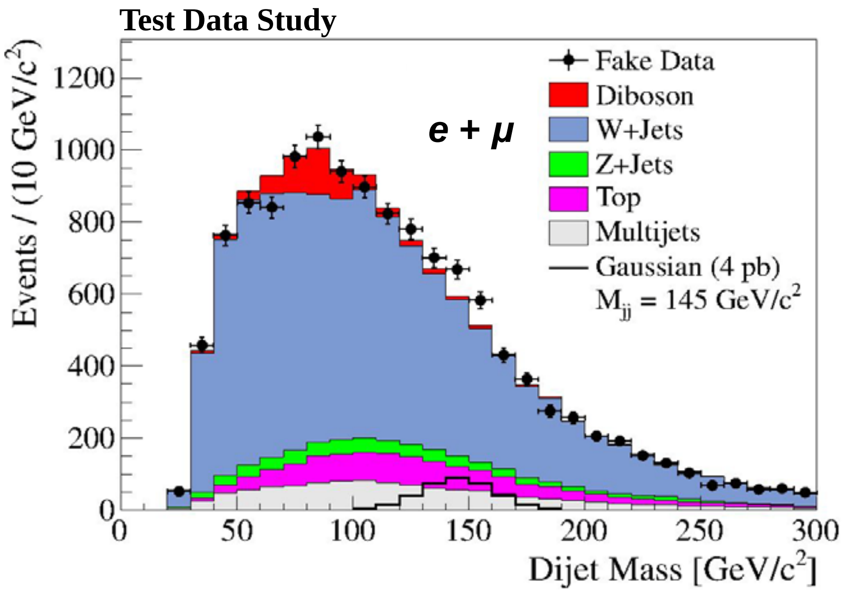


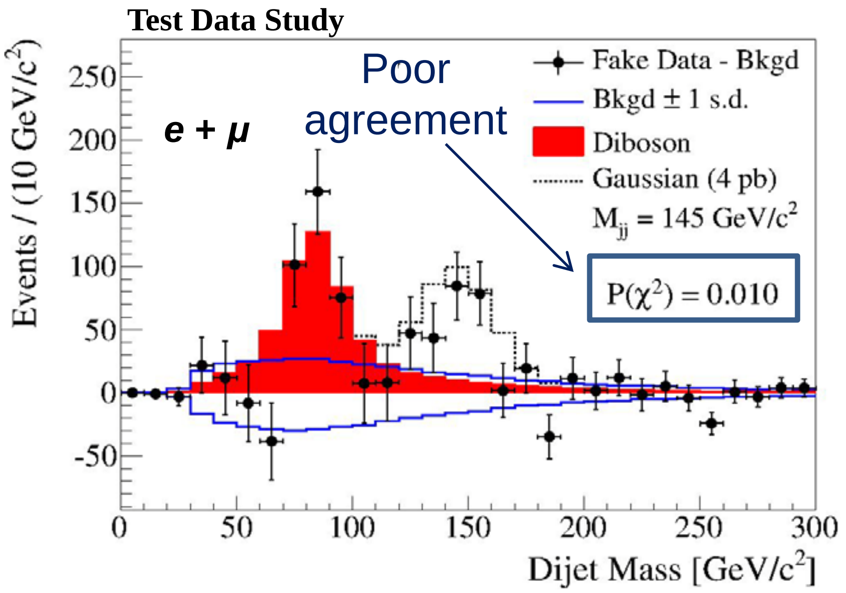
Model of 4 pb is inconsistent with the DØ data at 4.3σ

Signal Injection

If a resonance of ~4 pb is present would we be able to see it?

- Build the test data: “data + WX→lνjj” (CDF model at 145 GeV)
- Fit all **SM processes** to test data using the dijet mass distribution
- Normalizations for dibosons and W+jets are free parameters





Signal Injection

If a resonance of ~4 pb is present would we be able to see it?

- Build the test data: “data + WX→lνjj” (CDF model at 145 GeV)
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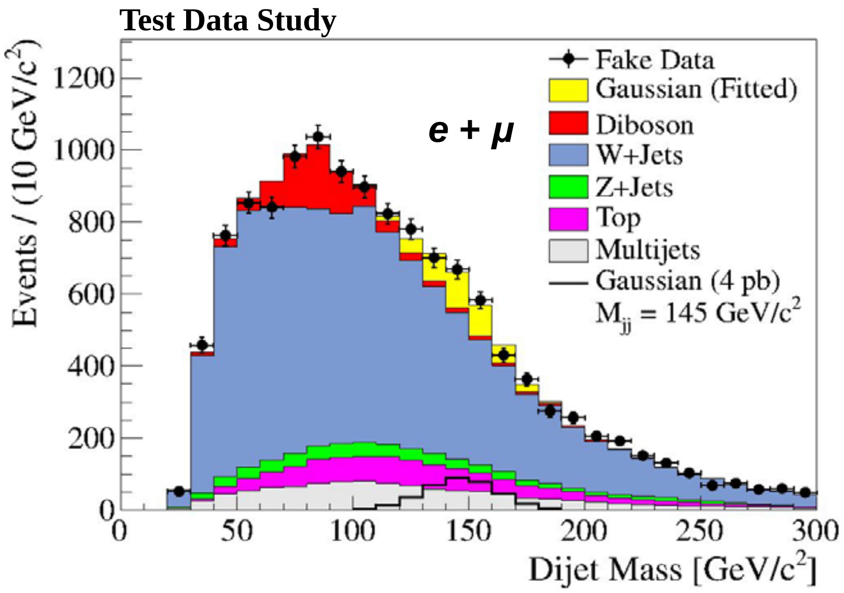
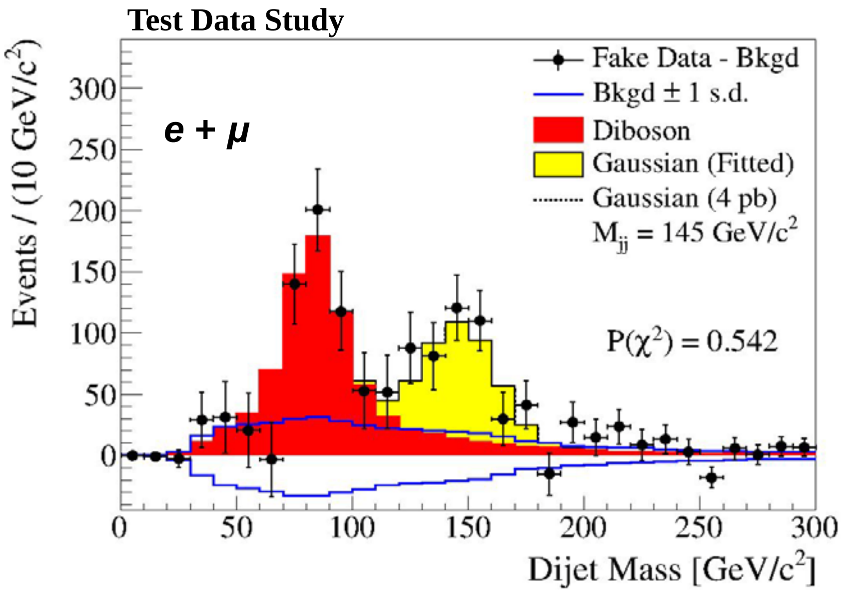
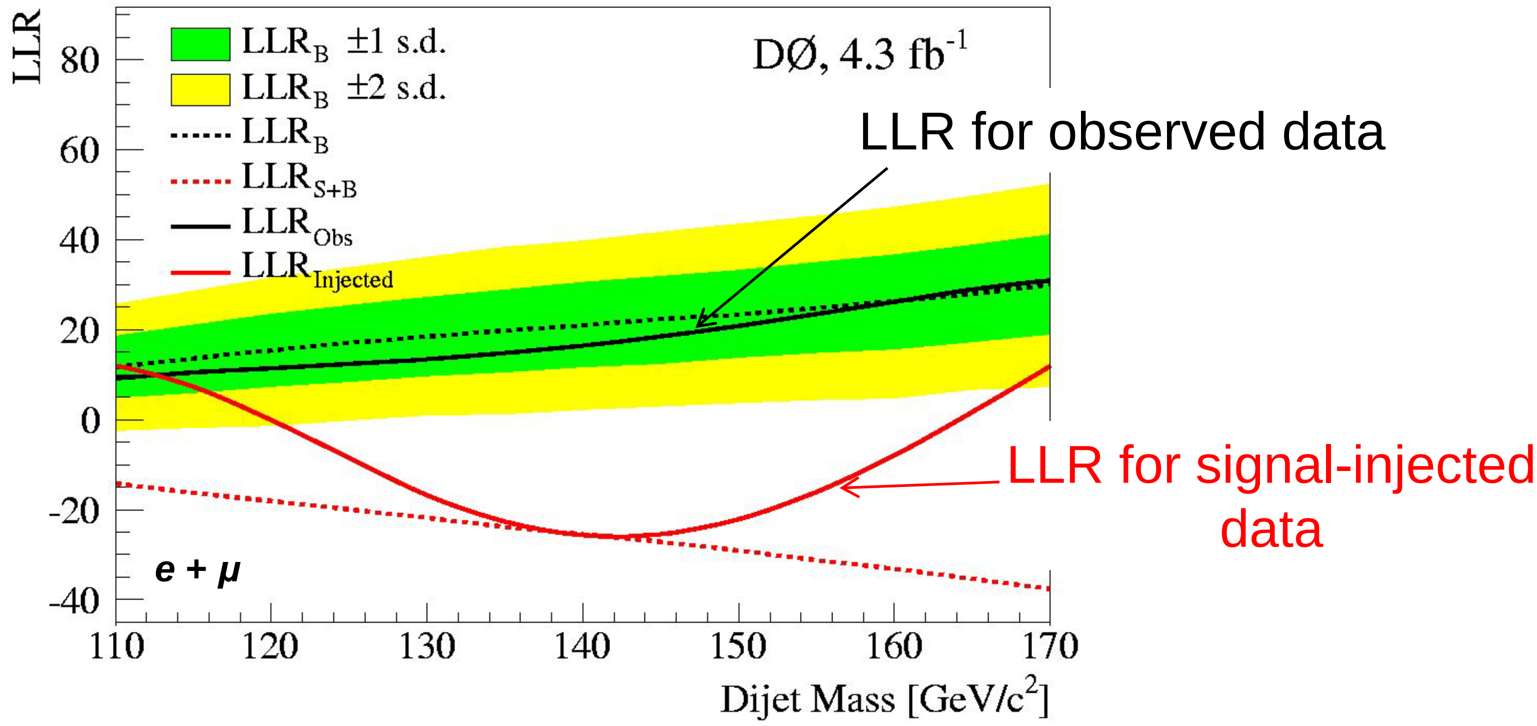
- Normalizations for dibosons, W+jets and WX are free parameters





Signal Injection

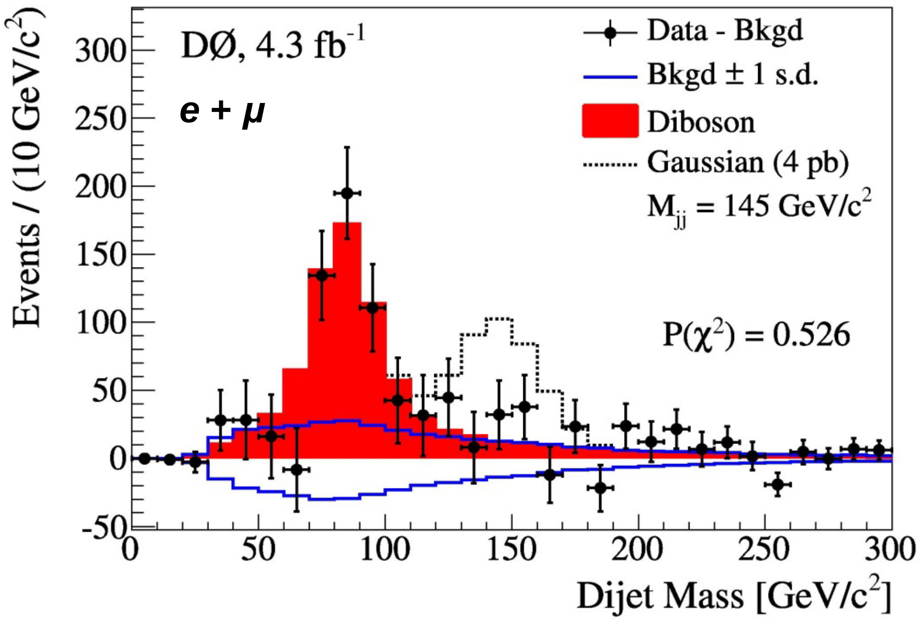
If a resonance of ~4 pb at M_{JJ} ~145 GeV were present in our data, we would certainly see it !



Summary & Conclusions

- Search for the resonance @ M_{JJ} = 145 GeV in W+2 jet events using the same event selection
- We studied extensively the dijet mass distribution

DØ data are consistent with the SM prediction



For an excess (resonance) at 145 GeV:

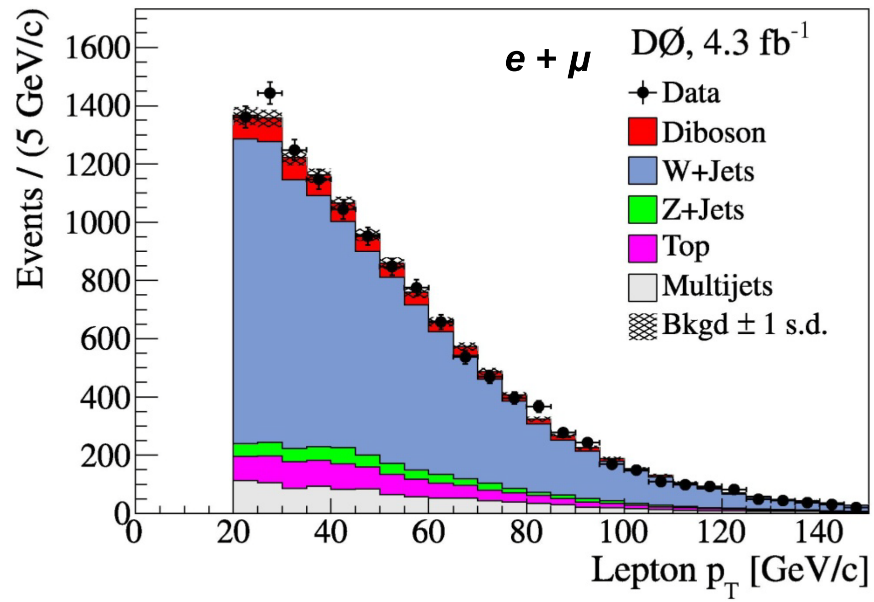
- data exclude cross sections larger than 1.9 pb at 95% CL
- cross section of 4 pb excluded at 4.3σ
- result published in [PRL 107, 011804 (2011)]

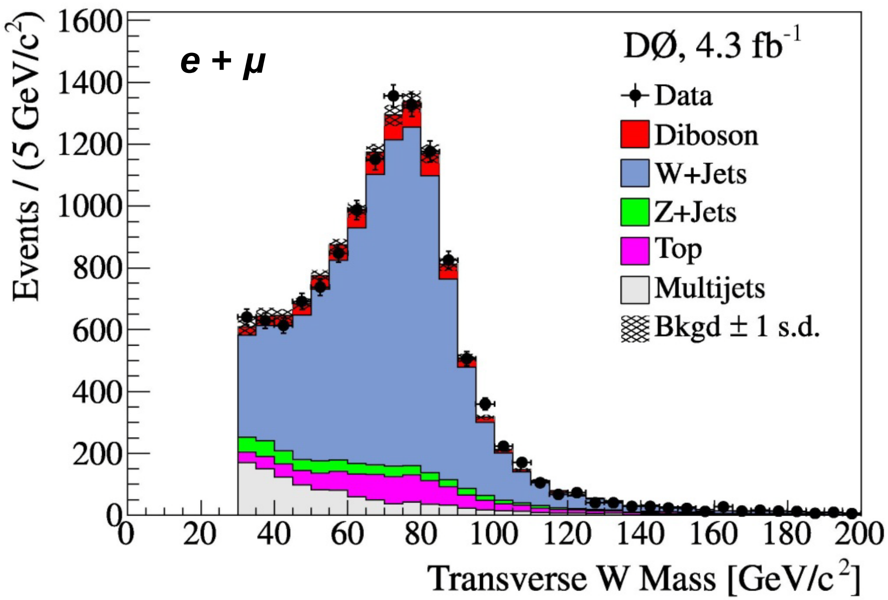
Backup Slides

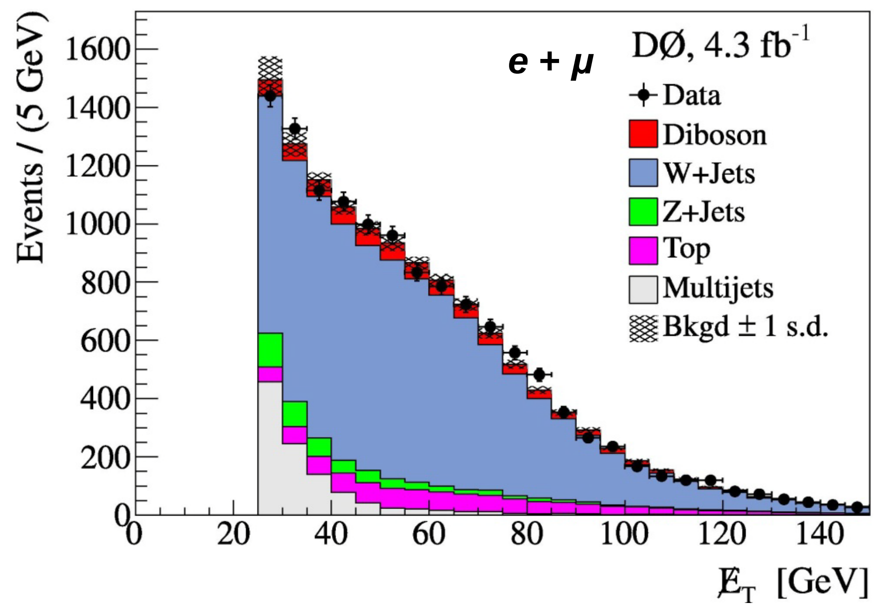
Fit of SM processes to data

Reconstructed **W→lν** distributions after fitting the SM contributions to the data

Normalizations for dibosons and W+jets are free parameters







Fit of SM processes to data

Reconstructed **jet** distributions after fitting the SM contributions to the data
Normalizations for dibosons and W+jets are free parameters