THE STORY OF A W+JETS MASS BUMP

G. Watts
(UW/Seattle)

CPPM Seminar
27/6/2011

DISCLAIMER

The Big Issues

Dark Matter

EWSB

Where is the Higgs?

Couplings

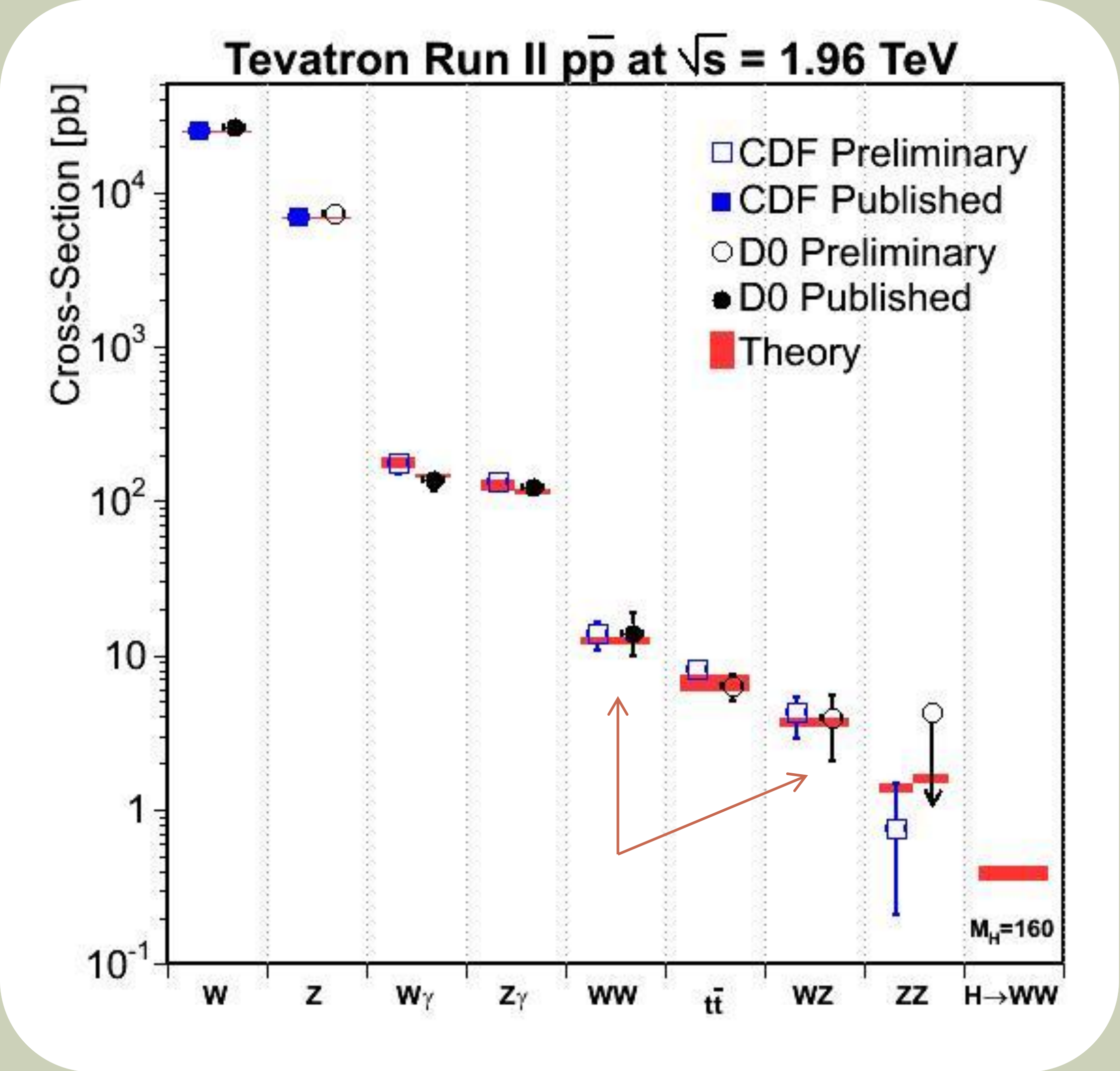
Beyond the Standard Model

First evidence seen with about 1 fb^{-1} of WW and WZ to jets

CDF has measured the σ (2010)

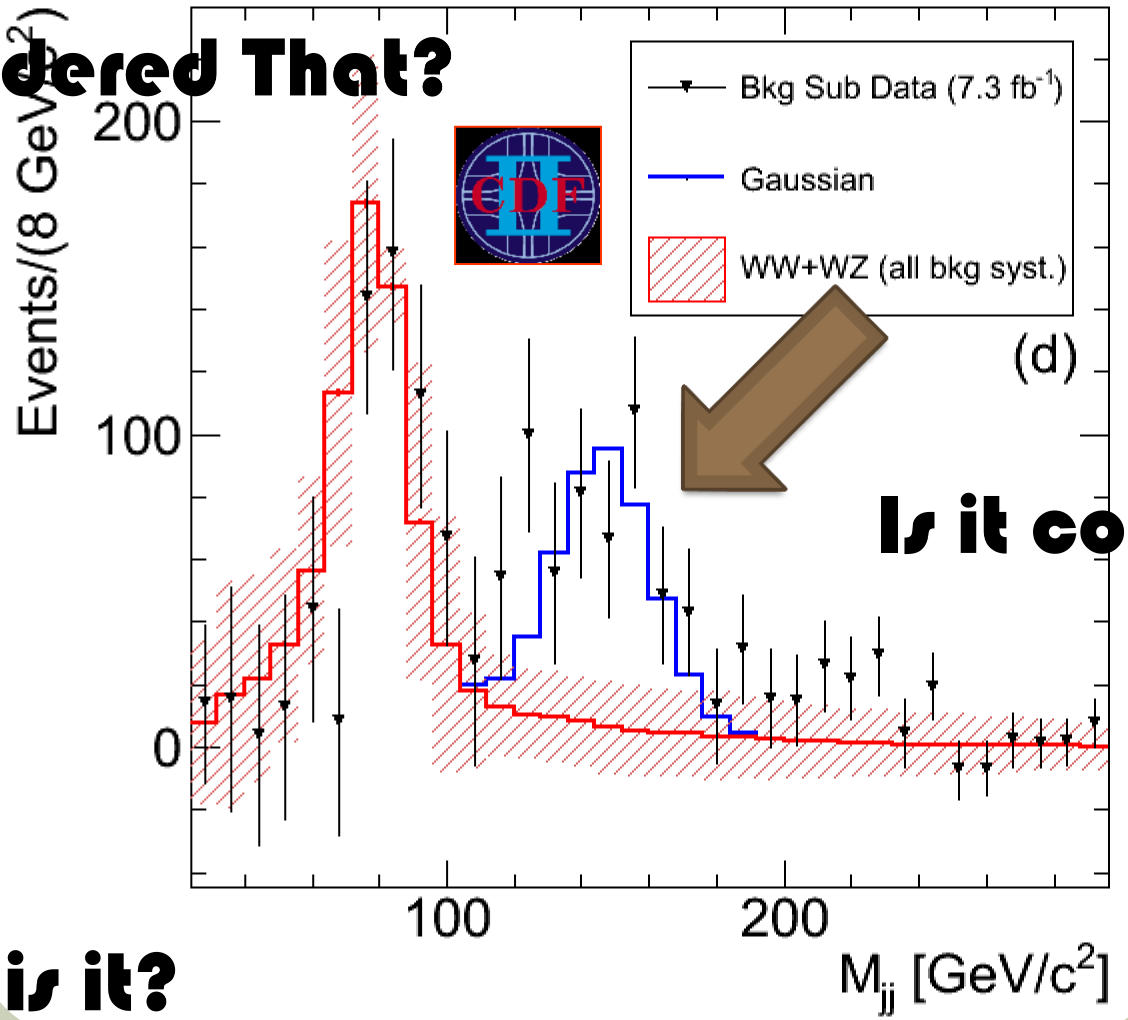
Both experiments working on updates…

When…



Who Ordered That?

$7.3\ fb^{-1}$

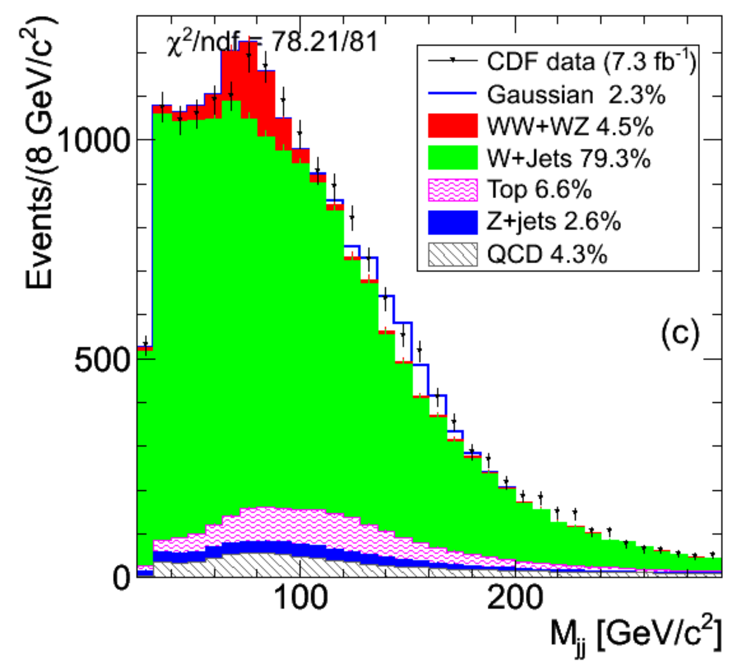


Is it correct?

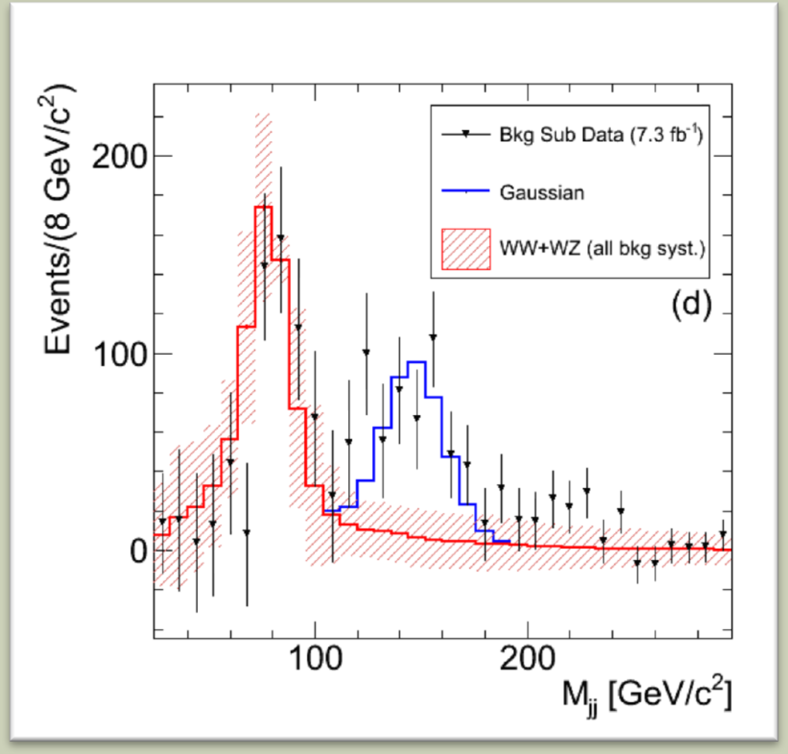
What is it?

$WW + WZ \rightarrow l\nu jj$

1 Lepton (e or μ)
Missing E_T
2 Jets



Background Subtracted



December 2010 *Measurement of ww + wz production cross section and study of the dijet mass spectrum in the lnu + jets final state at CDF. Viviana Cavaliere (Siena)*

A few theorists find the thesis…

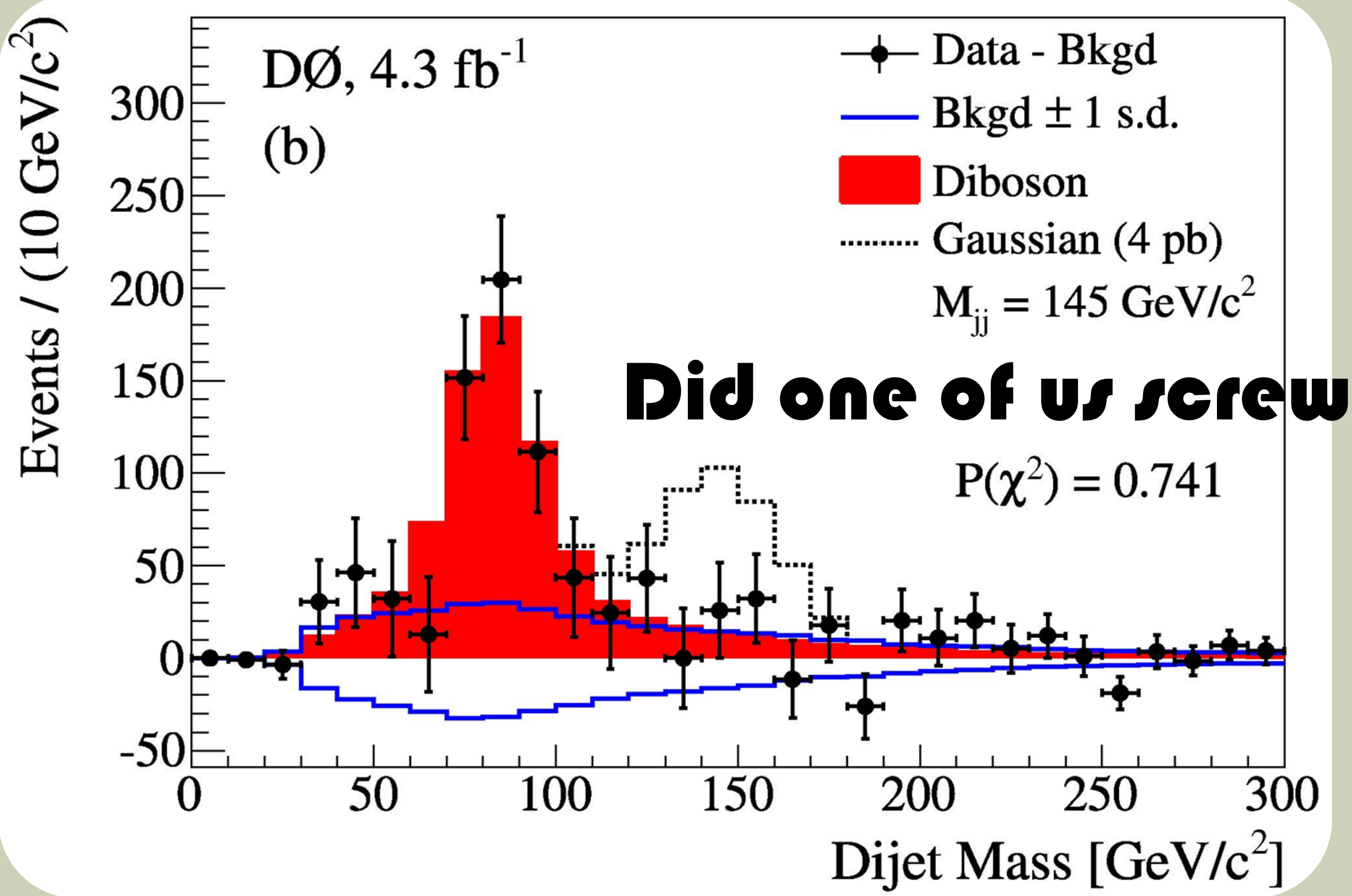
April 2011 *Invariant Mass Distribution of Jet Pairs Produced in Association with a W boson in ppbar Collisions at sqrt(s) = 1.96 TeV*, arXiv:1104.0699

(60 citations)

June 2011 *Study of the dijet invariant mass distribution in* $p\overline{p} \rightarrow W(\rightarrow l\nu + jj)$ *final states at* $\sqrt{s} = 1.96$ *TeV.* arXiv:1106.1921

(1 citations)

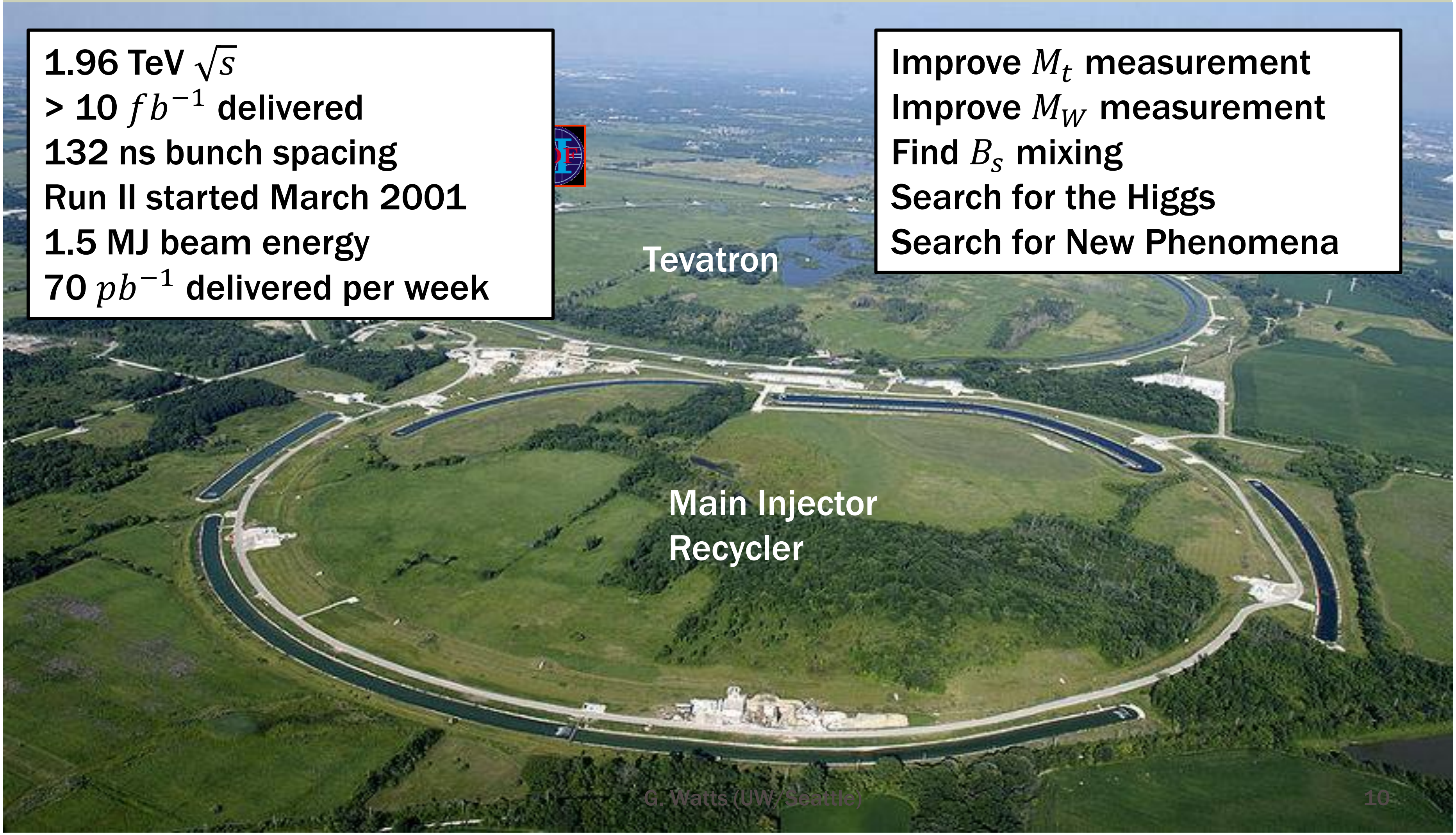
Are they compatible?



Did one of us screw up?

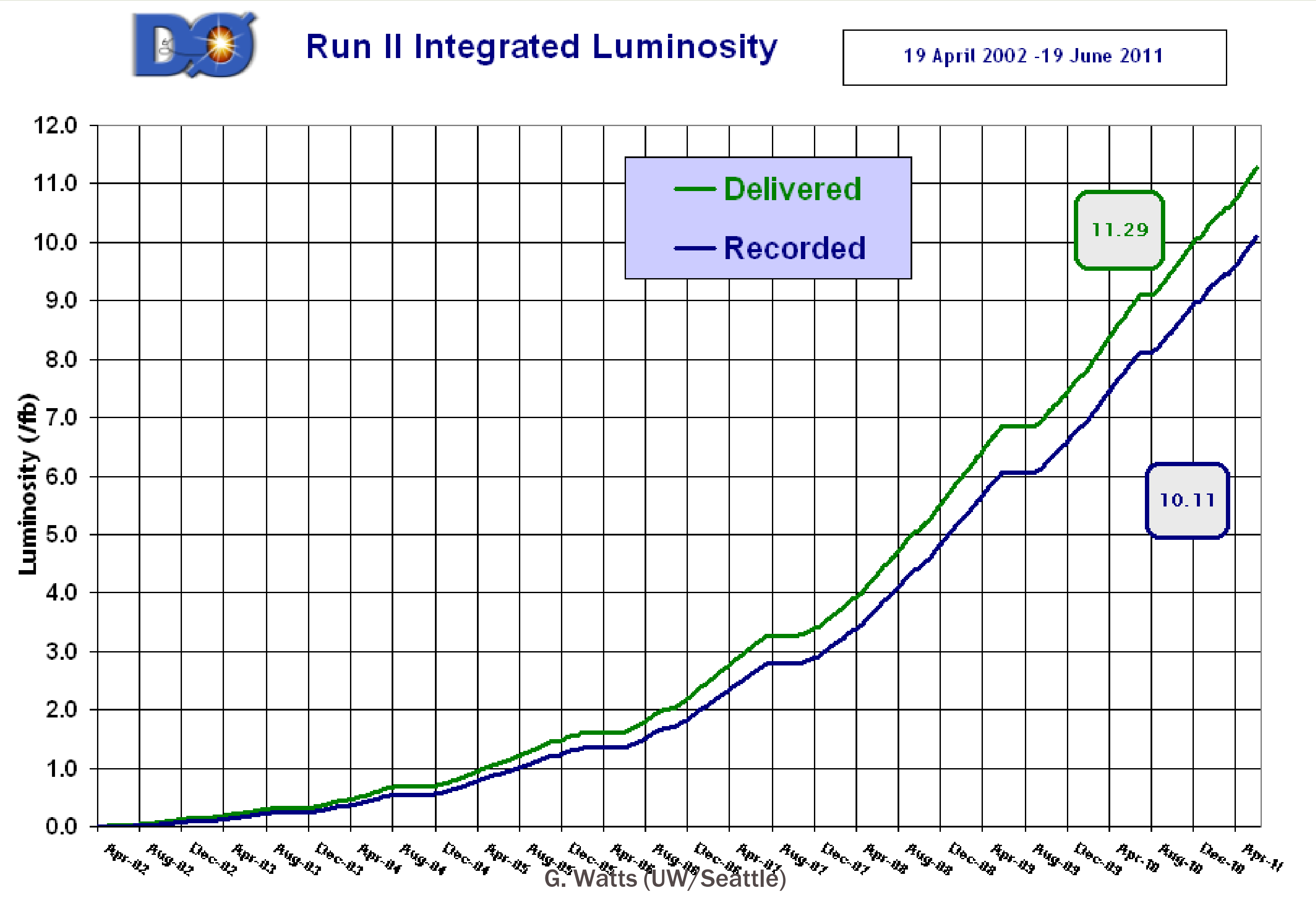

Tevatron?
LHC?

THE TEVATRON

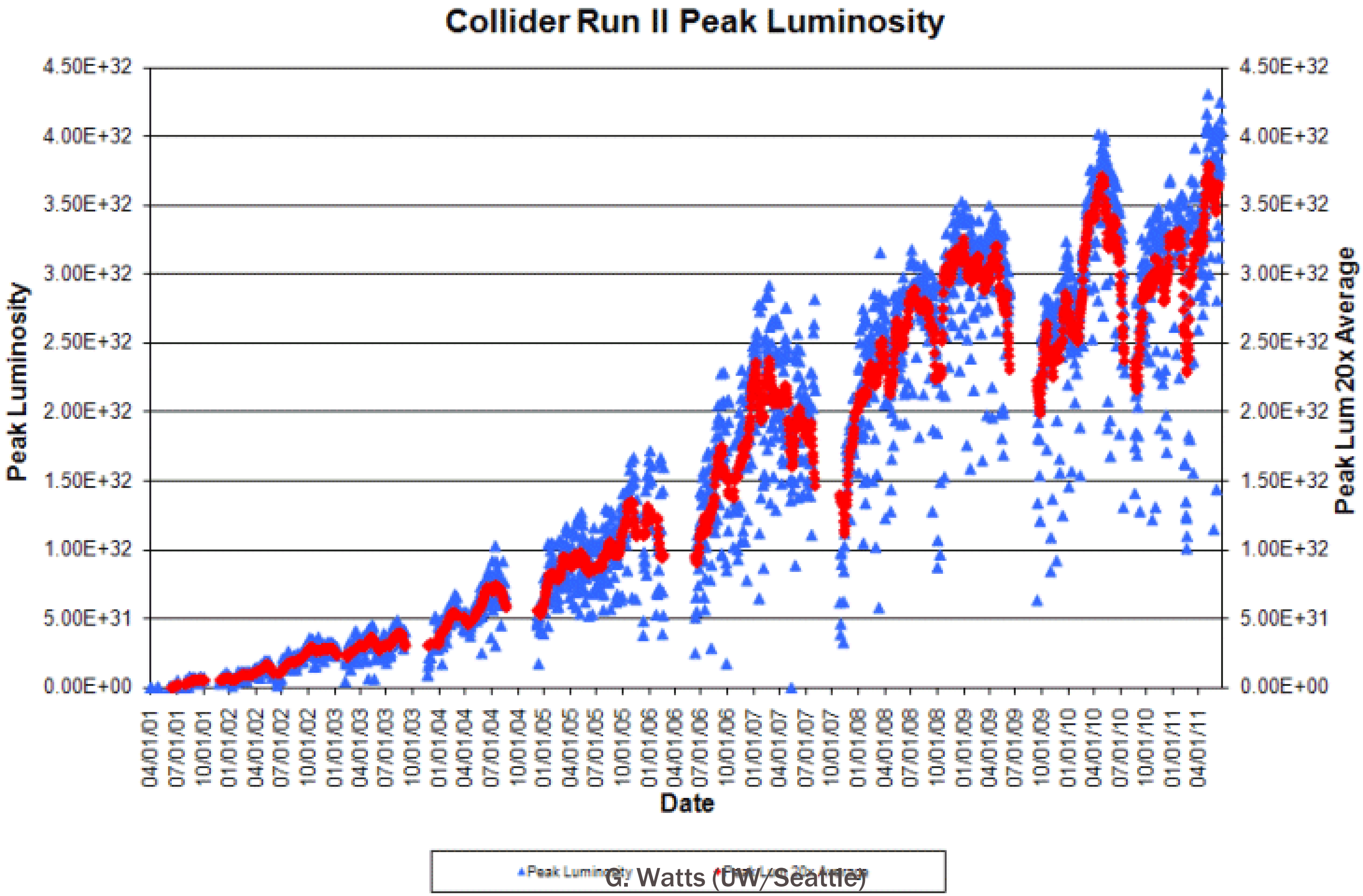


1.96 TeV $\sqrt{s}$
> 10 fb^{-1} delivered
132 ns bunch spacing
Run II started March 2001
1.5 MJ beam energy
70 pb^{-1} delivered per week

Improve M_t measurement
Improve M_W measurement
Find B_s mixing
Search for the Higgs
Search for New Phenomena


Run II Integrated Luminosity
19 April 2002 -19 June 2011
Delivered
Recorded
11.29
10.11
Luminosity (/fb)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
Apr-04
Aug-04
Dec-04
Apr-05
Aug-05
Dec-05
Apr-06
Aug-06
Dec-06
Apr-07
Aug-07
Dec-07
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
Dec-10
Apr-11

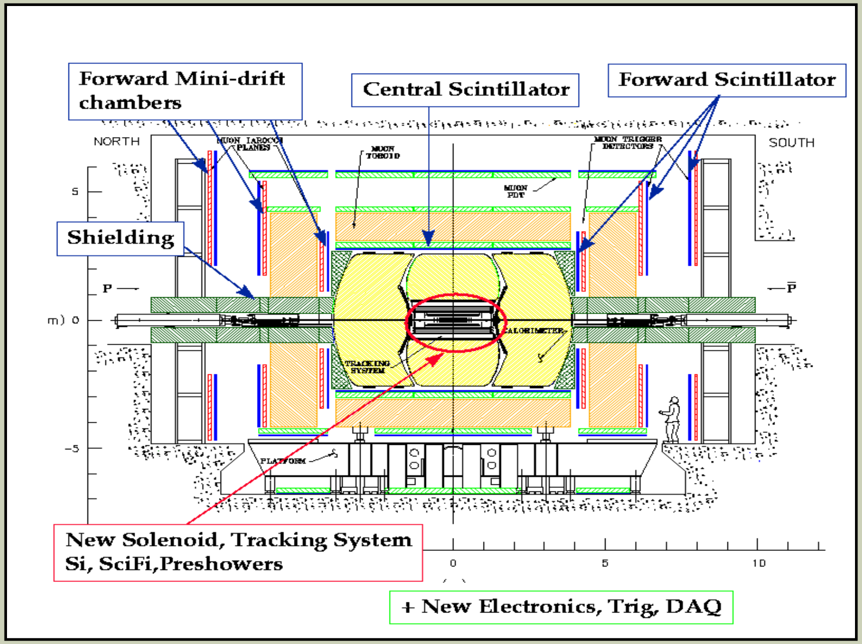
PEAK LUMINOSITY

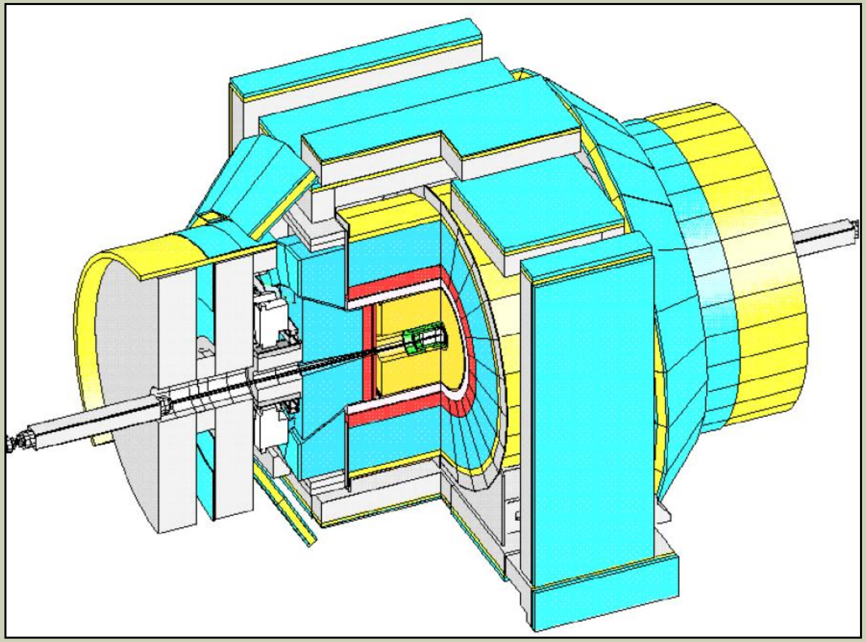


September 30
2011

Fondly remembered for ~12 fb^{-1}
delivered and countless papers published

THE DETECTORS





Silicon Tracking $|\eta| < 3$
Scintillating Fiber Tracker
  1.9 T B Field, $|\eta| < 1.7$
LAr/DU Calorimeter $|\eta| < 2$
Jet Energy Scale 1-2%

Silicon Tracking $|\eta| < 2 - 2.5$
Open Drift Cell Tracker
  1.4 T B Field, $|\eta| < 1.1$
Pb/Cu/Scint Calorimeter $|\eta| < 3.2$
Jet Energy Scale 2-3%

THE DØ ANALYSIS

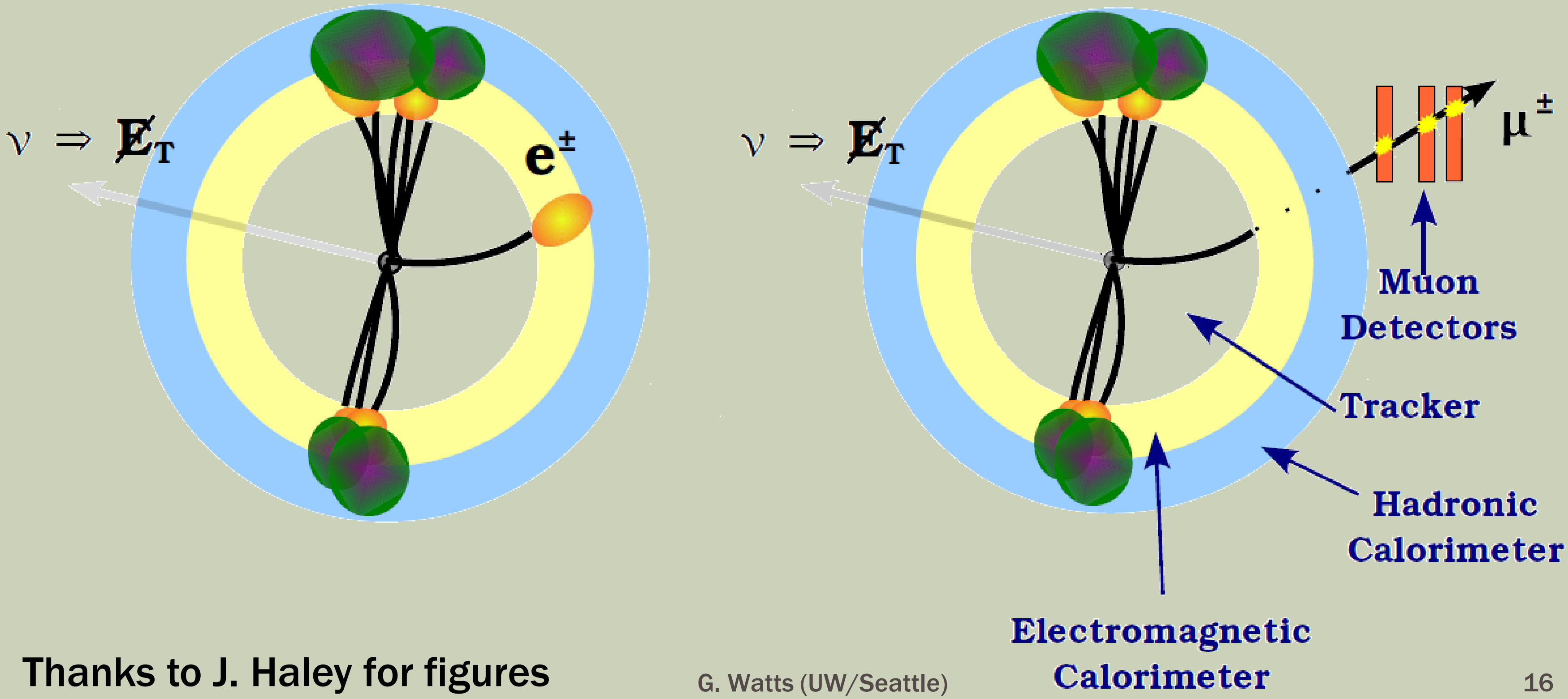
Copy CDF

DØ’s Normal Analysis opens up cuts to increase acceptance → Increased reweightings for Data/MC agreement

★ Copy CDF’s cuts → Eliminate most reweightings

★ Model $WX \rightarrow l\nu jj$ as CDF model’s it → How big an excess does our data support?

THE $WX \to l\nu jj$ SEARCH



$WX \to e\nu jj$

$WX \to \mu\nu jj$

Thanks to J. Haley for figures

SELECTING THE $W \rightarrow l\nu$

Electron

- $p_T \geq 20$ GeV, $|\eta| < 1.0$
- Isolation: track and EM shower
- Electron Shower Shape Requirements

- $p_T \geq 20$ GeV, $|\eta| < 1.0$
- Isolation: Calorimeter

Muon

- $p_T \geq 20$ GeV, $|\eta| < 1.0$
- Hits in all three muon layers
- Isolation: track and Calorimeter

- $p_T \geq 20$ GeV, $|\eta| < 1.0$
- Isolation: Calorimeter

(Isolation: kill off Heavy Flavor Decays)

SELECTING THE $W \rightarrow l\nu$

The Missing E_T

Missing $E_T > 25$ GeV

M_T^W Cuts

$30 < M_T^W < 200$ GeV

Reject events with more than one reconstructed lepton

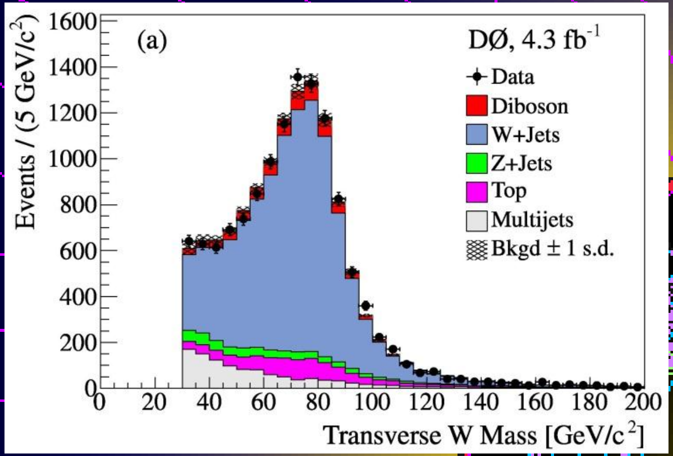
Missing $E_T > 25$ GeV

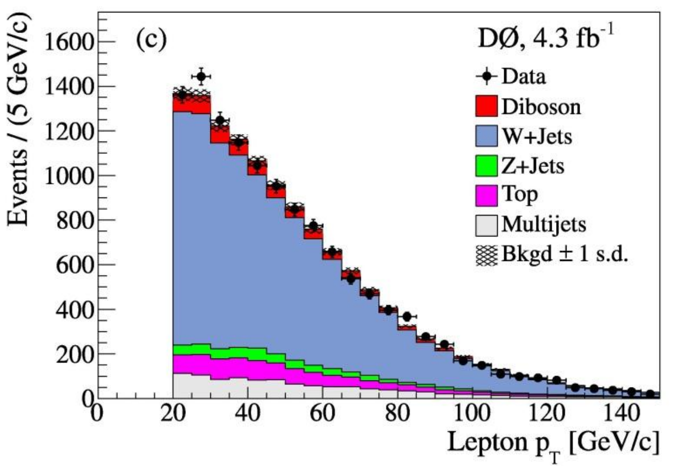
$30 < M_T^W$

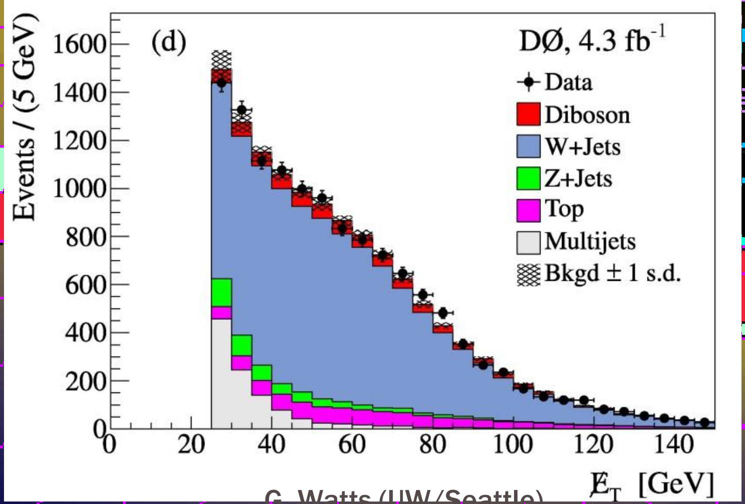
Reject events with second loose lepton an $76 < M_{ll} < 106$ GeV

Reject events with good lepton $p_T > 10$ GeV

SELECTING THE $W \rightarrow l\nu$







THE JETS

Reconstruction

DØ iterative mid-point cone algorithm
$R = 0.5$
Clean up cuts: hadronic, noisy cell removal
Vertex Confirmation: >2 tracks from IP

Fixed cone algorithm
$R = 0.4$

Selection

$p_T > 30$ GeV
$|\eta| < 2.5$

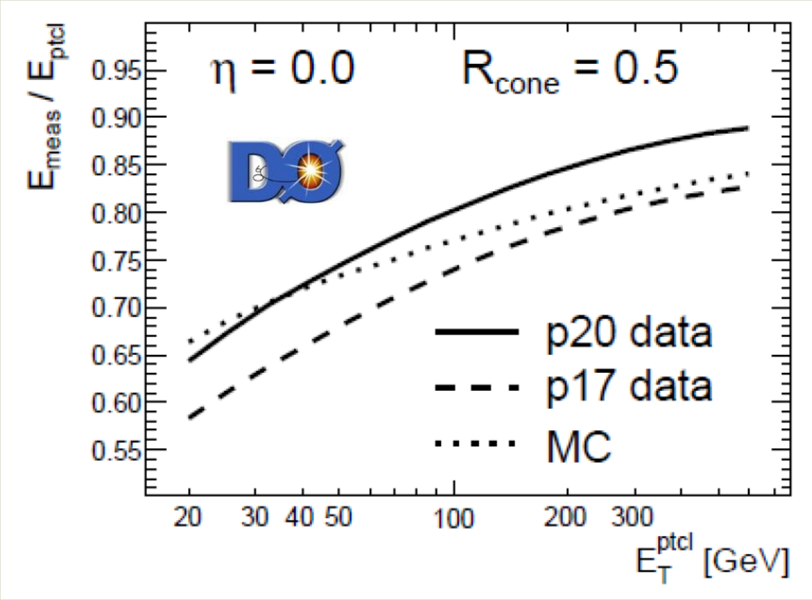
$p_T^{jj} > 40$ GeV, $\left|\Delta\eta^{jj}\right| < 2.5$
$\Delta\phi > 0.4$ missing E_T and high p_T jet
Exactly 2 good jets

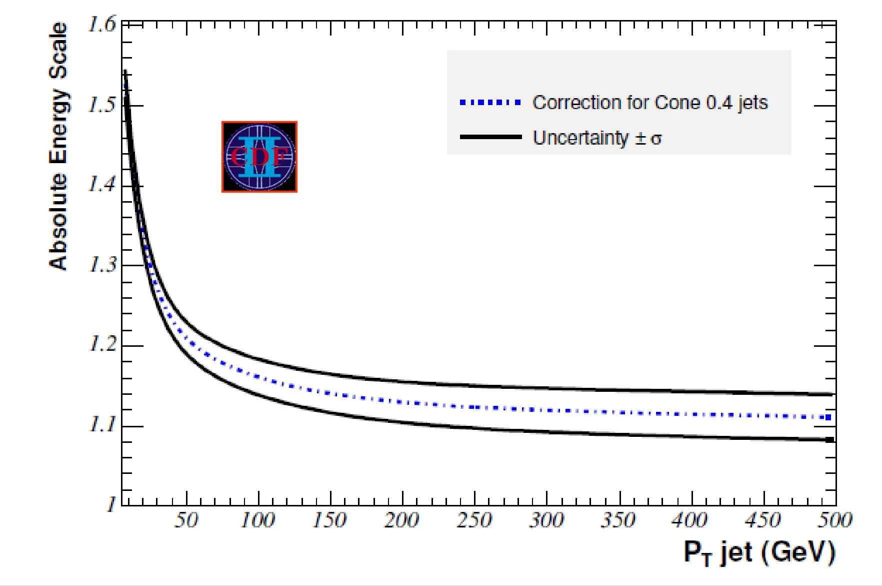
$p_T > 30$ GeV
$|\eta| < 2.4$
Jets with μ or e $R < 0.52$ removed
$p_T^{jj} > 40$ GeV, $\left|\Delta\eta^{jj}\right| < 2.5$
$\Delta\phi > 0.4$ missing E_T and high p_T jet
Exactly 2 good jets

JET ENERGY SCALE

Both use $\gamma + jets$ and dijet events

Correct for response, out of cone showering, overlap/pileup



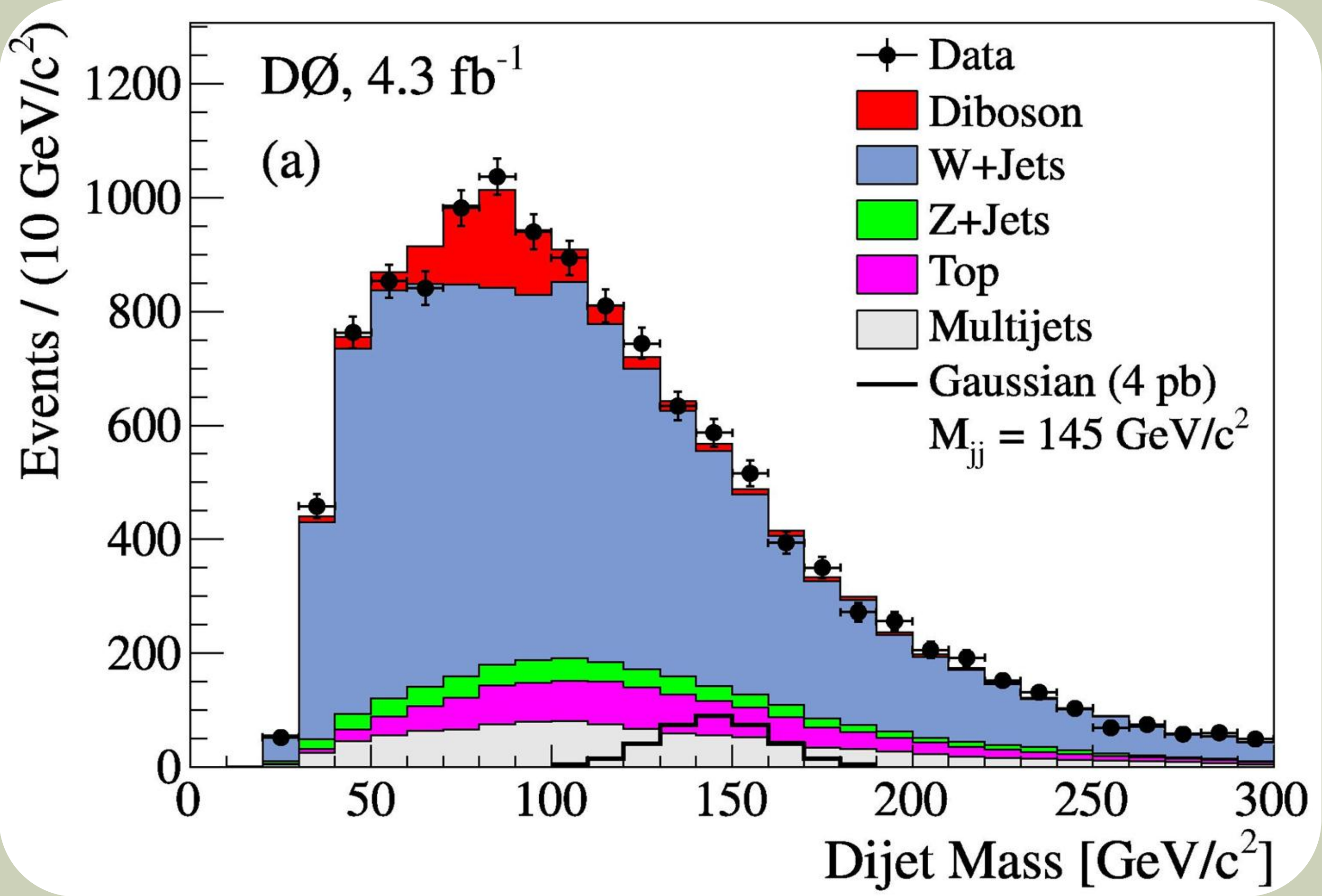


J. BackusMayes Thesis

V. Cavaliere Thesis

Corrections similar in size

M_{JJ}


DØ, 4.3 fb^{-1}
(a)
Data
Diboson
W+Jets
Z+Jets
Top
Multijets
Gaussian (4 pb)
M_{jj} = 145 GeV/c^2
Events / (10 GeV/c^2)
0
200
400
600
800
1000
1200
0
50
100
150
200
250
300
Dijet Mass [GeV/c^2]

MODELING THE SM BACKGROUND

Background Shapes

- Diboson: WW, WZ, ZZ
- Single Top
- $t\bar{t}$
- W+Jets, Z+Jets

Monte Carlo Based

- QCD Multijet

Data Driven

Background Normalization

- Diboson: WW, WZ, ZZ
- Single Top
- $t\bar{t}$
- Z+Jets

Theory NLO or NNLO cross sections

- W+Jets
- QCD Multijet

Fit to data

GENERATORS

Pythia: WW, WZ, ZZ
COMPHEP: Single Top
ALPGEN + Pythia: $t\bar{t}$, W+Jets, Z+Jets

CDF:
- Pythia: WW, WZ, ZZ, $t\bar{t}$, single top
- ALPGEN+Pythia: W+Jets, Z+Jets

	DØ	CDF
PDF Set	CTEQ6L1	CTEQ5L
Pythia	6.409	6.326
Pythia Tune	DØ Tune A (tune A, PDF corrected)	Tune A
ALPGEN	V2.11_wcfix	V2.1

Private GEANT3 based detector models + reconstruction software!

Our handling of systematic errors for the generators is almost certainly different as well.

REWEIGHTINGS

Luminosity Profile
Interaction Region Profile

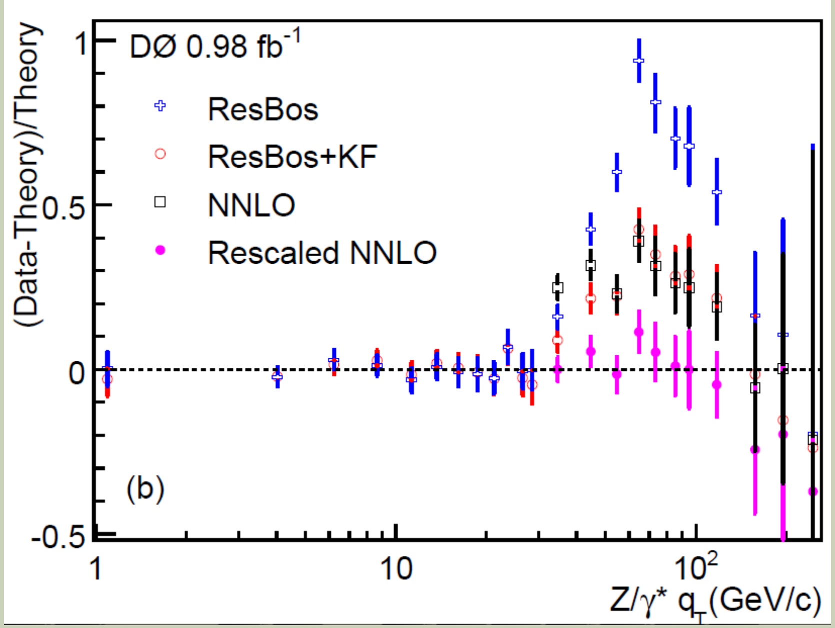
Detector Based Reweighting's

Z p_T reweighting

We checked does not affect the dijet mass distribution

Also correct MC for object ID

e.g. jet finding efficiency is too good

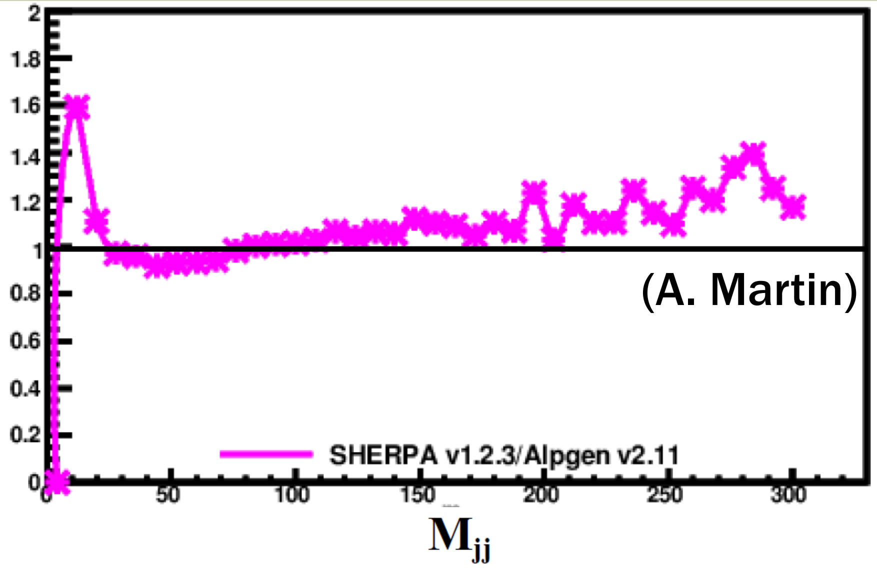


arXiv:0712.0803

GETTING W+JETS RIGHT

We have found region of low $p_T(W)$ badly modeled.

Jet η, $p_T(W)$, $\Delta R(j_1, j_2)$



(A. Martin)

However, CDF cuts mostly eliminate that region

No Other Reweightings Applied

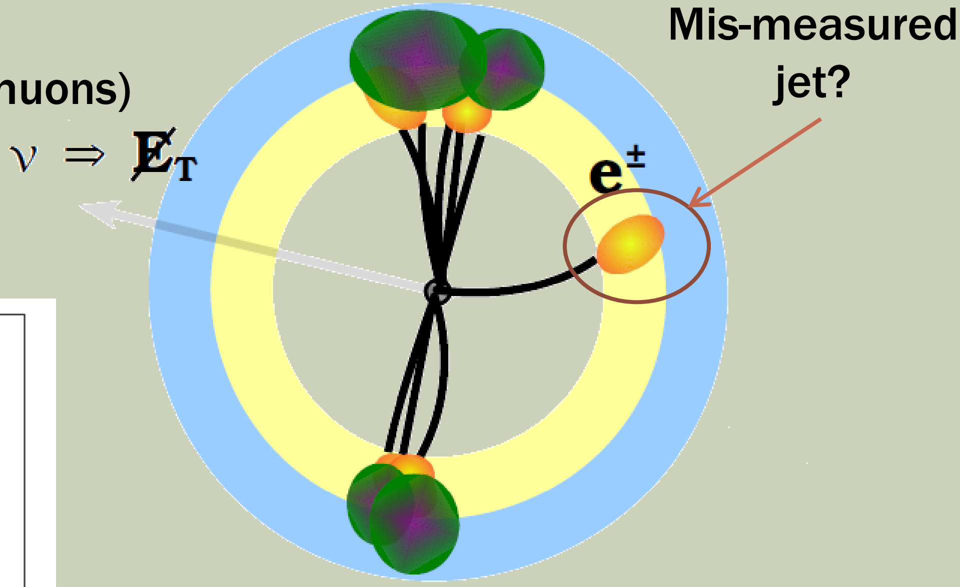
But we take expected differences into account as uncertainties

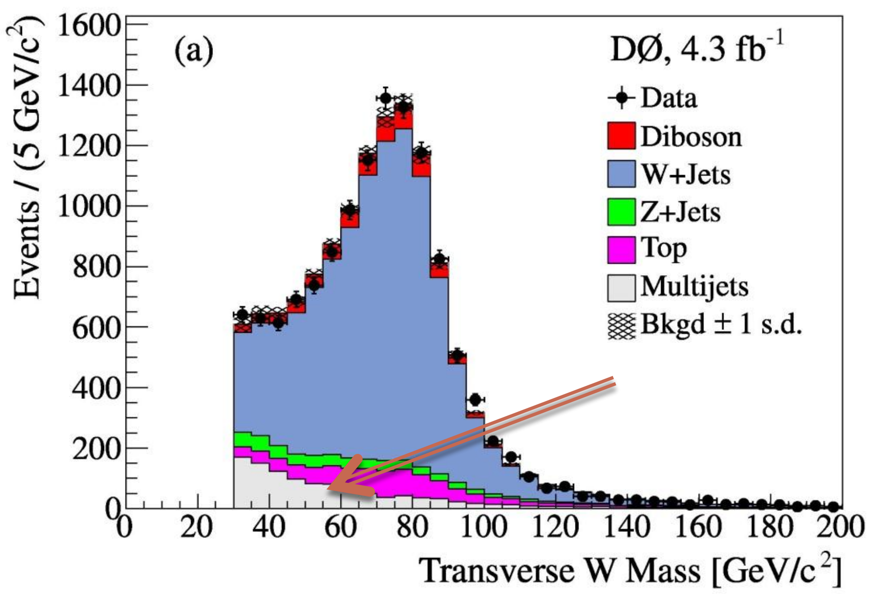
We also cross-checked the effect of the reweightings on M_{jj} as well as completing the complete analysis with and without these reweightings.

QCD MULTIJET BACKGROUND

Includes all manner of sins

- Jets faking a lepton (electrons)
- Heavy Flavor not removed otherwise (muons)
- Instrumental Backgrounds





Difficult to simulate

⇩

Data Driven

QCD SIDEBAND SAMPLES

Muons

- DØ: Reverse the μ isolation cut
- CDF: Reverse the μ isolation cut

Electrons

- DØ: Matrix Method (remove EM shower shape cuts)
- CDF: Anti-select on electron quality variables (low statistics issue)

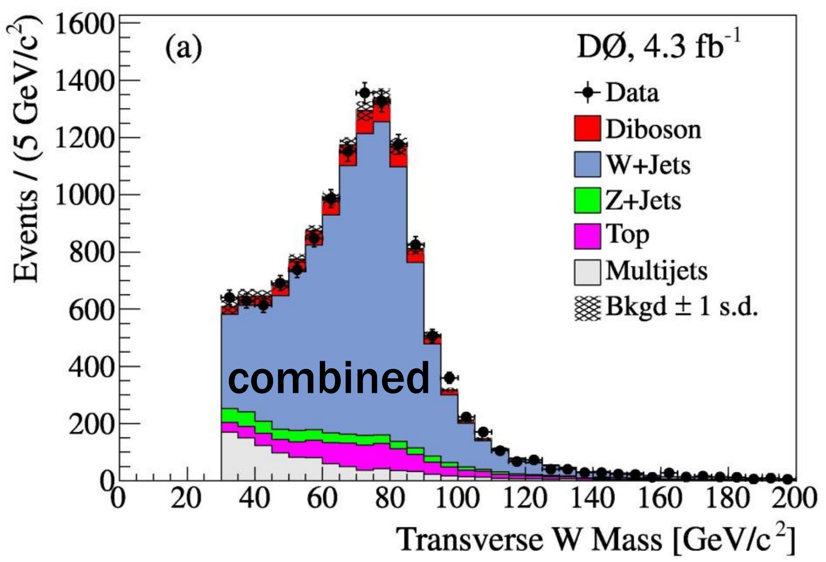
Gives us the shape (template) of the QCD multijet background

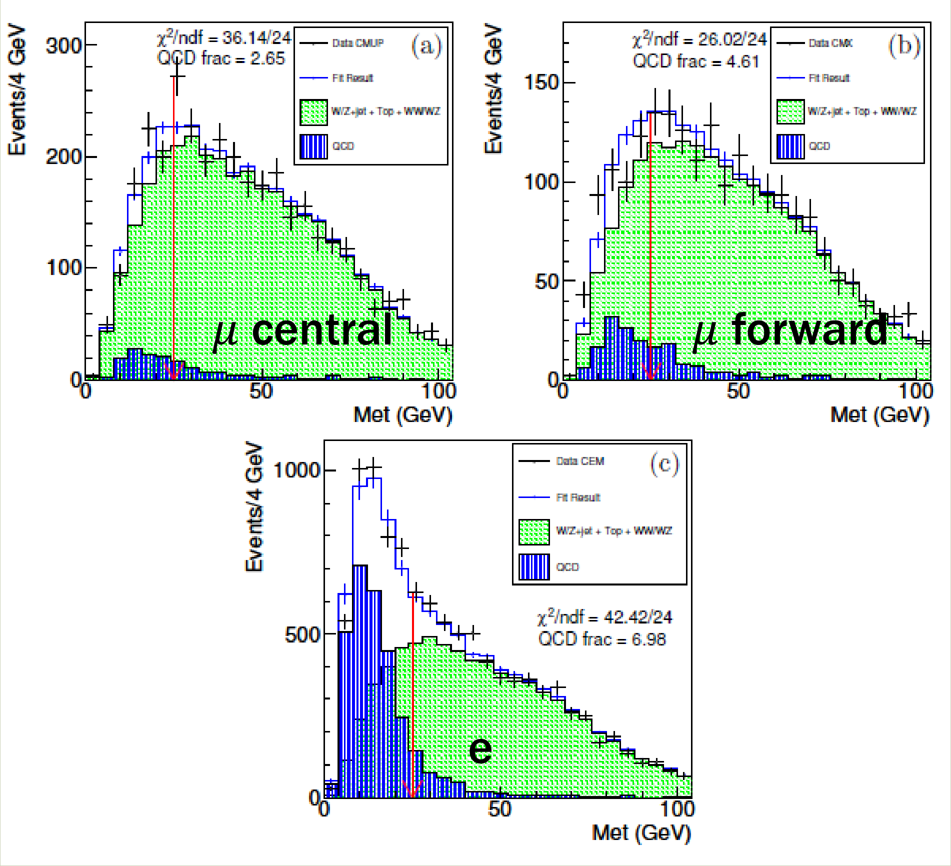
Overall shape and normalization:

- DØ: Fits the M_T^W distribution
- CDF: Fits the missing E_T distribution (release cut first!)

DØ explicitly removes W+Jets contributions from their QCD templates. CDF probably does, but couldn't find a reference.

NORMALIZATION FITS





Let both the W+jets and the QCD multijet background float

(taken from V. Cavaliere’s thesis, but referenced in CDF PRL)

Hypocrite!

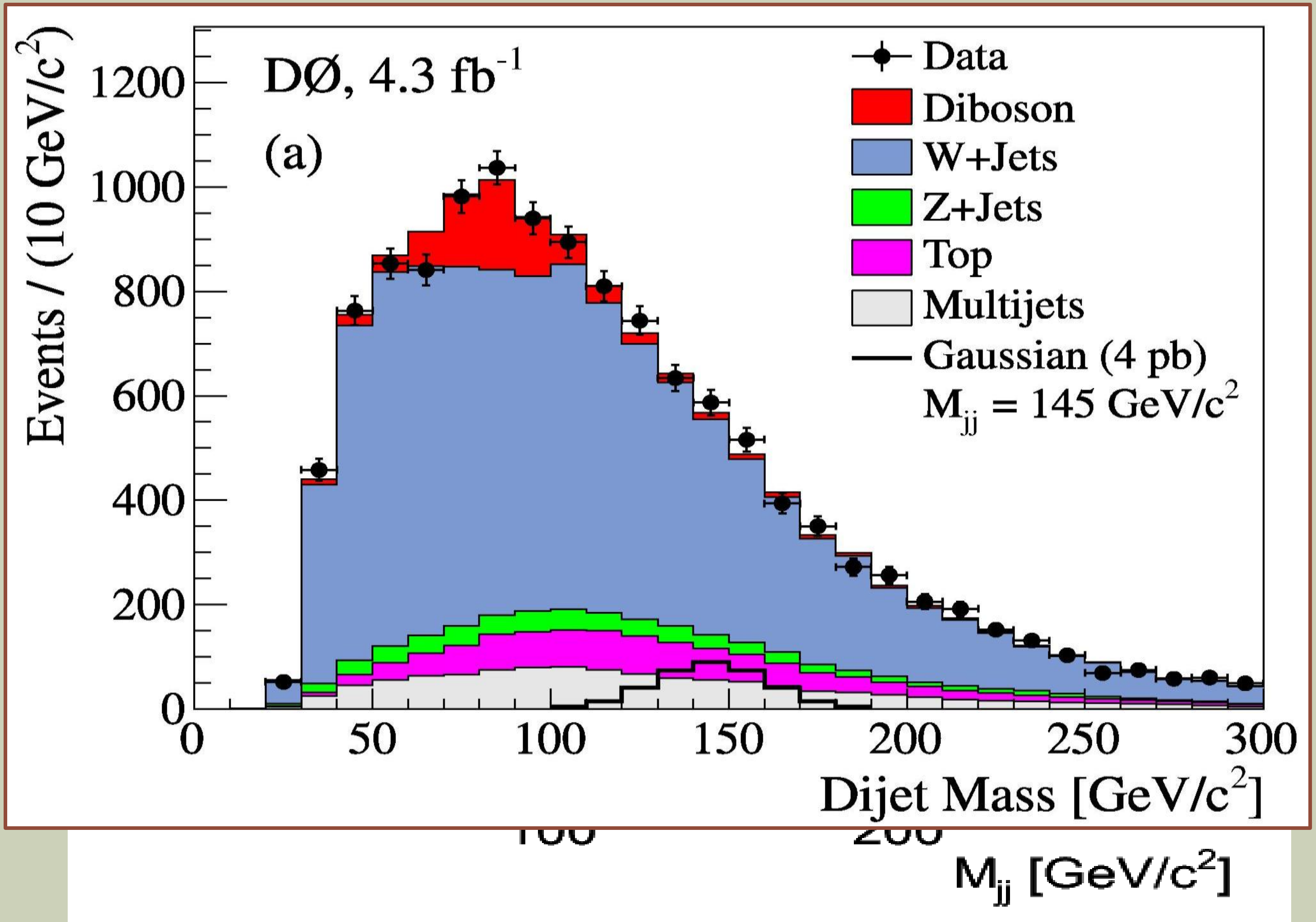
FINAL BACKGROUND TALLY

Ele Channel	DØ	V. Cavaliere
W+Jets	5620 ± 500	4719 ± 141
Z+Jets	180 ± 42	92 ± 11
Diboson	434 ± 38	403 ± 24
Top	600 ± 69	366 ± 37
QCD	932 ± 230	394 ± 98
Data	7763	5859

Muon Channel	DØ	V. Cavaliere
W+Jets	3850 ± 290	3341 ± 100
Z+Jets	350 ± 60	162 ± 19
Diboson	304 ± 25	301 ± 18
Top	363 ± 39	275 ± 28
QCD	151 ± 69	117 ± 29
Data	5026	4137

- Both analyses use $4.3\ fb^{-1}$
- Absolute yield larger @ DØ
- Fractionally, 20% better diboson yield for Cavaliere
- Fractionally, W+jets/Z+Jets same within 10%
- QCD has dramatic differences in yield (fractionally 30%-50%)
- Muon QCD error 50% of DZEROs (electron the same)

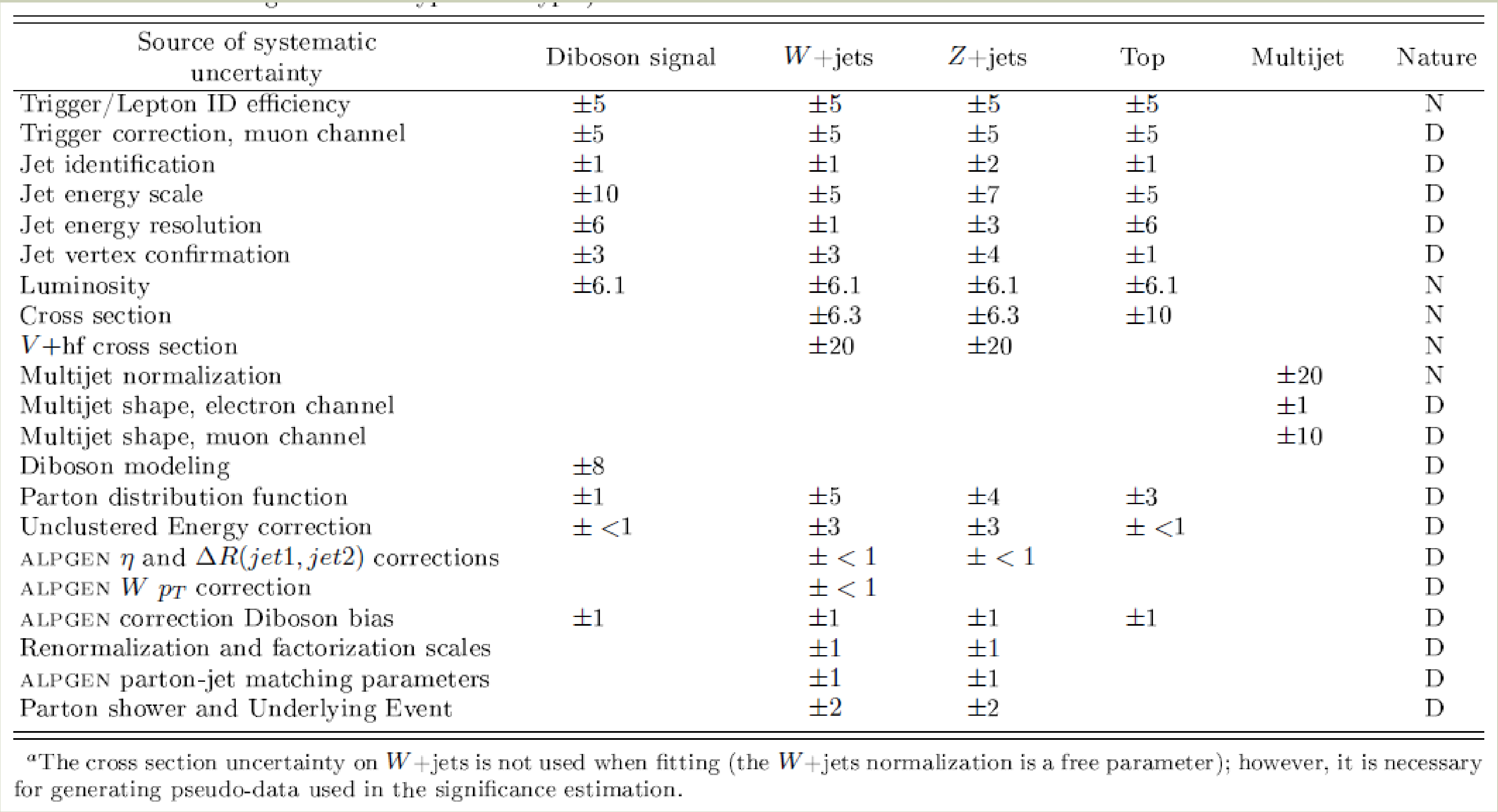
QCD COMPARISON



J. Wacker had this idea originally, G. Brooijmans improved upon it

“Same Cuts”

SYSTEMATIC UNCERTAINTIES



Source of systematic uncertainty	Diboson signal	W+jets	Z+jets	Top	Multijet	Nature
Trigger/Lepton ID efficiency	±5	±5	±5	±5		N
Trigger correction, muon channel	±5	±5	±5	±5		D
Jet identification	±1	±1	±2	±1		D
Jet energy scale	±10	±5	±7	±5		D
Jet energy resolution	±6	±1	±3	±6		D
Jet vertex confirmation	±3	±3	±4	±1		D
Luminosity	±6.1	±6.1	±6.1	±6.1		N
Cross section		±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 correction		$\pm < 1$				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		±2	±2			D

[a] The cross section uncertainty on W+jets is not used when fitting (the W+jets normalization is a free parameter); however, it is necessary for generating pseudo-data used in the significance estimation.

DOES OUR BACKGROUND MODEL WORK?

Fit the dijet mass distribution

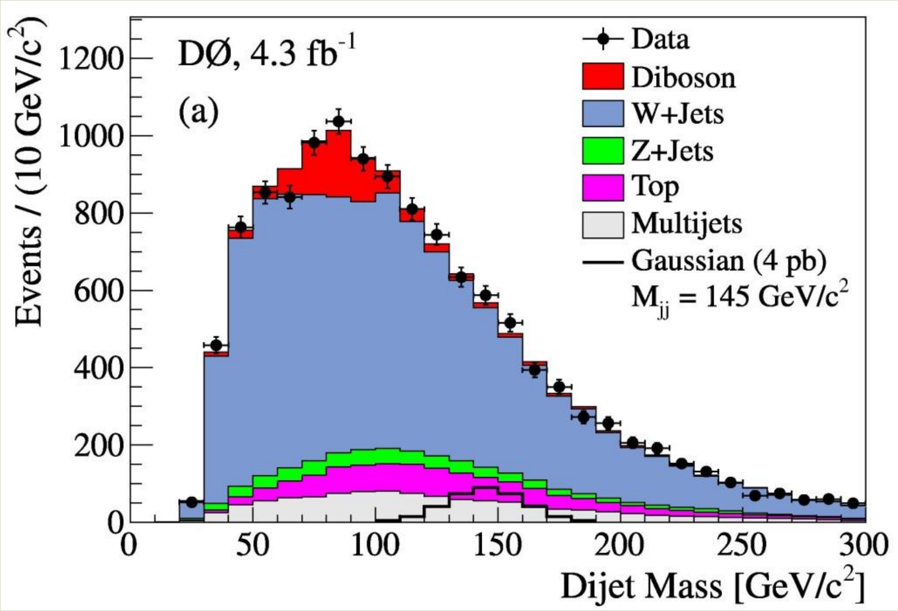
$$\chi^2(\theta, S, B; D) = 2\sum_{i=0}^{N_{bins}} \underbrace{(B_i + S_i - D_i)}_{} - D_i \ln\left(\frac{B_i + S_i}{D_i}\right) + \underbrace{\sum_{k=0}^{N_{sys}} \theta_k^2}_{}$$

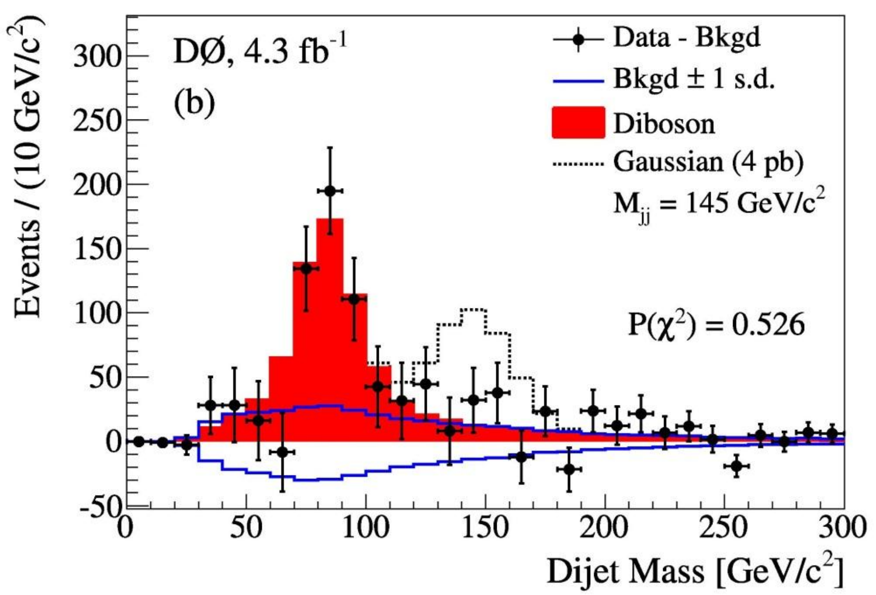
Background, Signal, and observed Data

θ_k is # of standard deviations systematic k has been pulled from nominal. Allows templates to vary with Gaussian prior.

The W+Jets and diboson cross sections are allowed to float for this fit (no θ_k).

DOES OUR BACKGROUND MODEL WORK?





COULD WE HAVE MISSED IT?

Dijet mass fit, with a $WX \to l\nu jj$ template, and set a limit

Narrow Bump @ Experimental Resolution

Simple mass scaling:

$$\sigma_{jj} = \sigma_{W\to jj} \times \sqrt{M_{jj}/M_{W\to jj}}$$

At 145 GeV, $\sigma_{jj} = 15.7$ GeV

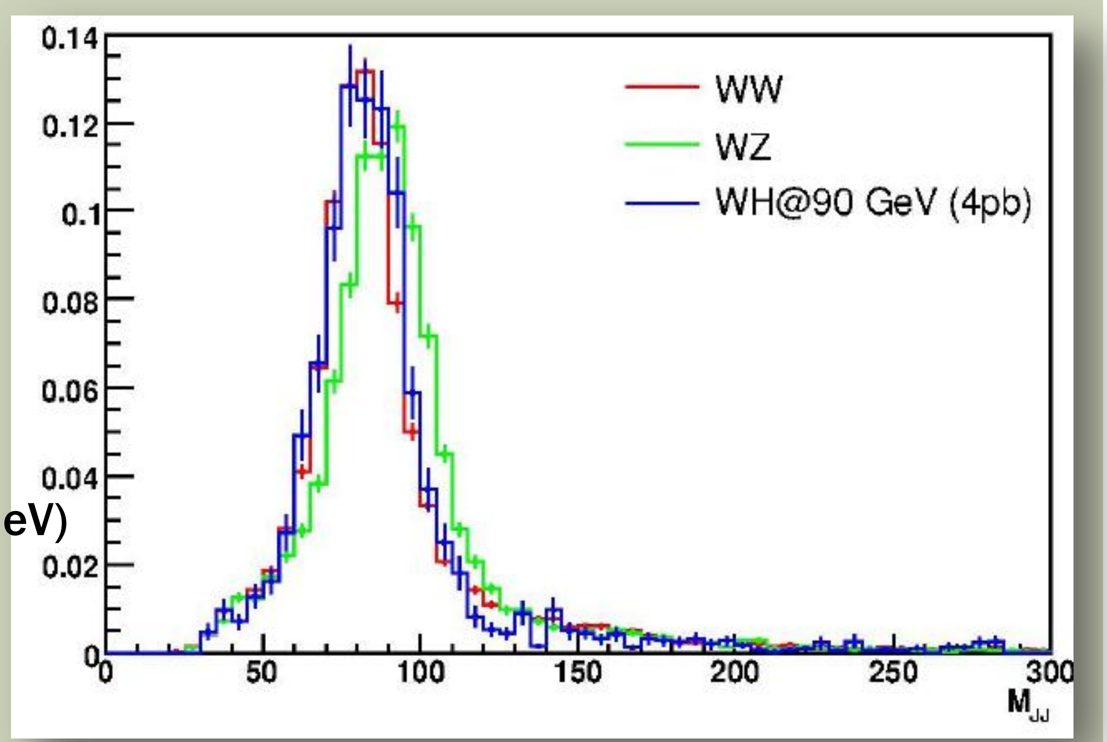
Cross Section

$BR(X \to jj) = 1.0$

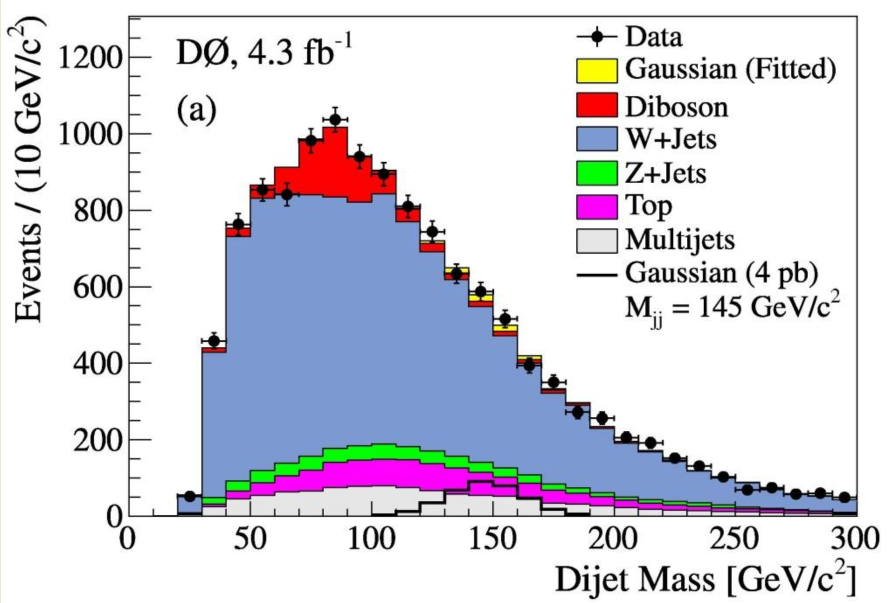
Efficiency from WH ($M_H = 150$ GeV)

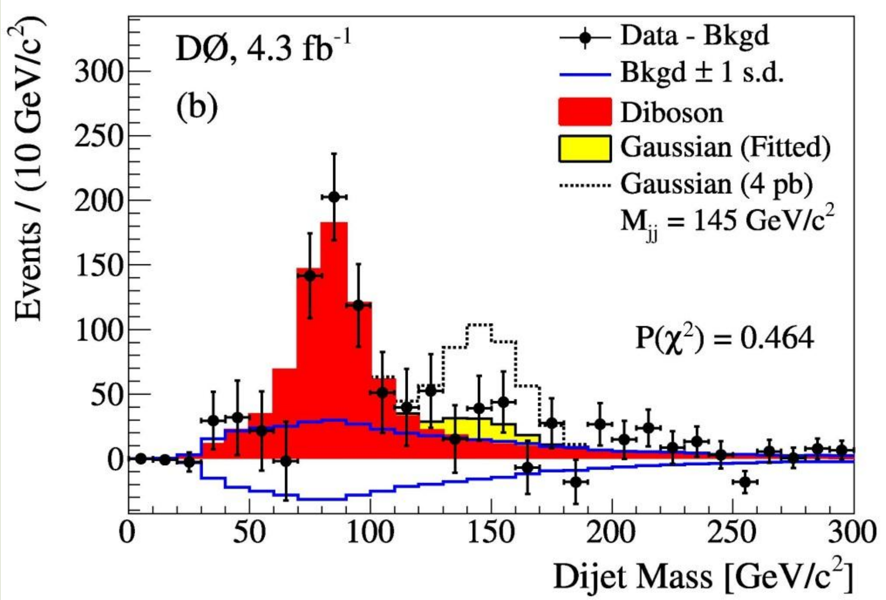
JES (changes mean by $\pm 1.5\%$)

JER (norm by 5%, width by 3%)



FIT WITH $WX \rightarrow l\nu jj$ TEMPLATE





LIMIT SETTING

If we re-ran the experiment many times, how often would we see a “real” excess?

Frequentist

Generate ensembles of pseudo-experiments
Allow statistical and systematic fluctuations

Re-run the dijet mass fit

$$LLR = -2\log\left(\frac{P(D;S+B)}{P(D;B)}\right) = \chi^2(D|S+B) - \chi^2(D|B)$$

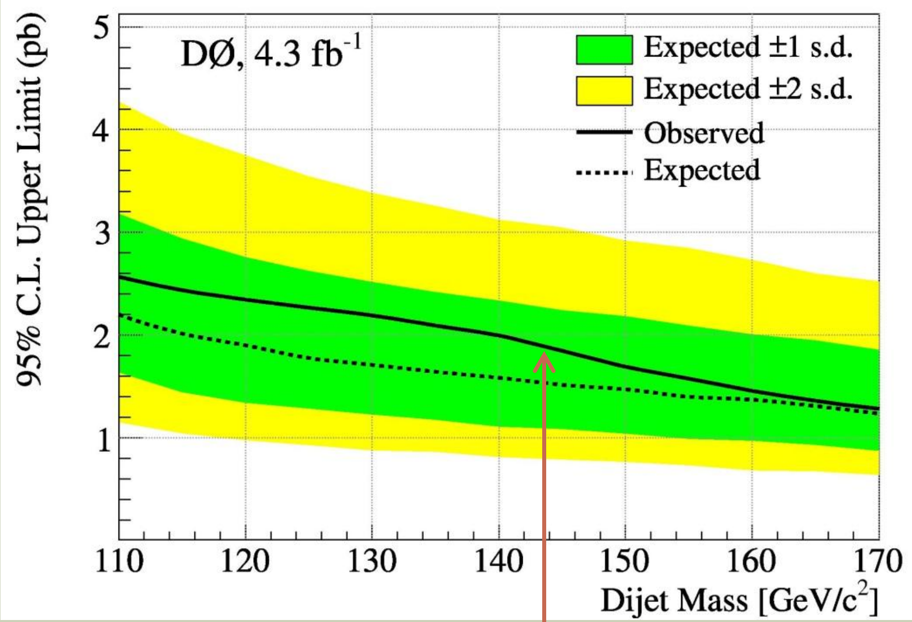
Signal+Background Model

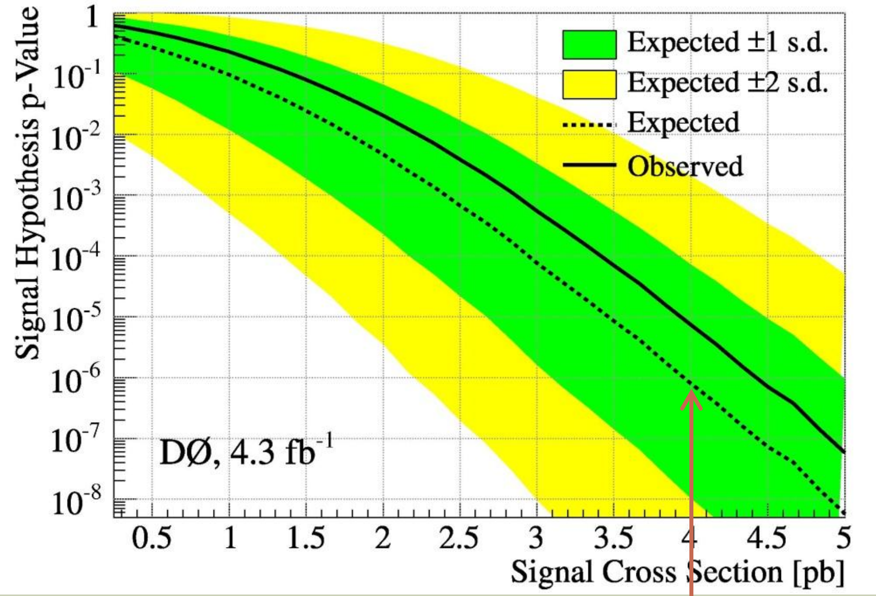
Background Model

Turn the LLR probability distributions into straight limits (95% CL).

D – Observed Events
S – Expected Signal
B – Expected Background

LIMIT



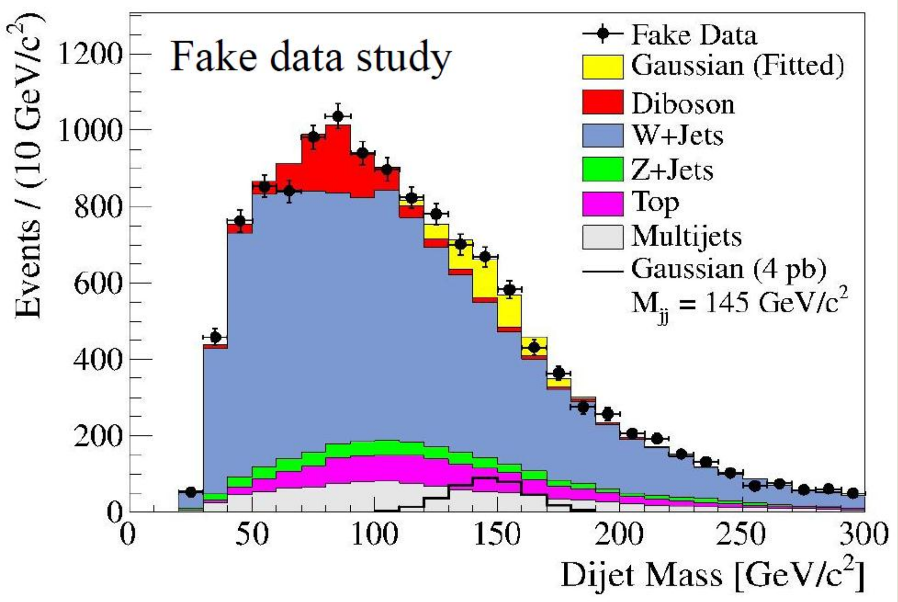


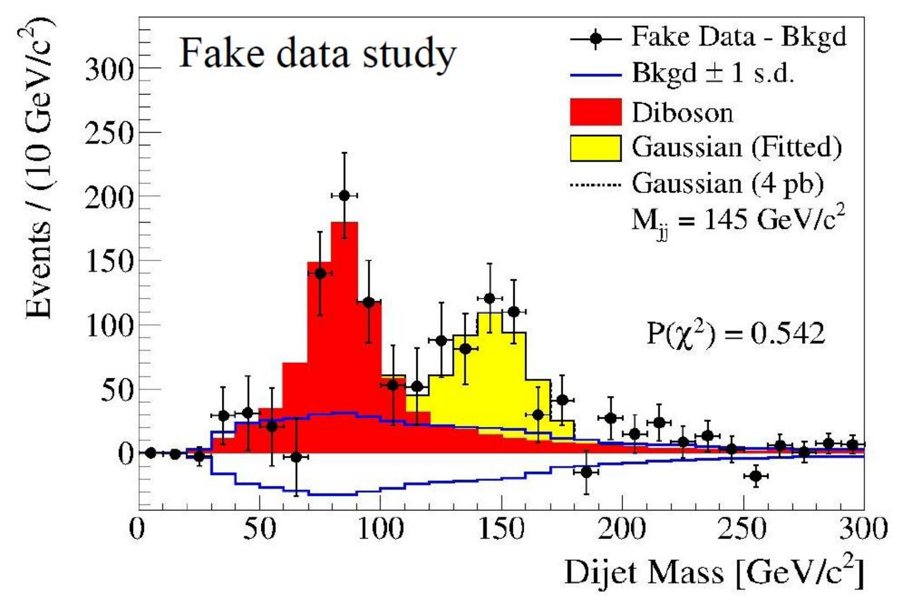
Rule out $1.9\ pb^{-1}$ or larger @ 95% CL

Rule out $4\ pb^{-1}$ or larger @ 4σ (99.9999%)

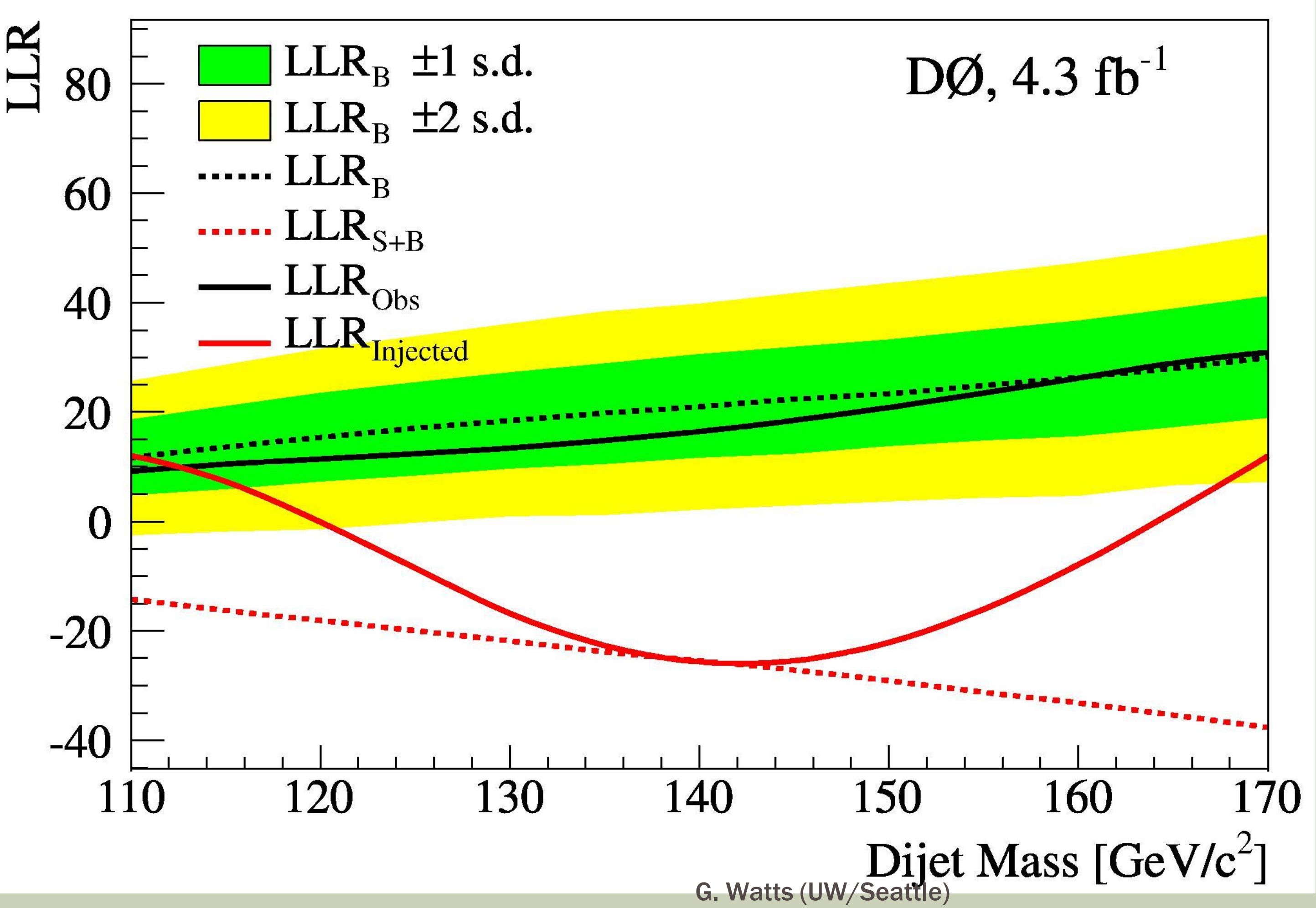
MOCK THE SIGNAL

Use the data plus the WX template
Use the CDF $4\ pb^{-1}$ cross section





LLR PLOT



There is no way we would have missed a $4\ pb^{-1}$ signal!

WHAT ABOUT THE LHC?

WHAT COULD IT BE?

- Gauged Baryon and Lepton Number in MSSM_4 Brane Worlds
- A two-Higgs-doublet interpretation of a small Tevatron Wjj excess
- Subjects: High Energy Physics - Phenomenology (hep-ph)
- Chiral Quirkonium Decays
- Subjects: High Energy Physics - Phenomenology (hep-ph)
- Top condensation as a motivated explanation of the top forward-backward asymmetry
- Quirks at the Tevatron and Beyond
- Hermitian Flavor Violation
- A Higgsophilic s-channel Z' and the CDF W+2J Anomaly
- Dissecting the Wjj Anomaly: Diagnostic Tests of a Leptophobic Z'
- Theory and phenomenology of two-Higgs-doublet models
- Deriving the mass of particles from Extended Theories of Gravity in LHC era
- Direct detection and CMB constraints on light DM scenario of top quark asymmetry and dijet excess at Tevatron
- Measurements of top quark properties at the Tevatron collider
- Production of Charged Higgs Bosons in a 3-3-1 Model at the CERN LHC
- NLO predictions for a lepton, missing transverse momentum and dijets at the Tevatron
- An Explanation of the CDF Dijet Anomaly within a $U(1)_X$ Stueckelberg Extension
- Experimental proposal to study the excess at Mjj=150 GeV presented by CDF at Fermilab
- A light charged Higgs boson in two-Higgs doublet model for CDF Wjj anomaly
- Colored Scalars And The CDF $W+$dijet Excess
- A Scalar Doublet at the Tevatron?
- Reconciling anomalous measurements in $B_s-\bar{B}_s$ mixing: the role of CPT-conserving and CPT-violating new physics
- Dijet Signature of Low Mass Strings in the Early LHC Data
- The Prediction and Evidence for a New Particle - antiparticle Force and Intermediary Particle
- Color-Octet-Electroweak-Doublet Scalars and the CDF Dijet Anomaly
- Impact of extra particles on indirect Z' limits
- Z' from SU(6)$\times$SU(2)_h GUT, Wjj anomaly and Higgs boson mass bound
- Spontaneous Parity Violation in SUSY Strong Gauge Theory
- Anomaly Puzzle, Curved-Spacetime Spinor Hamiltonian, and
- String Phenomenology
- Dimuon CP Asymmetry in B Decays and Wjj Excess in Two Higgs Doublet Models
- Top quark asymmetry and Wjj excess at CDF from gauged flavor symmetry
- W plus two jets from a quasi-inert Higgs doublet
- Tevatron Signal for an Unmixed Radion
- The New Dijet Particle in the Tevatron IS the Higgs
- The CDF dijet excess and Z'_{cs} coupled to the second generation quarks
- A Possible Common Origin of the Top Forward-backward Asymmetry and the CDF Dijet Resonance
- An Effective Z'
- W+Jets at CDF: Evidence for Top Quarks
- Dijet resonance from leptophobic Z' and light baryonic cold dark matter
- Standard model explanation of a CDF dijet excess in Wjj
- B physics constraints on a flavor symmetric scalar model to account for the ttbar asymmetry and Wjj excess at CDF
- Dark Forces At The Tevatron
- Top quark asymmetry and dijet resonances
- Twelve massless flavors and three colors below the conformal window
- ~115 GeV and ~143 GeV Higgs mass considerations within the Composite Particles Model
- Weak-triplet, color-octet scalars and the CDF dijet excess
- Stringy origin of Tevatron Wjj anomaly
- A unified, flavor symmetric explanation for the t-tbar asymmetry and Wjj excess at CDF
- A Possible Interpretation of CDF Dijet Mass Anomaly and its Realization in Supersymmetry
- New Color-Octet Vector Boson Revisit
- The CDF dijet excess from intrinsic quarks
- No like-sign tops at Tevatron: Constraints on extended models and implications for the t tbar asymmetry
- Baryonic Z' Explanation for the CDF Wjj Excess
- $\mathscr{O}(100 GeV)$ Deci-weak $W^\prime/Z^\prime$ at Tevatron and LHC
- Signatures of Resonant Super-Partner Production with Charged-Current Decays
- Technicolor at the Tevatron
- A Z' Model for the CDF Dijet Anomaly
- Light Z' Bosons at the Tevatron
- Forward-Backward t tbar Asymmetry from Anomalous Stop Pair Production
- Searching for string resonances in e^+e^- and γγcollisions

LHC Implications

$p\bar{p}$ vs $p\bar{p}$ interaction

To have the LHC weight in we need a production mechanism

Can Search Fo

But we really need to wait for a $WW + WZ \to l\nu jj$ search at the LHC!

A unified, fla ymmetry and

We pre el
with a f ward-
backwa dijet
mass d GeV
that wa

Fi ckward
asym quark
with s nd as a
result, we expect to see larger t-$\bar{t}$ production cross section
that in the SM at high values of the invariant mass of the
t-$\bar{t}$ pairs. This would certainly be an interesting feature
to observe at the LHC.

CONCLUSIONS

- With out DØ's normal reweightings, rule out CDF bump of $1.9\ pb$, with reweightings it is $1.5\ pb$
- Very hard to make the two experiments compatible
  - CDF had a huge upwards fluctuation
  - And DØ was very unlucky
- Someone goofed??? ☺
  - Both CDF and DØ have done lots of cross checks
  - See CDF's recent update for answers to many initial questions
- There is now a task force trying to sort out the differences between the analyses
  - Officially composed of theorist Estia Eichten and Keith Ellis and members of both experiments
  - Meetings already have started
- This analysis is very similar to a low-mass Higgs analysis
  - Would be useful to compare background estimation techniques
- The next 6 months should be fun (for this an other reasons)