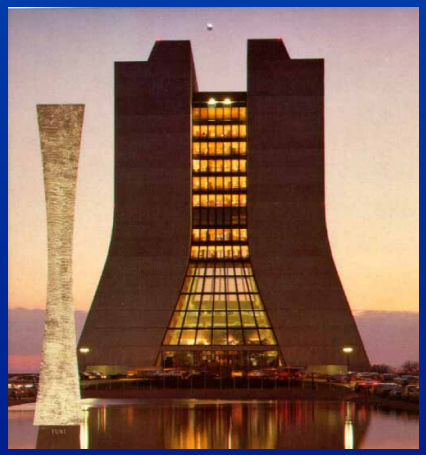
What's New in New Phenomena at DØ?

Todd Adams
Florida State University
for the DØ Collaboration

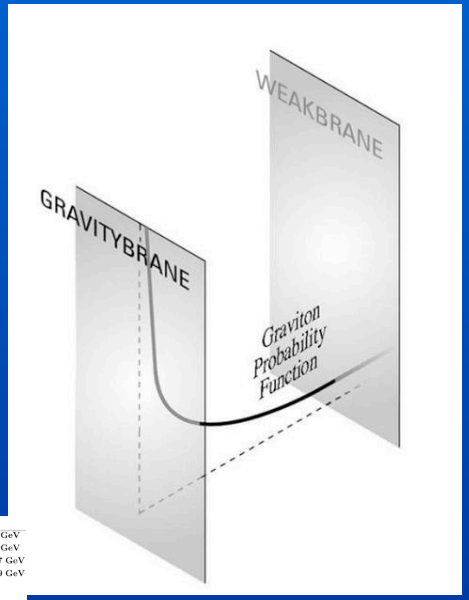


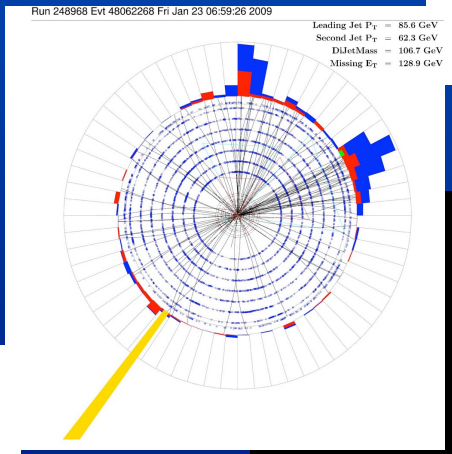
Fermilab Joint Experimental-Theoretical Physics Seminar

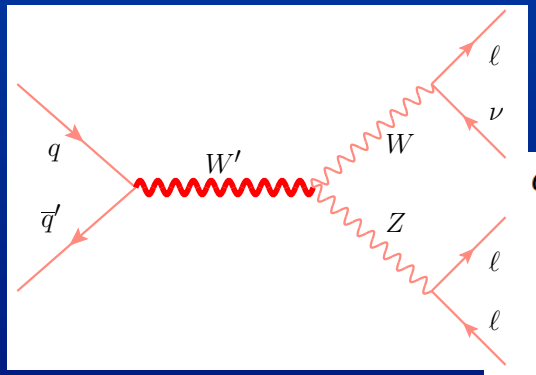
April 23, 2010

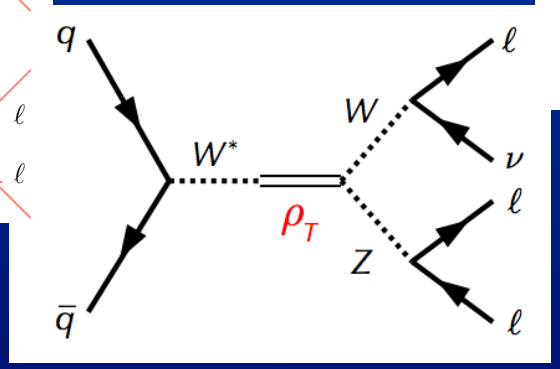
Outline

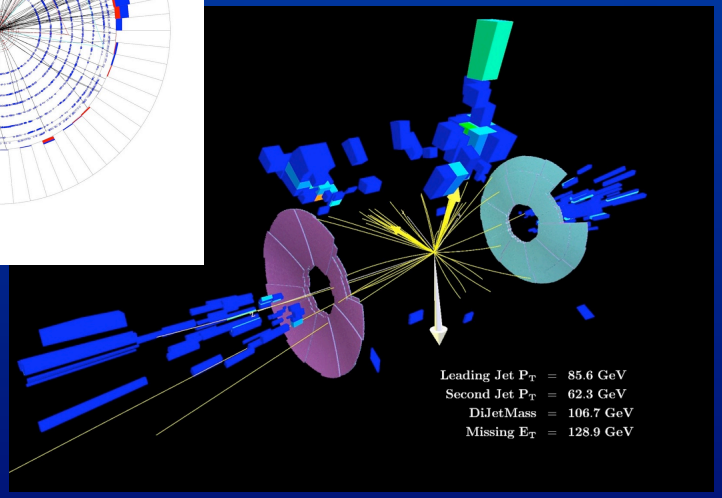
- Introduction
- W′ → WZ → 3l+ν and Technicolor
- Randall-Sundrum Gravitons
- Sbottom and
  3rd Generation Leptoquark
- Conclusions











Many interesting questions

- Why is the electroweak scale so different than the Planck scale?

or

- Why is gravity so much weaker than the other forces?

Commonly referred to as the Hierarchy Problem

- Many possible solutions to this and other interesting questions the standard model does not address

Lots of Ideas

Supersymmetry

Grand unified theories

little Higgs

Standard Model

???

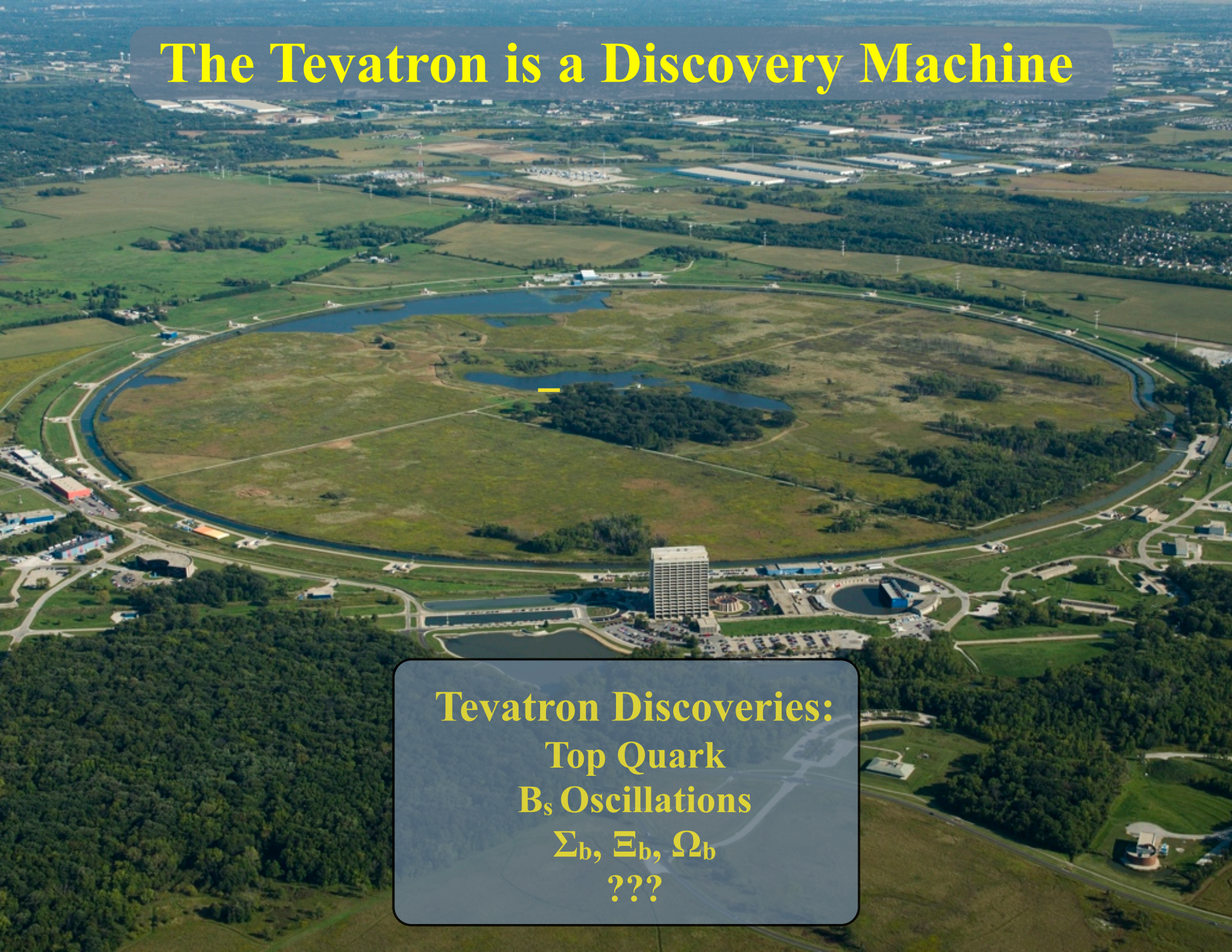
Extra dimensions (large, universal, warped, etc)

String theory

Technicolor

Need experimental evidence!!!

The Tevatron is a Discovery Machine



Tevatron Discoveries:

Top Quark

B_s Oscillations

Σ_b, Ξ_b, Ω_b

???

Lots of Data

e+e
e+μ
e+μ+2b+2ν
μ+μ
e+2μ+ν
μ+j+ν
e+j
e+μ+j
e+2τ+2b+3ν
2e+3j
3e+3ν+j
2μ+2τ+j
2μ+2b
e+τ+2j
e+2τ+ν+j
μ+τ+2b
2μ+2j+2ν
τ+τ
2e+τ+2ν+2j
2b+4j
e+2j+ν
2τ+2b
2τ+2j+ν
e+μ+τ+3ν
2b+2ν
γ+e+ν
γ+μ+ν+2j
γ+τ+ν
4j+ν
2b+2j
γ+2e+ν
γ+c+ν
γ+γ
γ+b+2j
j+ν
γ+ν
2γ+2j
2γ+2μ+3j
j+j

Today's Final States

e+μ

e+e

2e+μ+ν

e+μ+2b+2ν

e+2μ+ν

μ+μ

μ+j+ν

e+j

e+μ+j

e+2τ+2b+3ν

2μ+2b

2e+3j

3e+ν

2μ+2τ+j

3μ+ν

e+τ+2j

e+2τ+ν+j

2μ+2j+2ν

μ+τ+2b

3e+3ν+j

τ+τ

2e+τ+2ν+2j

2b+4j

e+2j+ν

2τ+2b

2τ+2j+ν

2b+2ν

e+μ+τ+3ν

γ+e+ν

γ+μ+ν+2j

γ+τ+ν

4j+ν

2b+2j

γ+2e+ν

γ+c+ν

γ+γ

γ+b+2j

j+ν

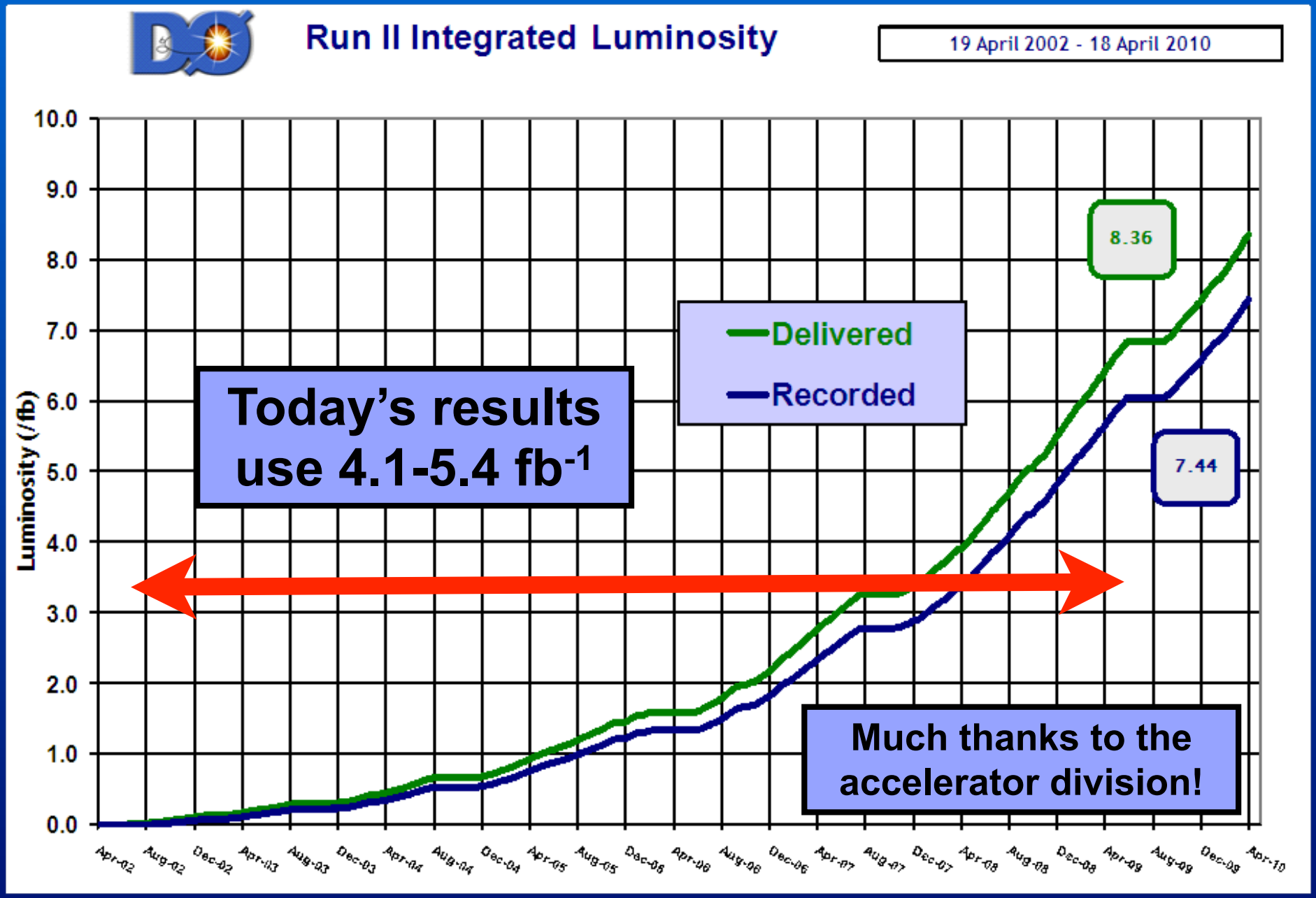
γ+ν

2γ+2j

2γ+2μ+3j

j+j

Luminosity


Run II Integrated Luminosity
19 April 2002 - 18 April 2010
Luminosity (/fb)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Delivered
Recorded
8.36
7.44
Today's results use 4.1-5.4 fb-1
Much thanks to the accelerator division!
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
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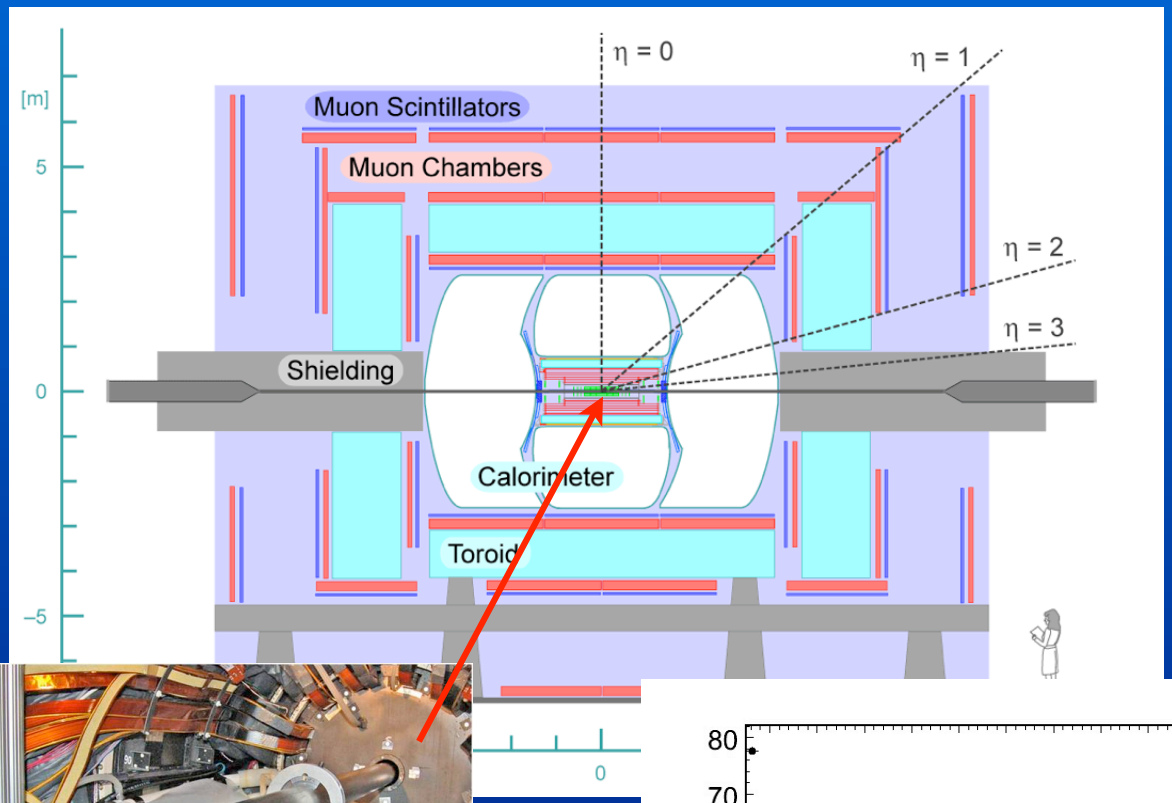
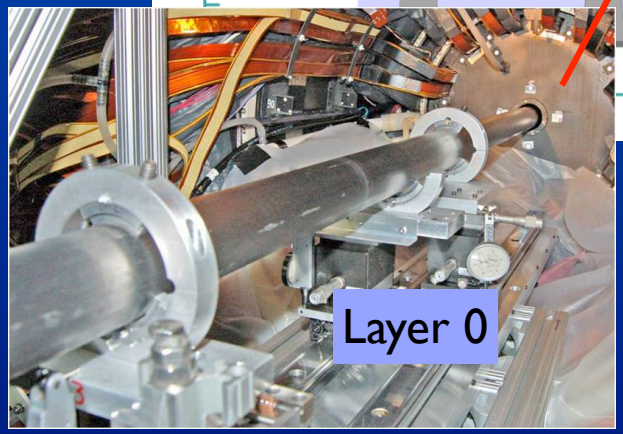
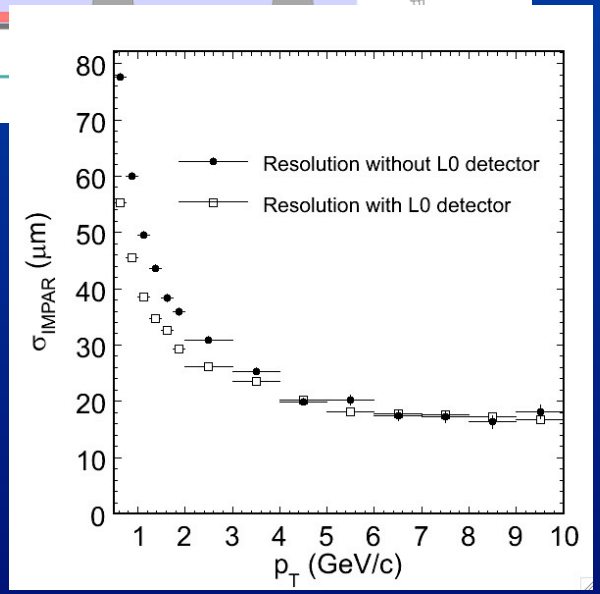
Dec-09
Apr-10

DØ Detector



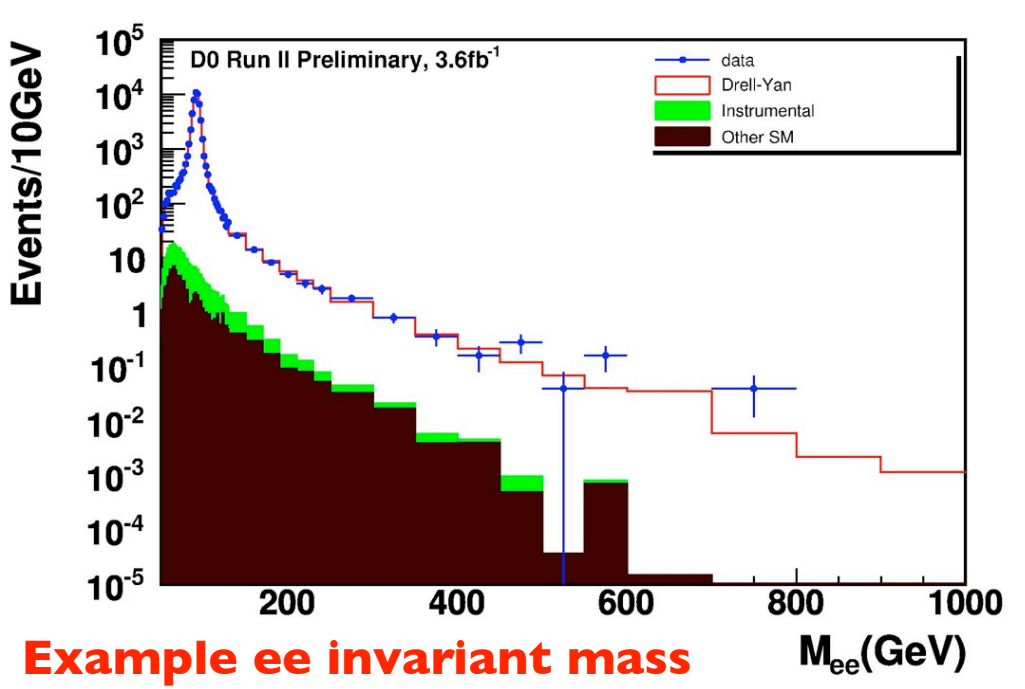




- electrons
- muons
- taus
- photons
- jets
- heavy quarks
- missing transverse energy (MET)

Resonance Searches

- Basic (simplest) strategy
  1. Understand object identification
  2. Optimize selection
  3. Plot invariant mass
  4. Look for new "bump"



Example ee invariant mass

- As we will see,
  - generally more complicated than this
  - more advanced strategies can be employed
- Detector resolution important for narrow states
- Sensitivity depends on energy available and branching ratios

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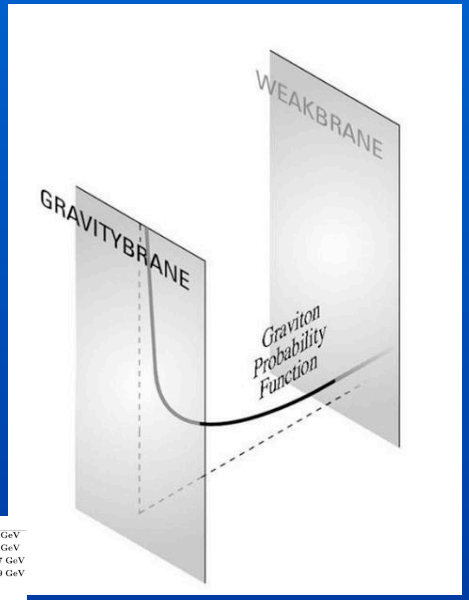
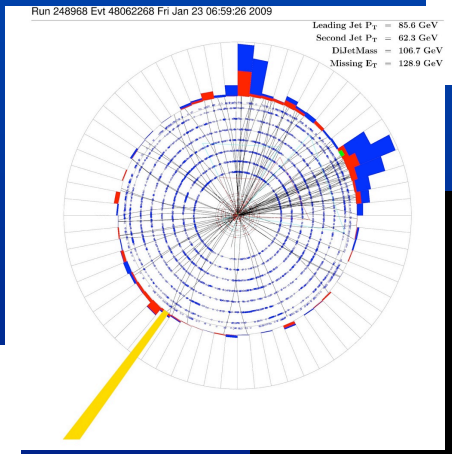
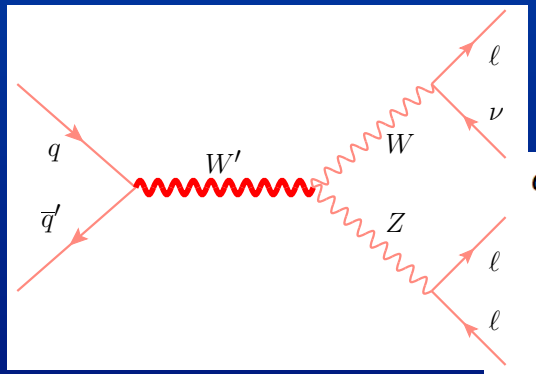
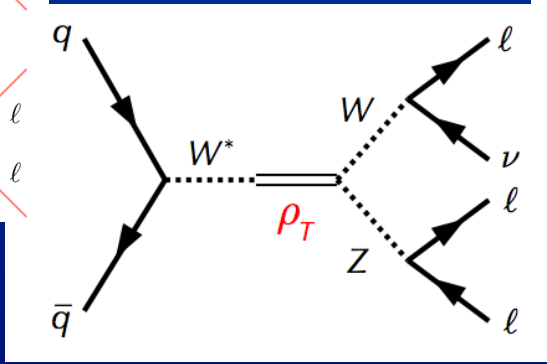
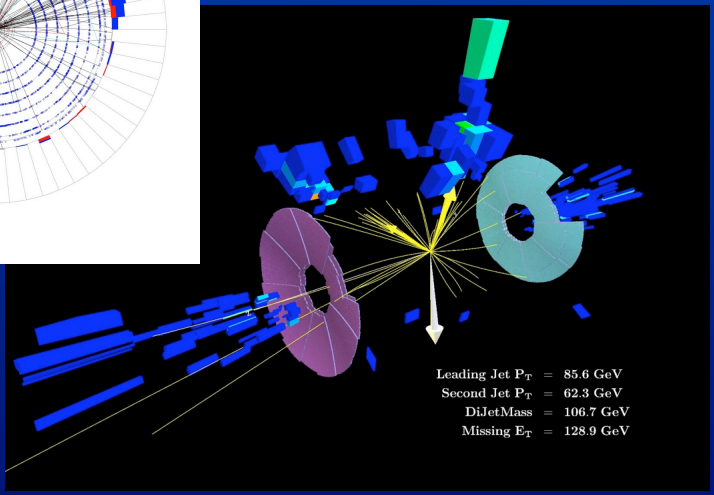










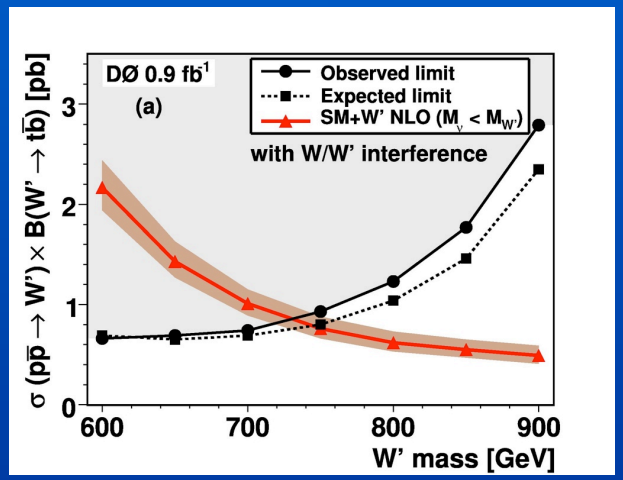
W′ Introduction

- Many theories predict additional heavy gauge bosons
  - extra dimensions (Kaluza-Klein W excitations)
  - little Higgs
  - technicolor
- Could provide evidence of method of electroweak symmetry breaking
- Many possible decay modes

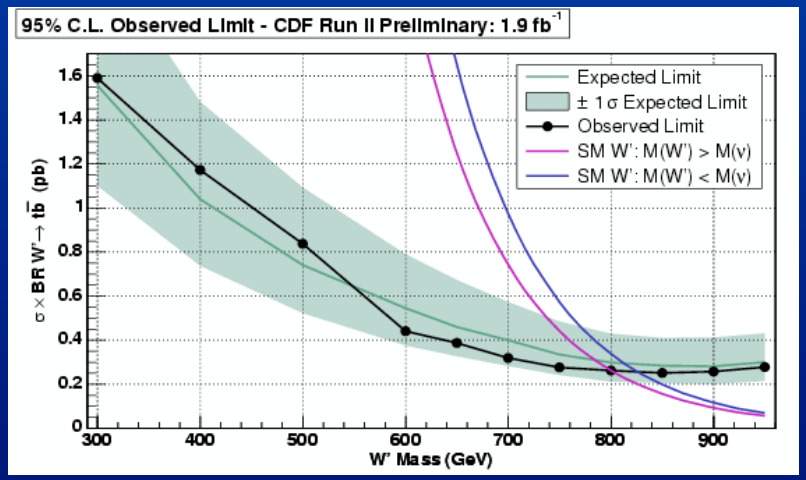
W′ Searches

W′ → tb

DØ (0.9 fb^{-1})

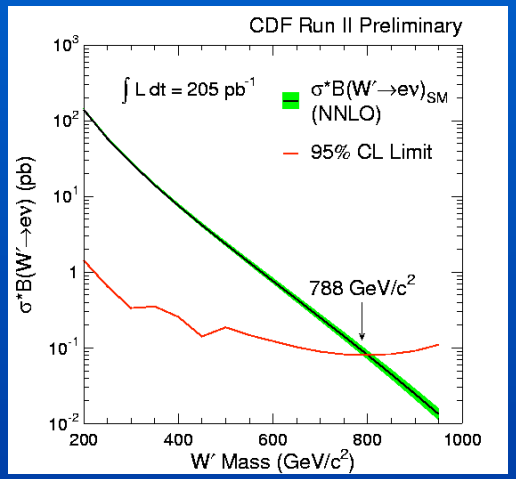


CDF (1.9 fb^{-1})

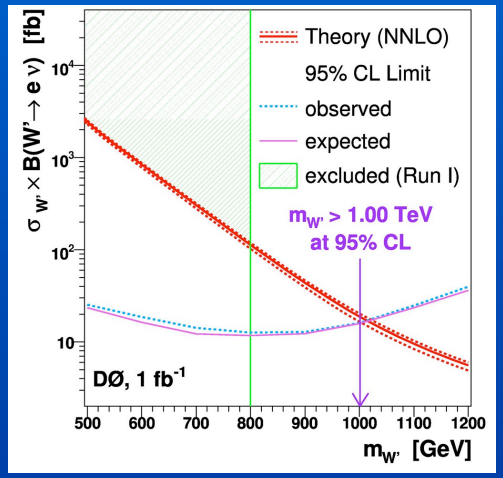


W′ → eν

CDF (0.2 fb^{-1})



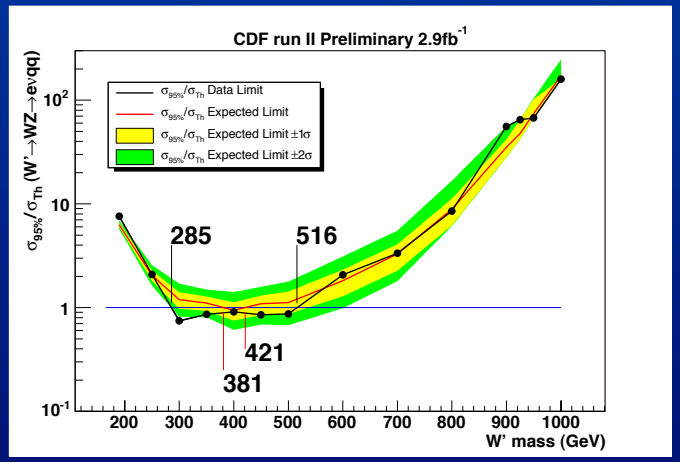
DØ (1 fb^{-1})



first Tevatron 1 TeV limit!

W′ → WZ

CDF (2.9 fb^{-1} eνjj)



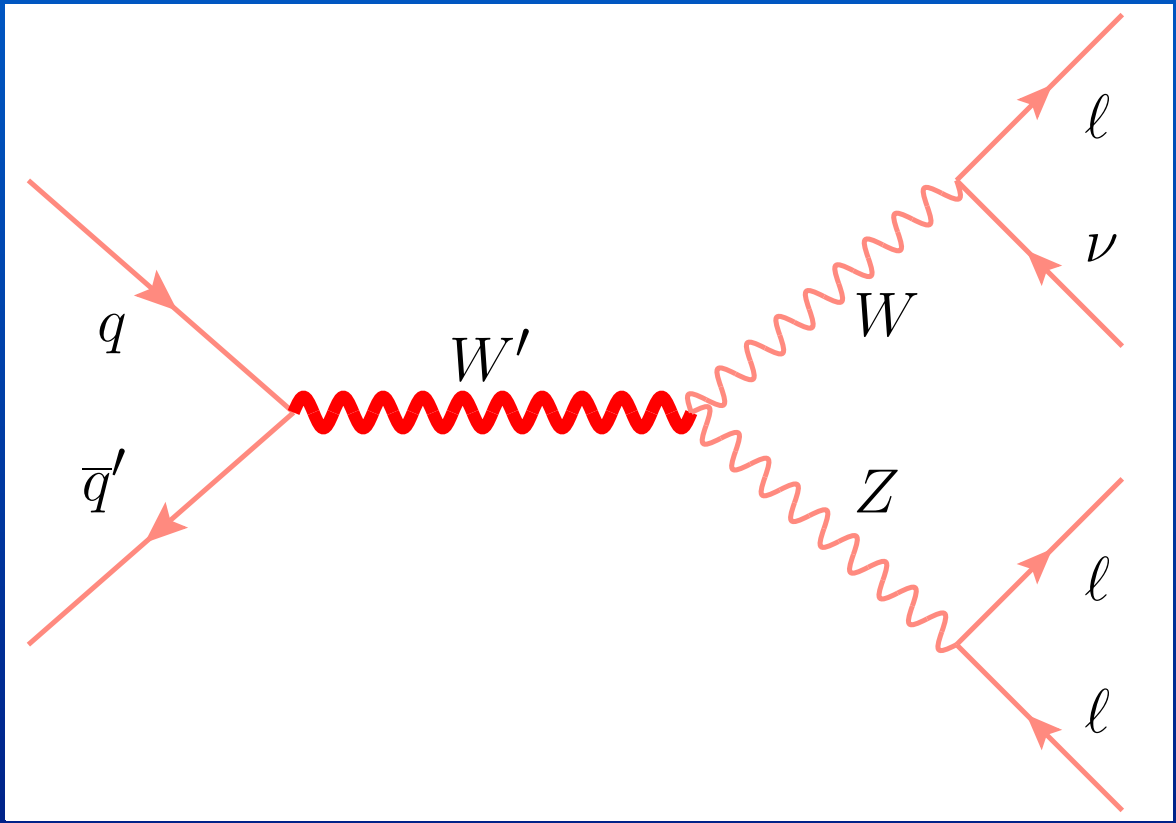
DØ (4.1 fb^{-1})

W′ → WZ → 3l +ν

???

$W' \rightarrow WZ \rightarrow 3l + \nu$

- Sequential standard model (SSM) W boson
  - same couplings as standard model



Final states of interest

eee eeμ eμμ μμμ

Event Selection: Z

Lepton selection

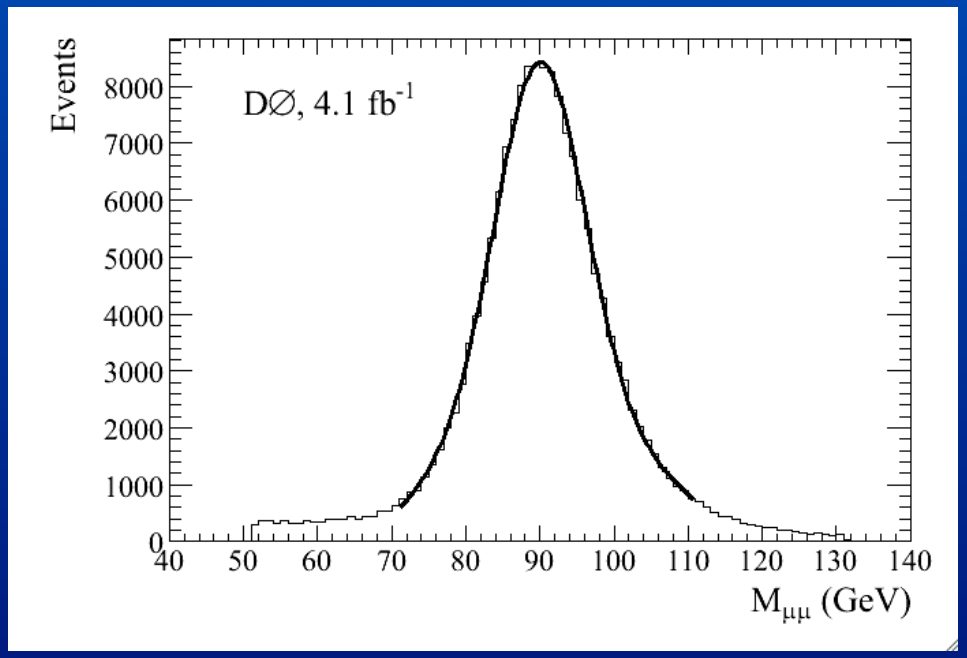
$p_T > 20$ GeV

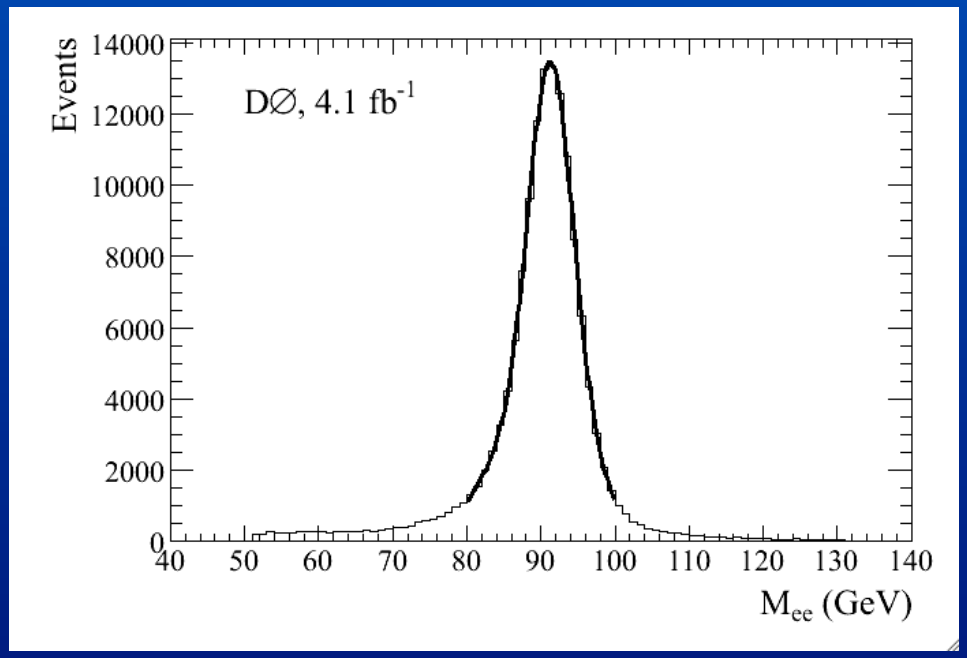
Muons

- muon and central track
- $|\eta| < 2$
- isolated in calorimeter and tracker

Electrons

- shower shape
- central track matched
- $|\eta| < 1.1$ or $1.5 < |\eta| < 2.5$
- isolated in calorimeter





Require two like flavor leptons within 3σ of Z mass

Additional Event Selection

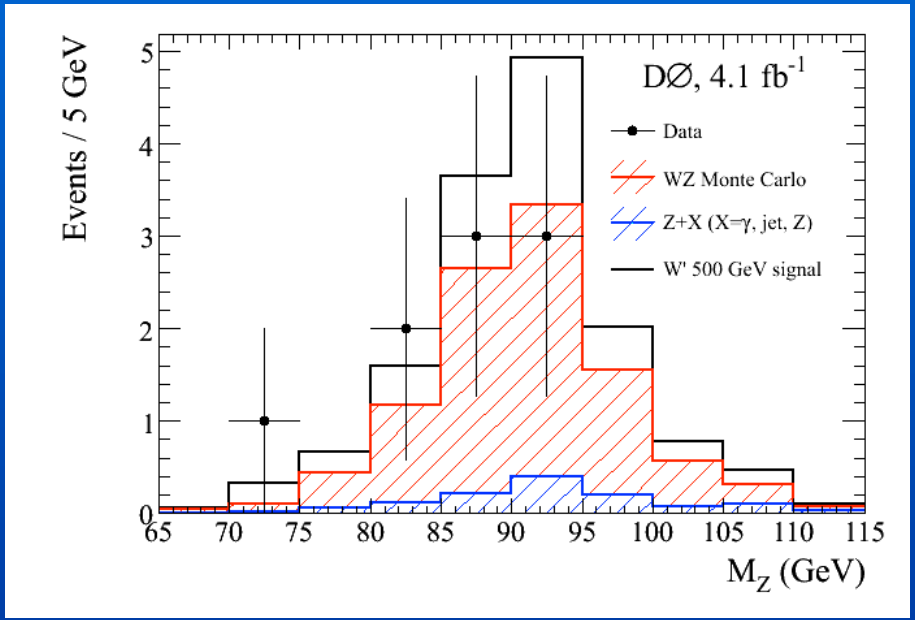
- Missing transverse energy (MET) > 30 GeV
- Highest p_T remaining lepton associated with W
- Require $\Delta R(l_W, l_{Z1,2}) > 1.2$

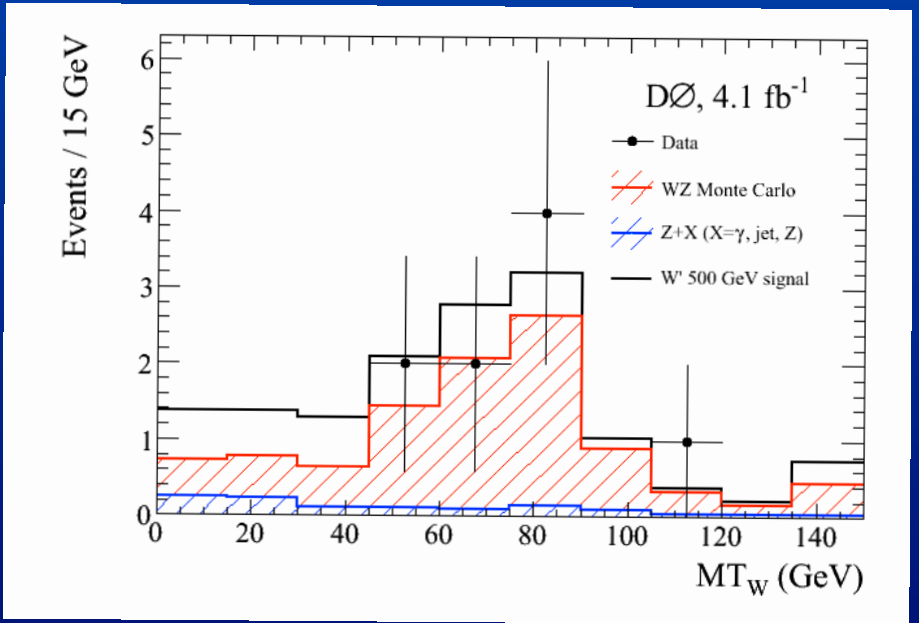
Background Estimate

- Diboson
  - WZ and ZZ
  - estimated from MC
- Instrumental
  - Z+jets and Zγ
  - estimated from data
- Z+jets
  - invert lepton quality criteria on l_W
  - Z+μ: fail isolation
  - Z+e: fail shower shape
- Zγ
  - measure γ → e mis-id with Z→ μμγ
  - apply to Zγ MC

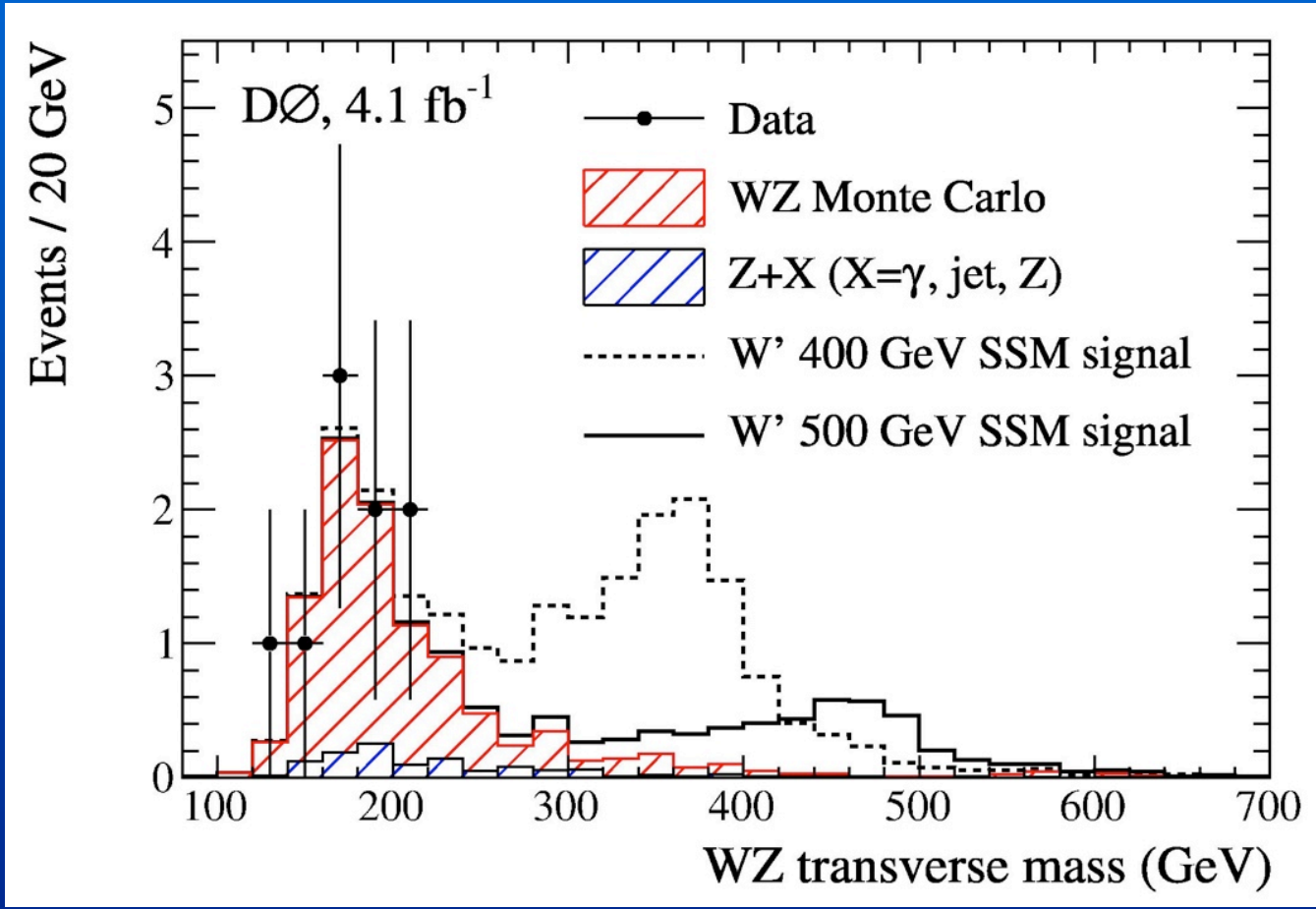
Final Event Sample

Source	# of Events
WZ	9.0 ± 1.5
ZZ	1.0 ± 0.2
Z + jets	0.2 ± 0.1
Zγ	0.1 ± 0.1
Total	10.2 ± 1.6
Observed	9
W′ (500 GeV)	4.4 ± 1.1



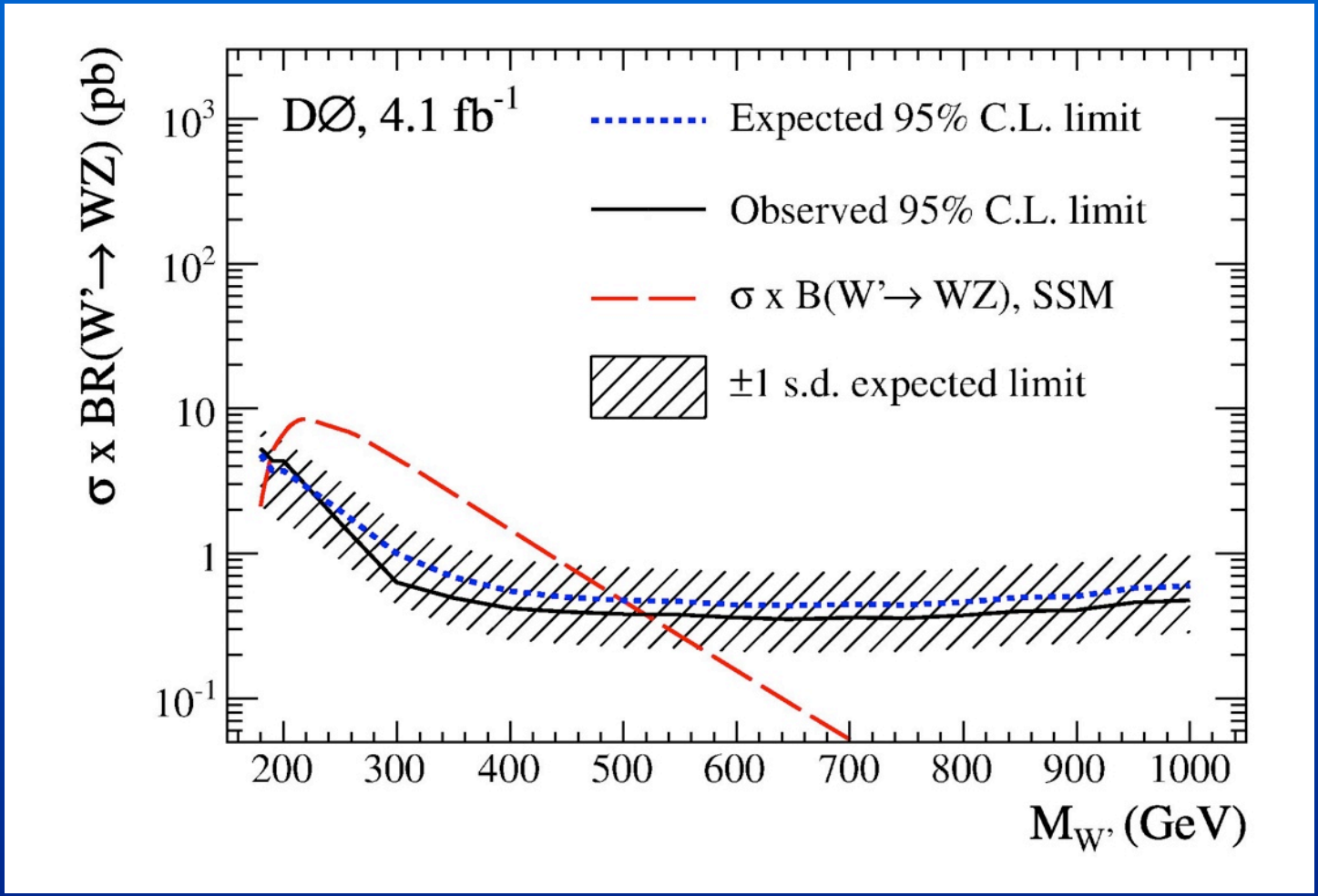


Final Event Sample



	eee	eeμ	eμμ	μμμ
Total Bkgd	1.52 ± 0.33	2.31 ± 0.49	2.21 ± 0.46	4.19 ± 0.89
Observed	3	2	2	2

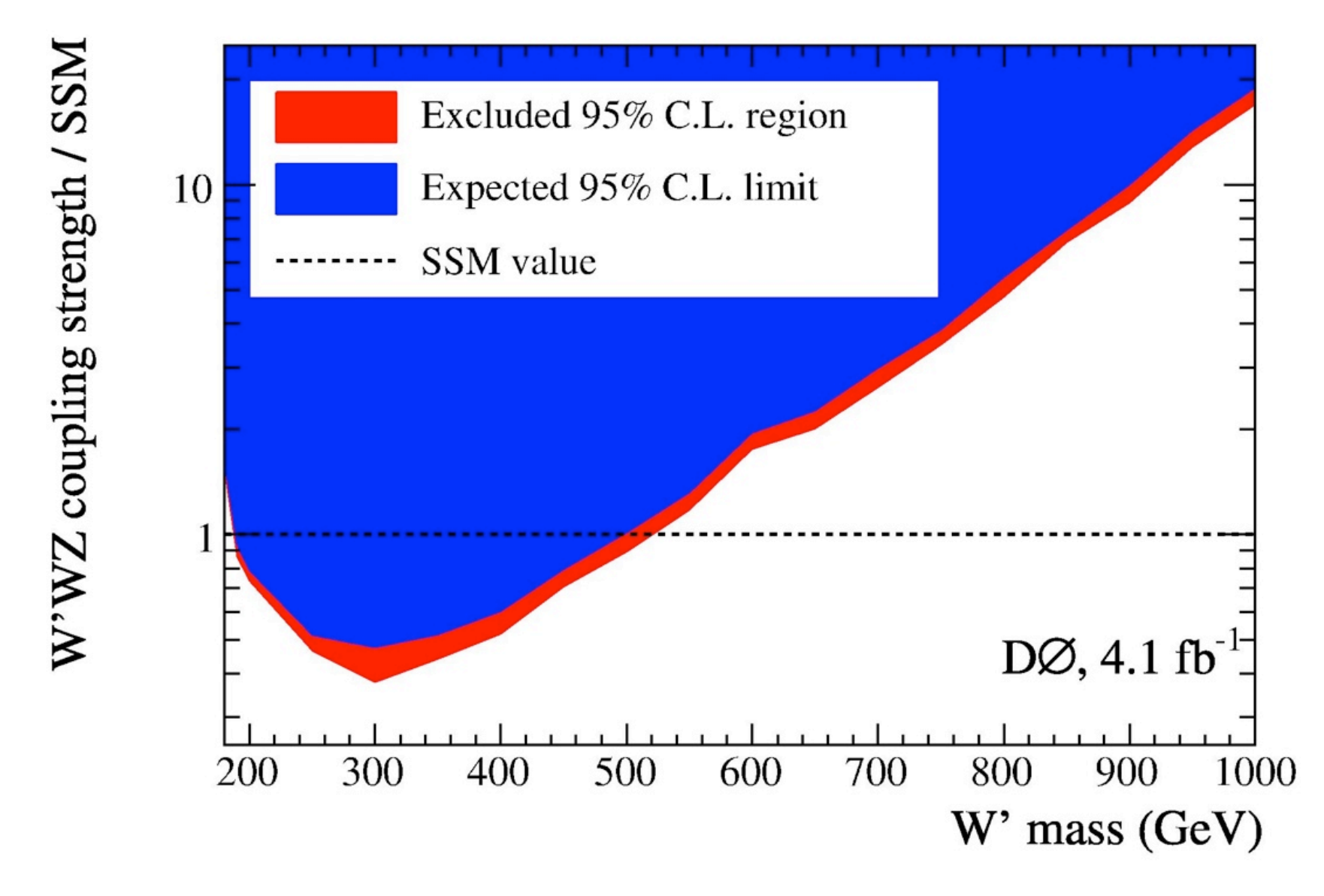
Cross Section Limits



- **Exclude SSM W′ masses 188 < M(W′) < 520 GeV (95% C.L.)**

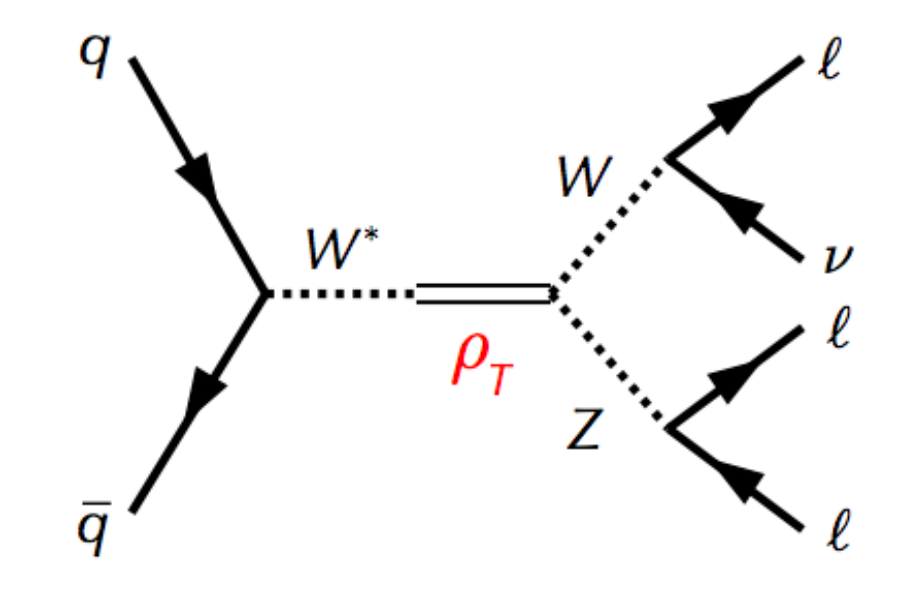
Phys. Rev. Lett. 104, 061801 (2010)

W′ Coupling Limits



Technicolor

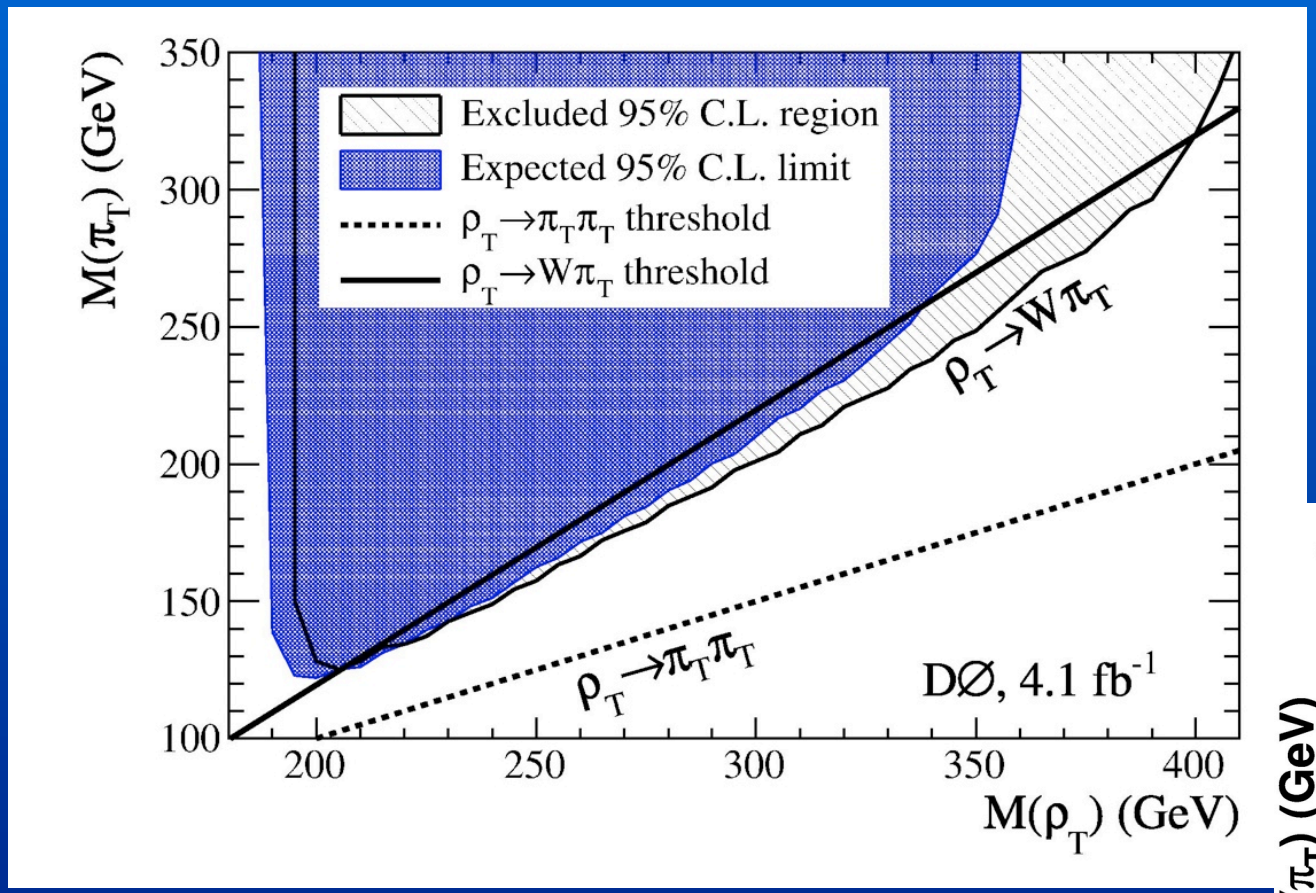
- New strong gauge interactions
  - dynamic breaking of electroweak symmetry
  - technifermions
- Low scale technicolor (LSTC)
  - preferred decays
    - $\rho^{\pm}_T/a^{\pm}_T \rightarrow W^{\pm}\pi_T$
      - $M(\rho_T) > M(\pi_T) + M(W)$
    - $\rho^{\pm}_T/a^{\pm}_T \rightarrow W^{\pm}Z$
      - $M(\rho_T) < M(\pi_T) + M(W)$



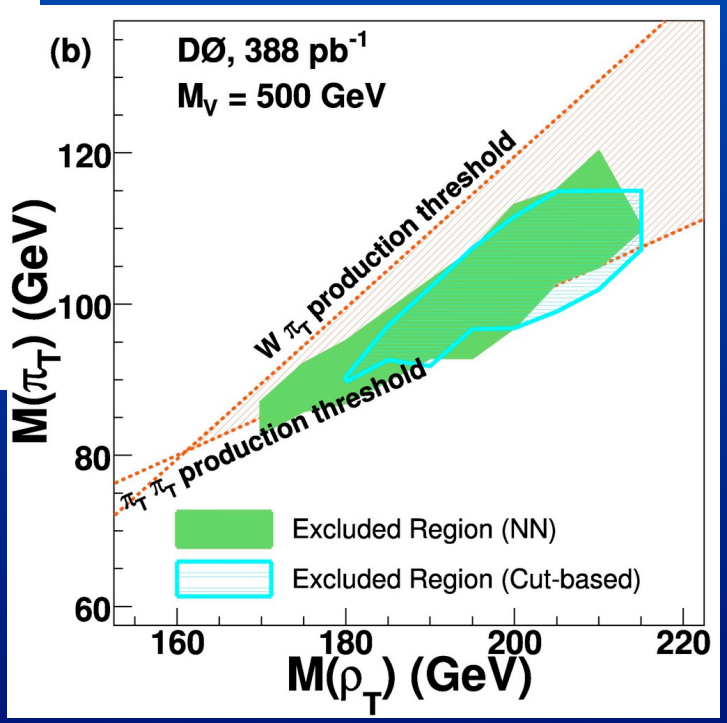
Re-interpret
$W' \rightarrow WZ \rightarrow 3l + \nu$

	# of Events
Total	10.2 ± 1.6
Observed	9

Technicolor Limits



We exclude
$208 < M(\rho_T) < 400$ GeV
at 95% C.L.



- **Complements previous search in e+jets final state (0.4 fb^{-1})**
  - **PRL 98, 221801 (2007)**

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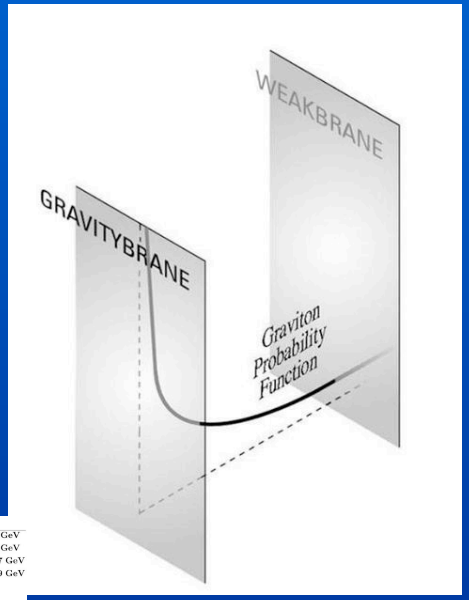
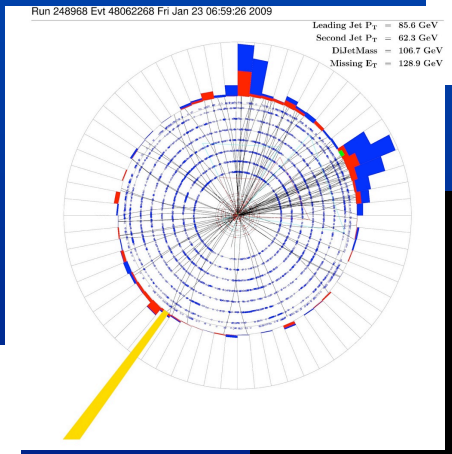
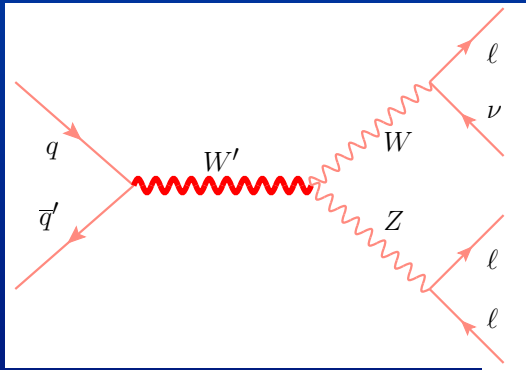
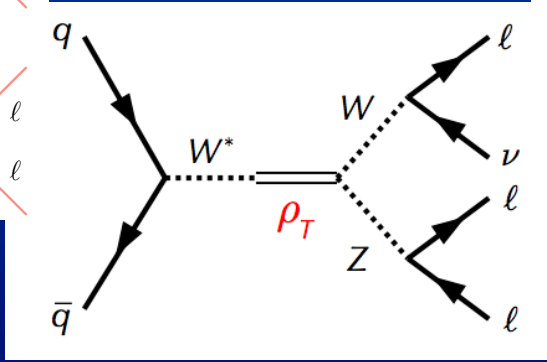
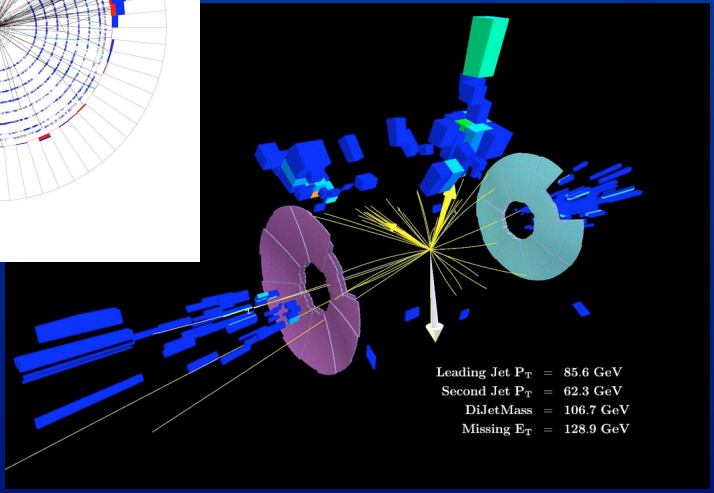








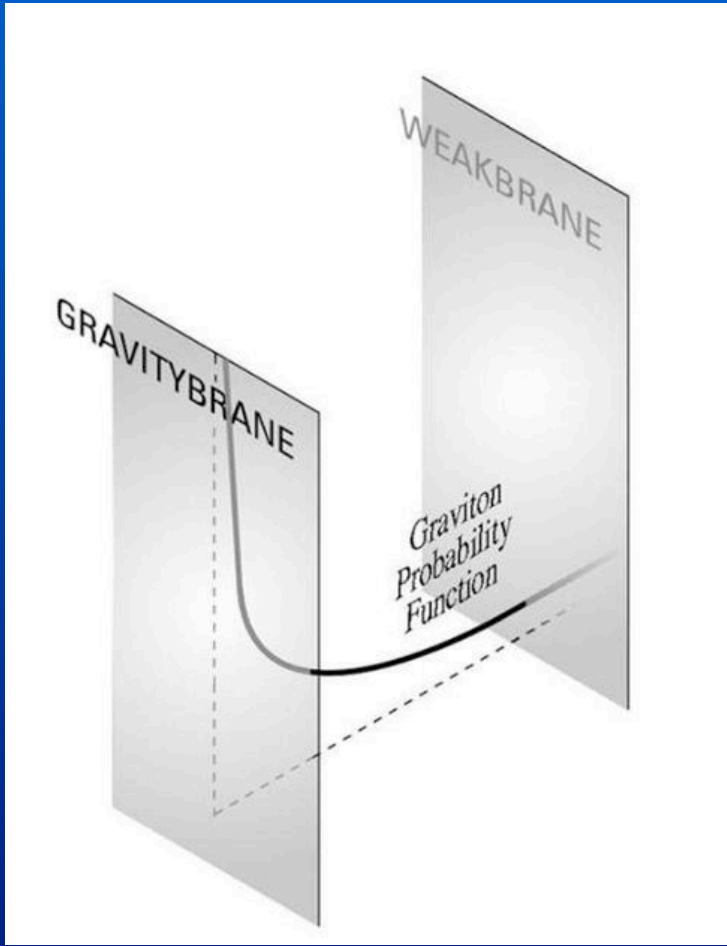


Randall Sundrum Model

- 5 dimensional warped geometry
  - two branes
  - r_c = compactification radius
  - k = curvature scale

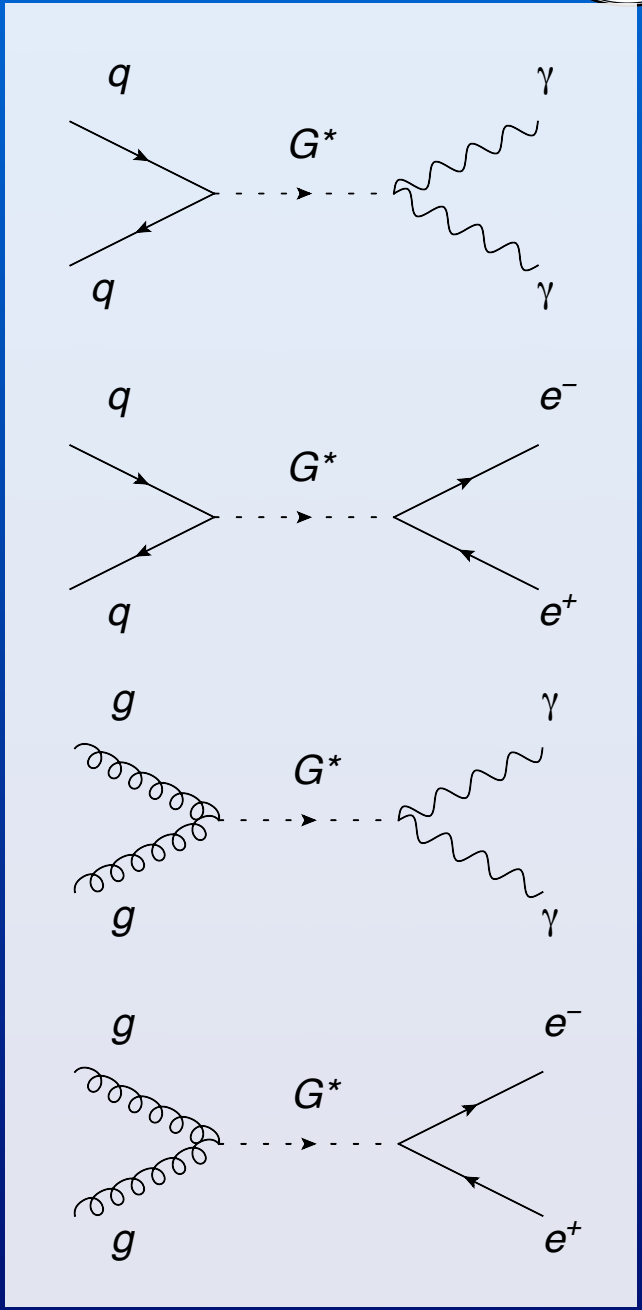
$$M = \exp(-kr_c\pi)M_0$$

  - any mass parameter M on the weakbrane yields a physical mass M_0 in the higher dimensional theory
  - kr_c = 11-12 yields SM observed electroweak/gravity scale



Randall-Sundrum Gravitons

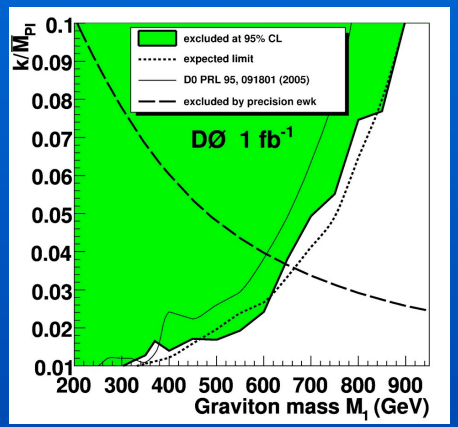
- Simplest model: only graviton propagates in extra dimensions
  - Kaluza-Klein towers
  - mass gaps of ~TeV
  - depends on
    - lightest tower m_1
    - dimensionless coupling $k/\overline{M}_{Pl}$
    - $0.01 \leq k/\overline{M}_{Pl} \leq 0.1$
  - spin-2
  - $BR(\gamma\gamma)/BR(ee) = 2$

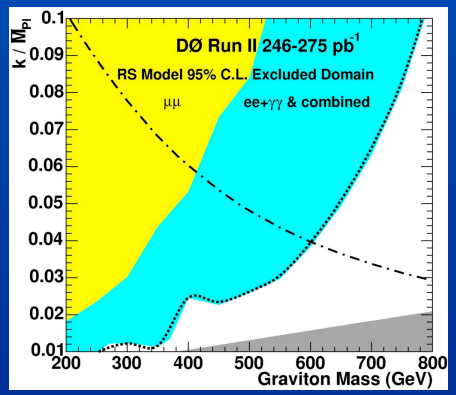


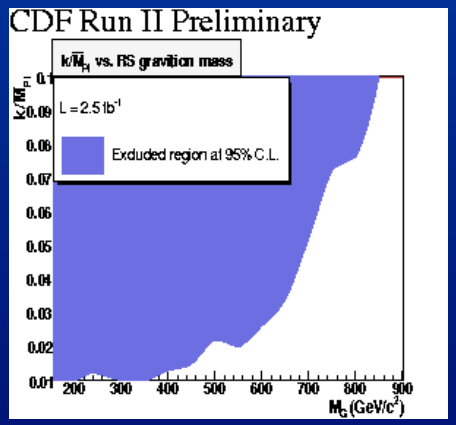
Previous Tevatron Searches

- Many previous searches

DØ		
ee, μμ, γγ	0.3 fb^{-1}	Phys. Rev. Lett. 95, 091801 (2005)
ee, γγ	1 fb^{-1}	Phys. Rev. Lett. 100, 091802 (2008)
ee, γγ	5.4 fb^{-1}	submitted to Phys. Rev. Lett
CDF		
ee, μμ	0.2 fb^{-1}	Phys. Rev. Lett. 95, 252001(2005)
γγ	1.2 fb^{-1}	Phys. Rev. Lett. 99, 171801 (2007)
ee	1.3 fb^{-1}	Phys. Rev. Lett. 99, 171802 (2007)
ee	2.5 fb^{-1}	Phys. Rev. Lett. 102, 031801 (2009)
μμ	2.3 fb^{-1}	Phys. Rev. Lett. 102, 091805(2009)







New Di-EM Technique

- Previous analysis: combine γγ and ee
- New analysis

di-EM Sample

Category I
"di-electron like"

important statistics

Category II
"di-photon like"

lower background
more signal

di-EM Sample

pT>25 GeV

|η|<1.1

EMfrac > 0.97

Calorimeter isolation

Category I

"di-electron like"

both matched to tracker activity

track isolation < 2.5 GeV

electron shower shape

Category II

"di-photon like"

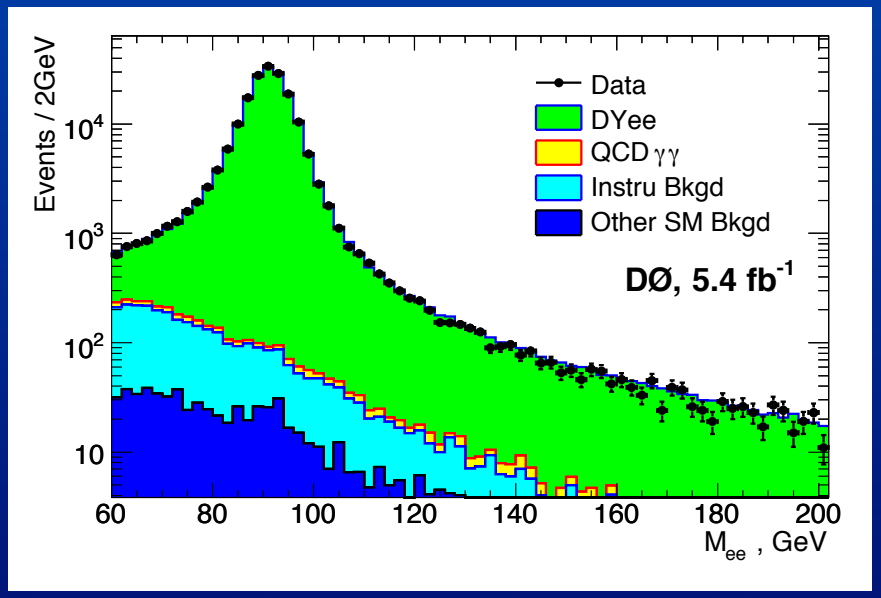
zero or one matched to tracker activity

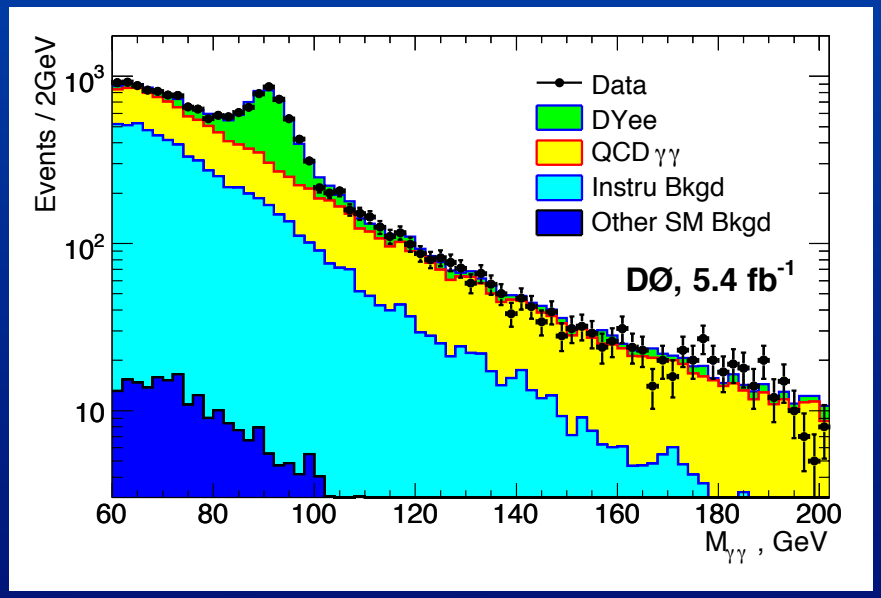
track isolation < 2.0 GeV

photon shower shape

Background Estimate

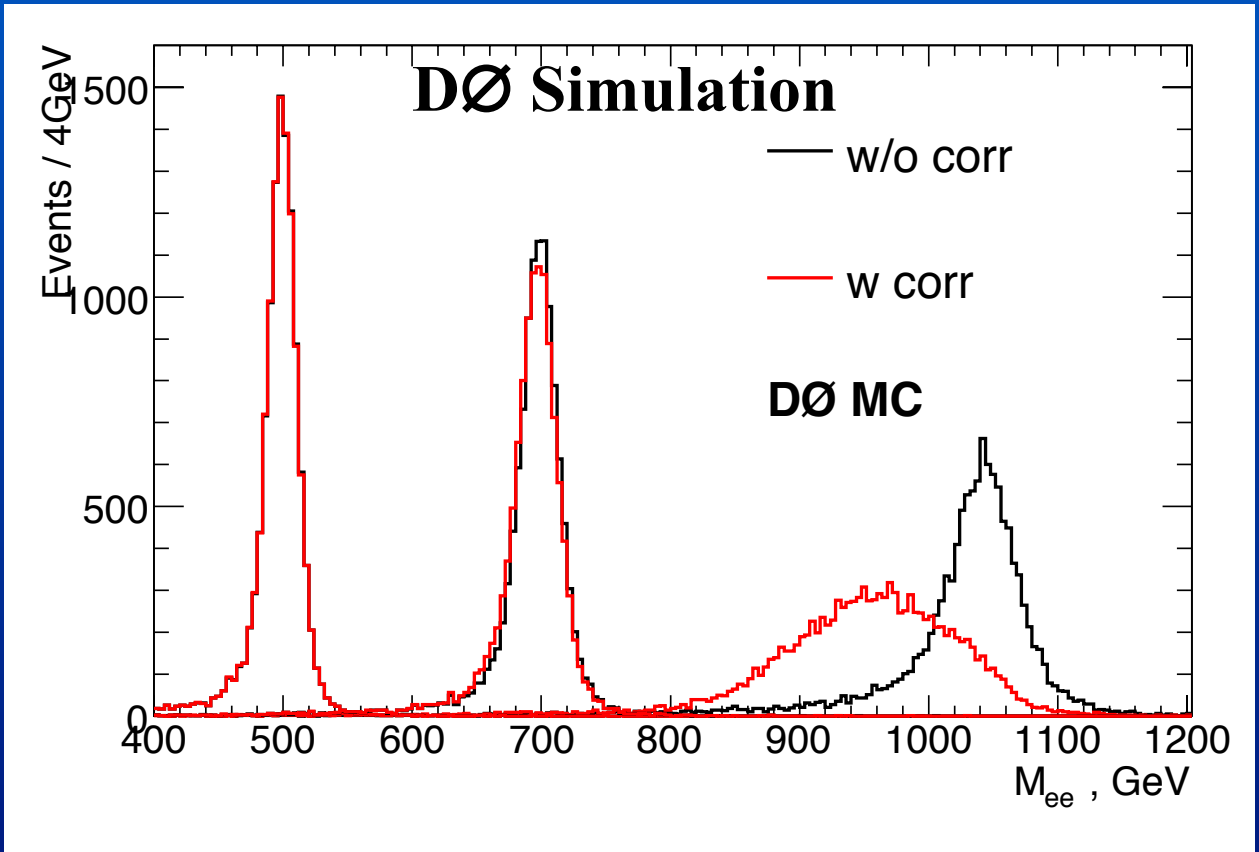
- Physics backgrounds
  - Z/Drell-Yan ← Use Monte Carlo
  - γγ
- Instrumental backgrounds
  - fake photon(s)/electron(s) ← Use data (inverted EM selection)
- Fit shapes to invariant mass (<200 GeV) to determine normalization





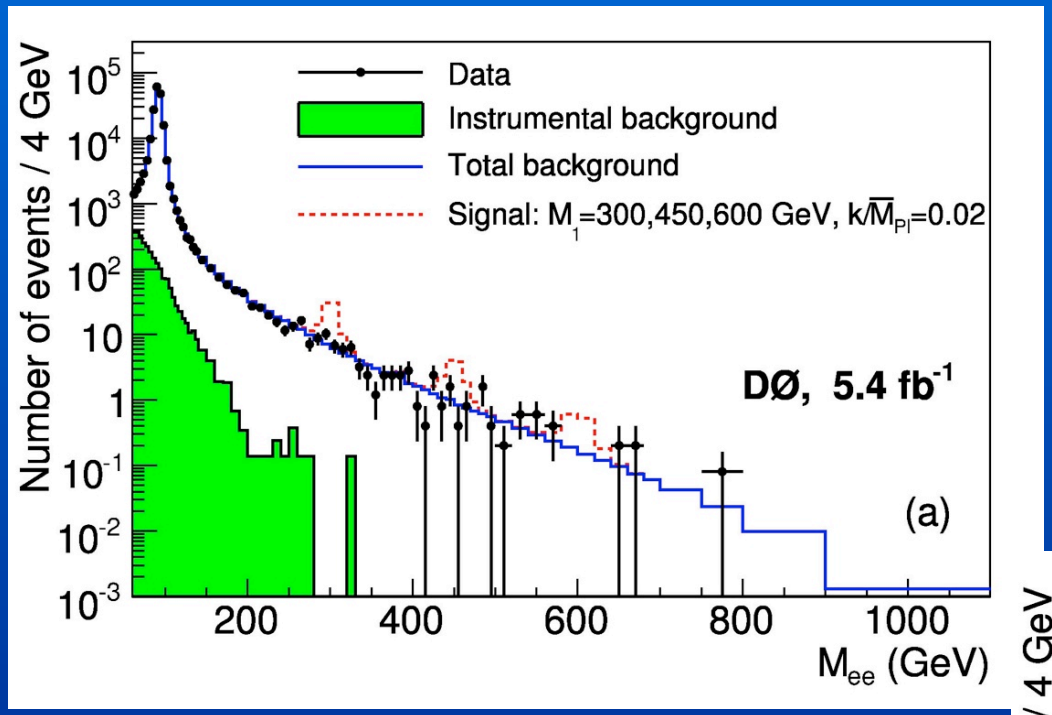
Saturation Effects

- Probing high energies - investigate effects of possible calorimeter readout saturation
- Add saturation to simulation

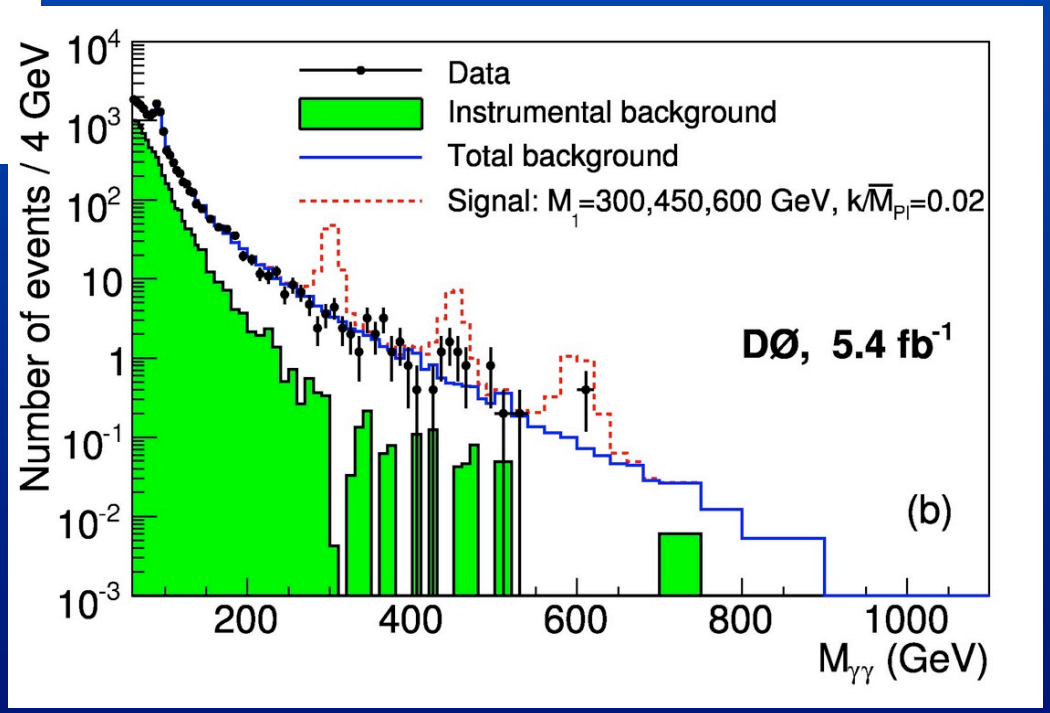


- Effect could be seen at highest masses

Final Data Samples

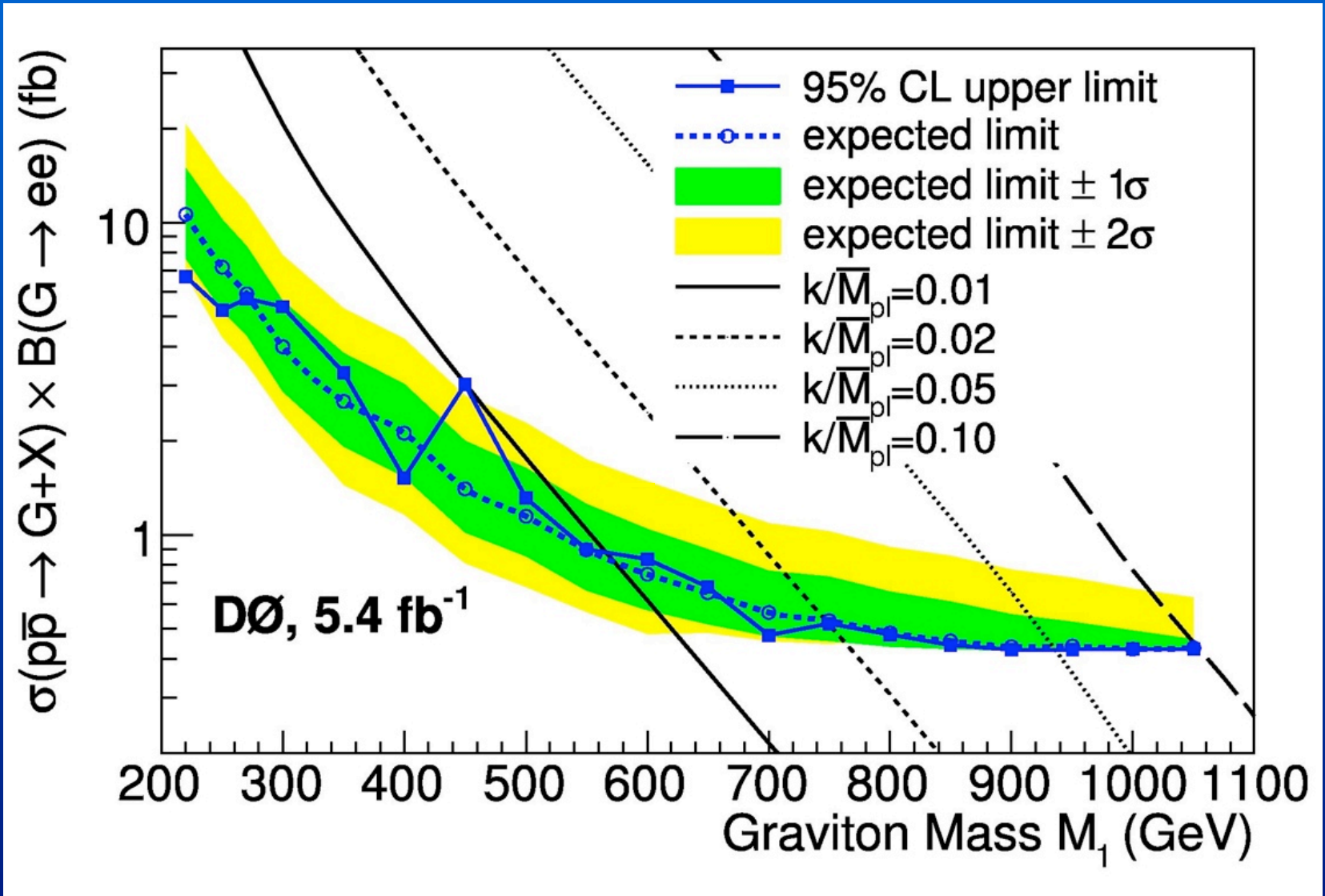


- Data consistent with background prediction in both categories



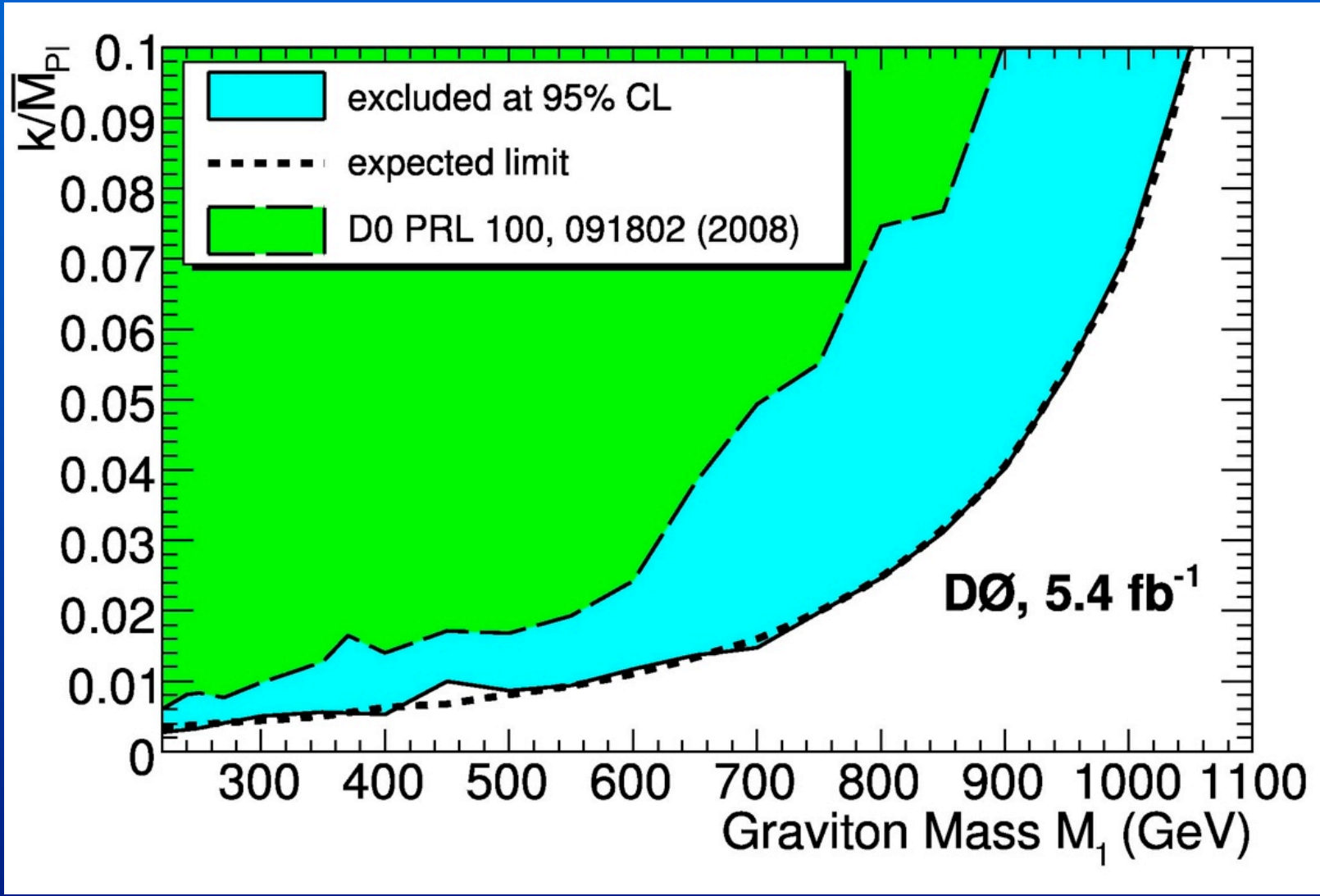
- Combine categories for final limits

Cross Section Limits



Exclude M_1<560 GeV ($k/\overline{M}_{pl}$=0.01) and M_1<1050 GeV ($k/\overline{M}_{pl}$=0.1)

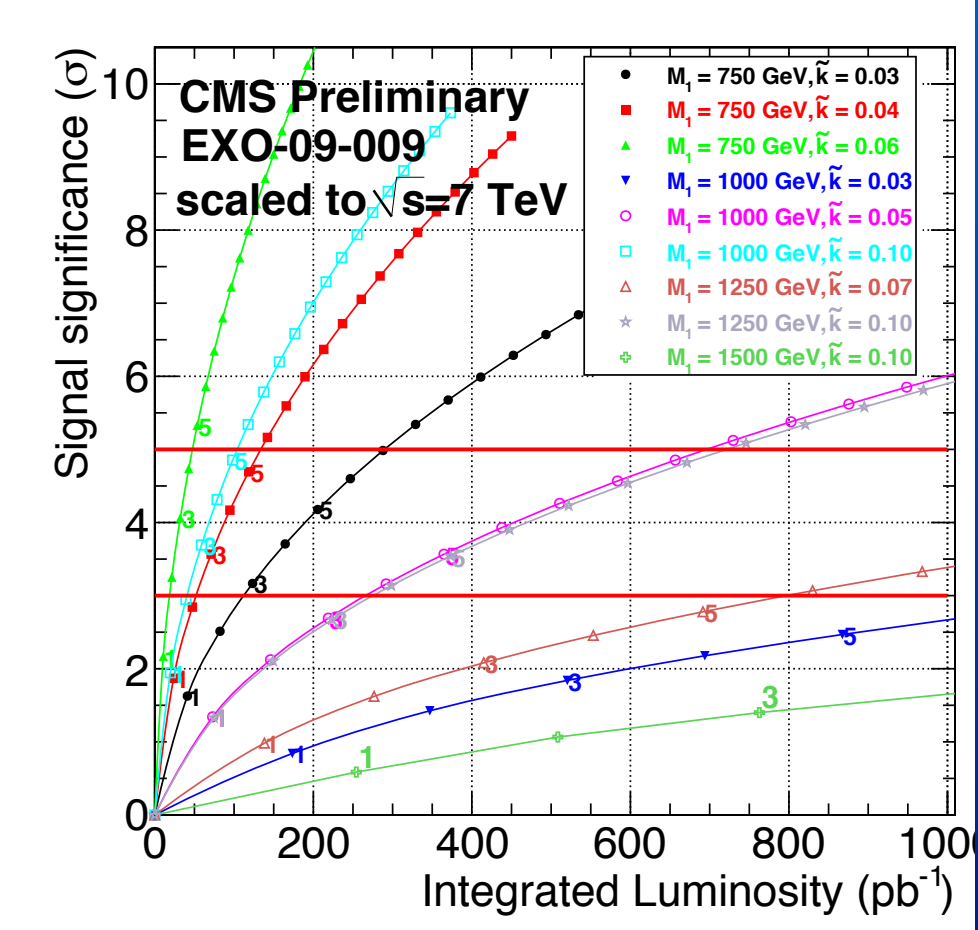
Randall-Sundrum Model Limits

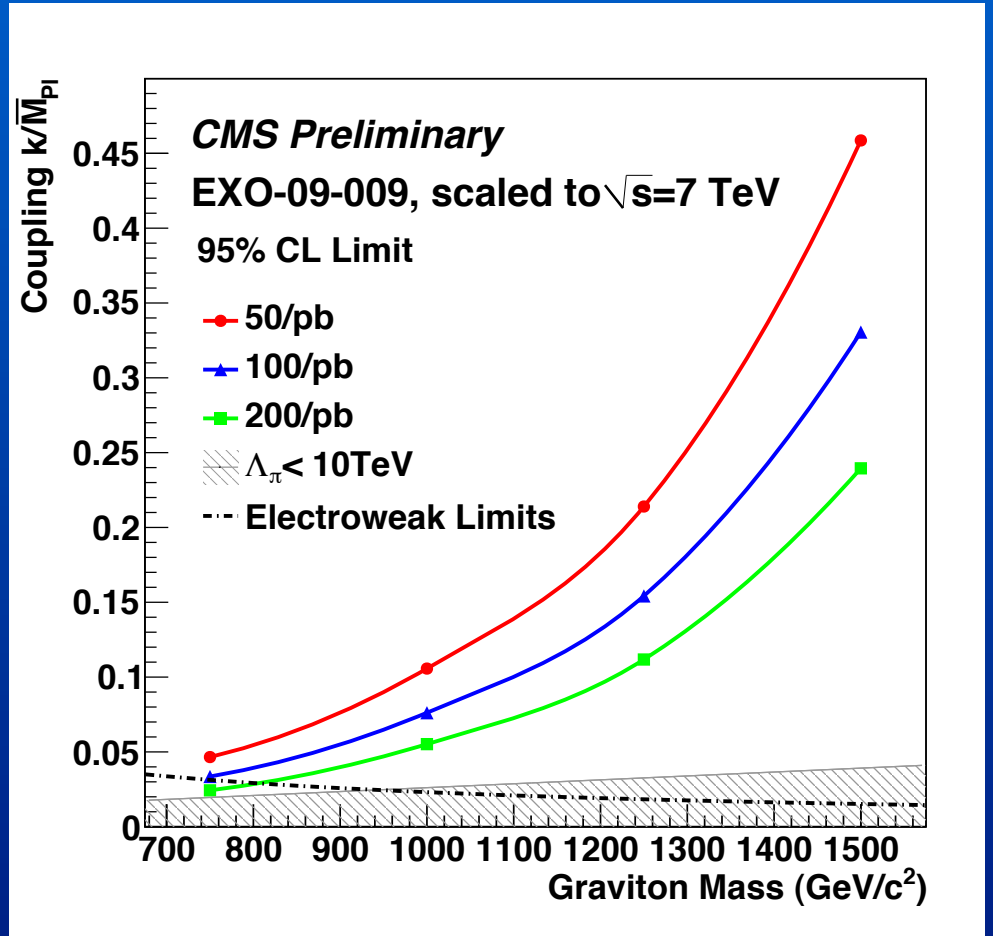


- submitted to Phys. Rev. Lett.

LHC Sensitivity - RS Gravitons

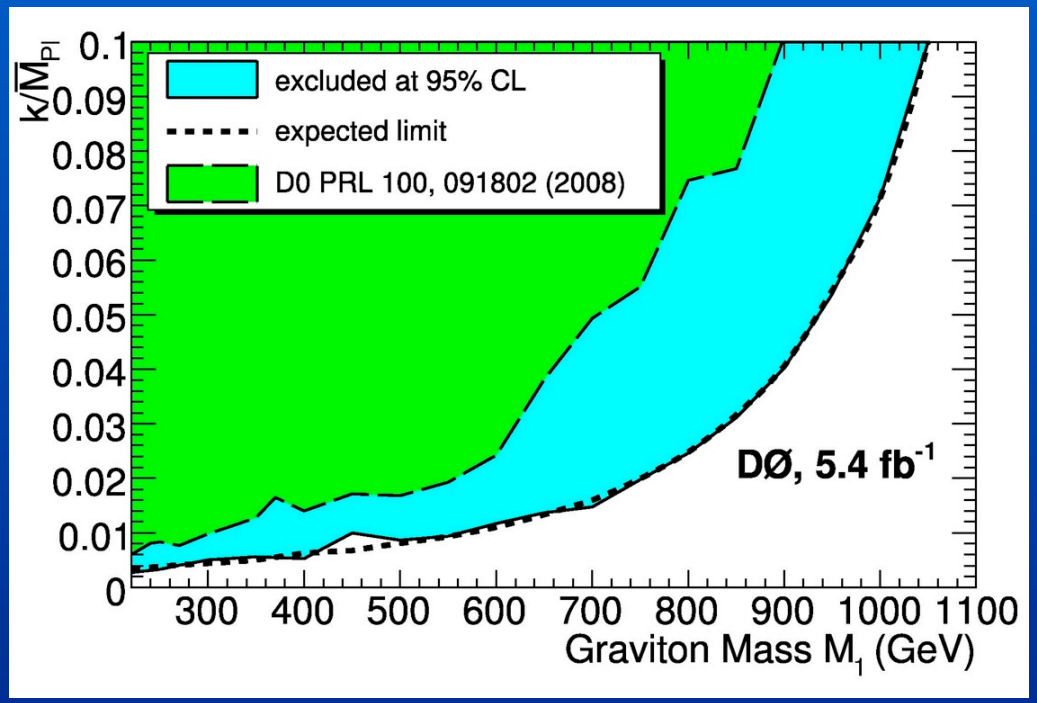
- CMS sensitivity scaled to 7 TeV collision energy

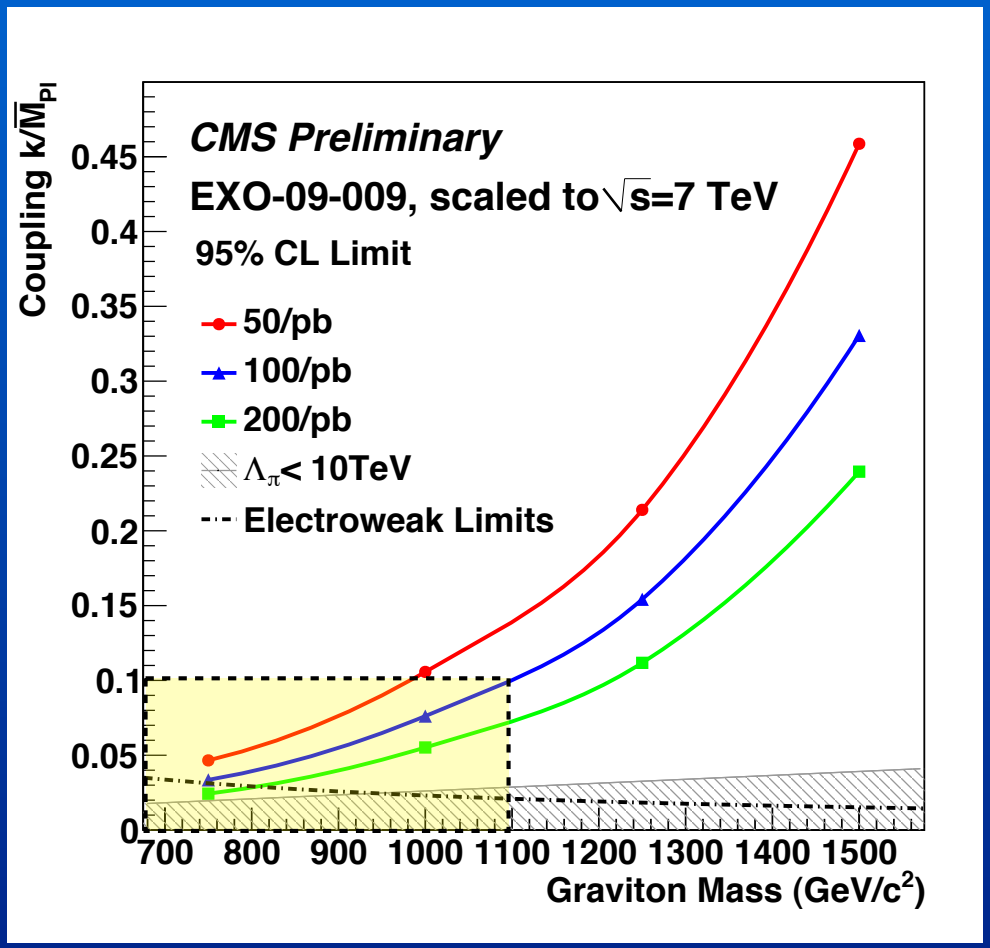




Note: acceptance not recalculated

Tevatron/LHC Comparison

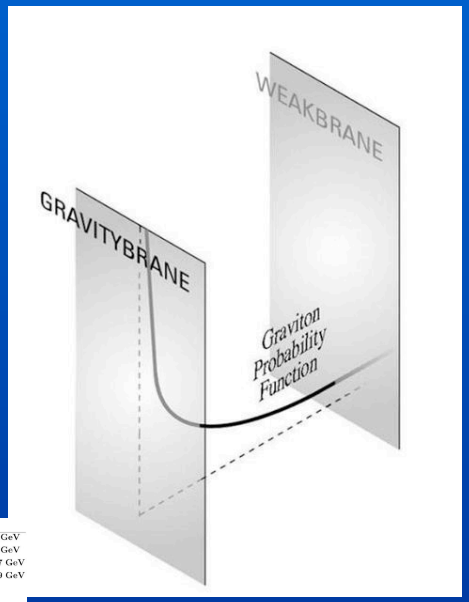


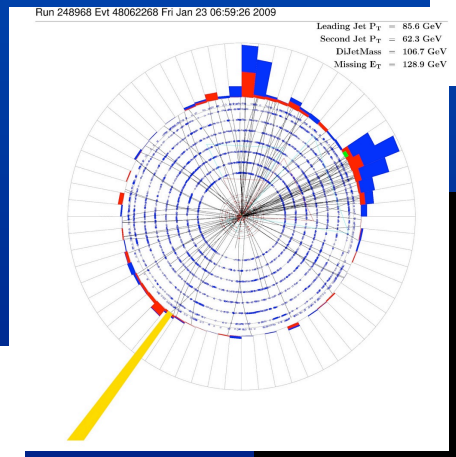


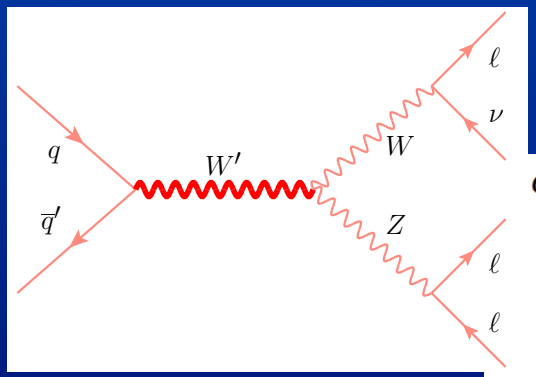
- With 100/pb, LHC could explore new territory at high mass, but small couplings will take much longer

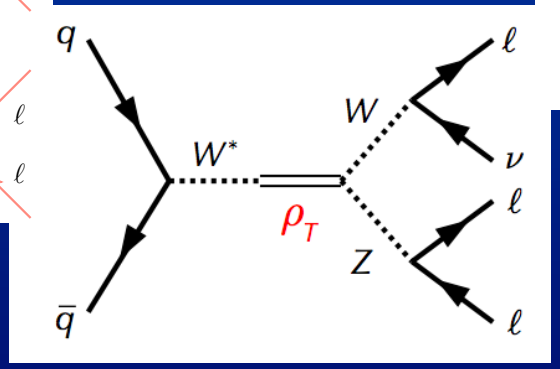
Outline

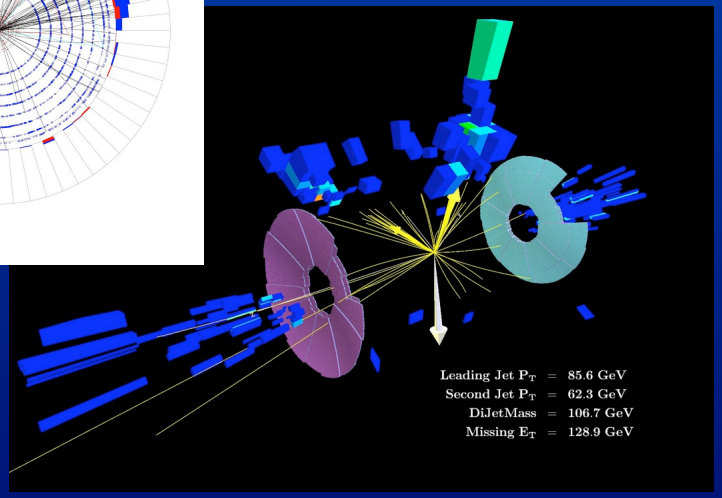
- Introduction
- $W' \rightarrow WZ \rightarrow 3l+\nu$ and Technicolor
- Randall-Sundrum Gravitons
- Sbottom and
  3rd Generation Leptoquark
- Conclusions







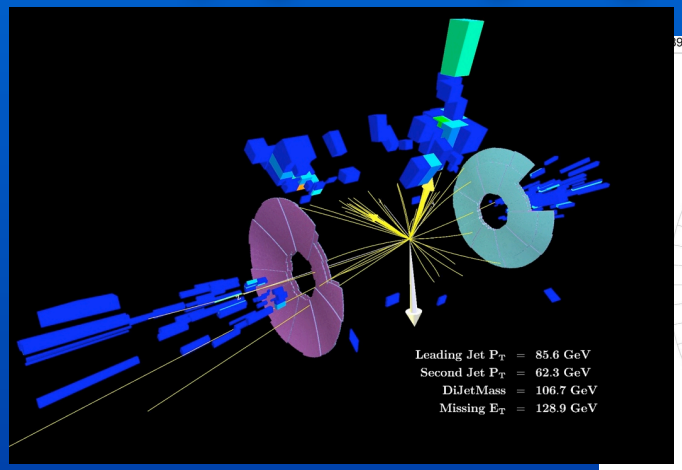


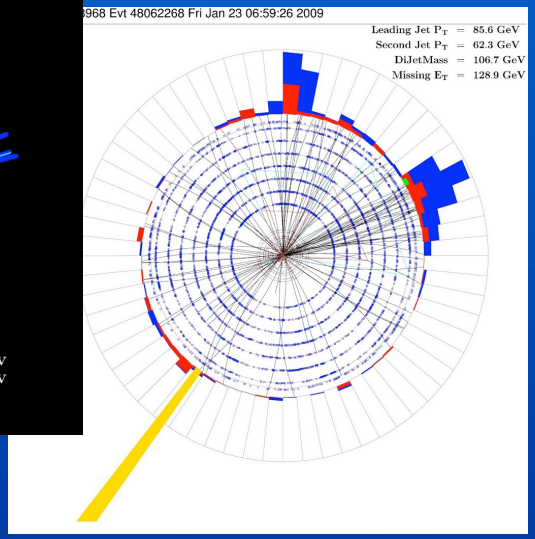


b-Jets + Missing Transverse Energy

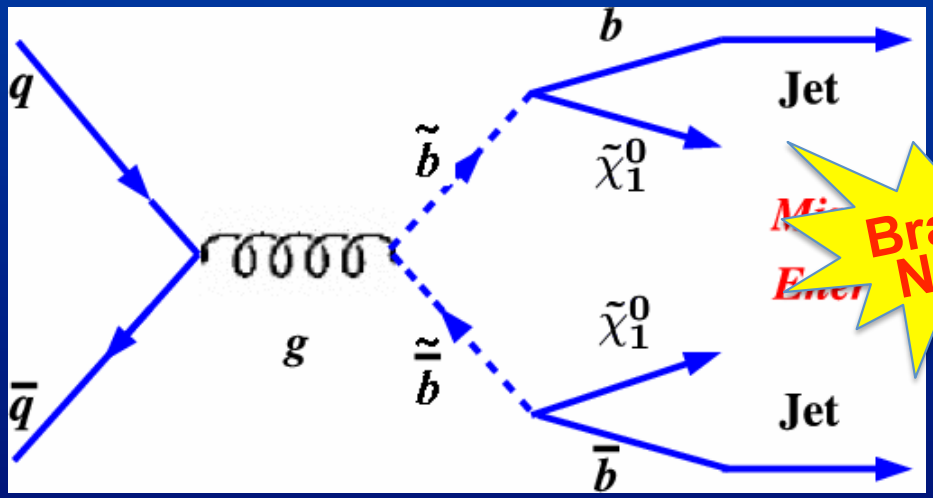
- Search for events with heavy quarks jets plus missing transverse energy

ZH → ννbb
PRL 104, 071801 (2010)
(see M. Eads W&C, Nov. 13, 2009)



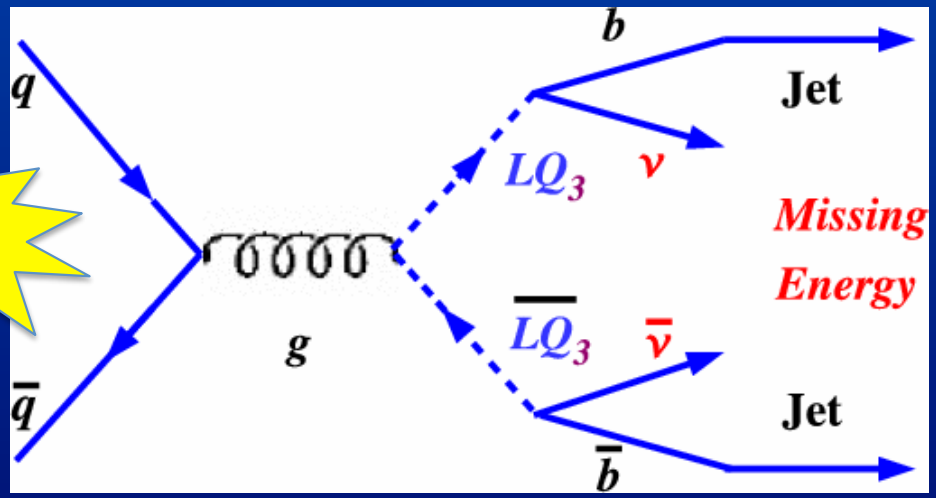


sbottom pair production



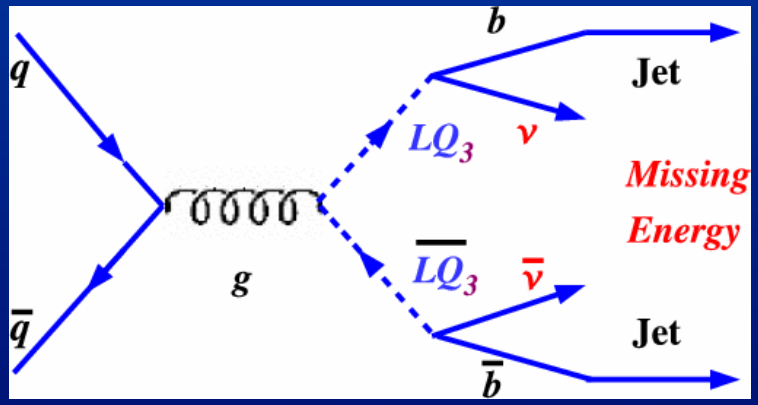
Brand New

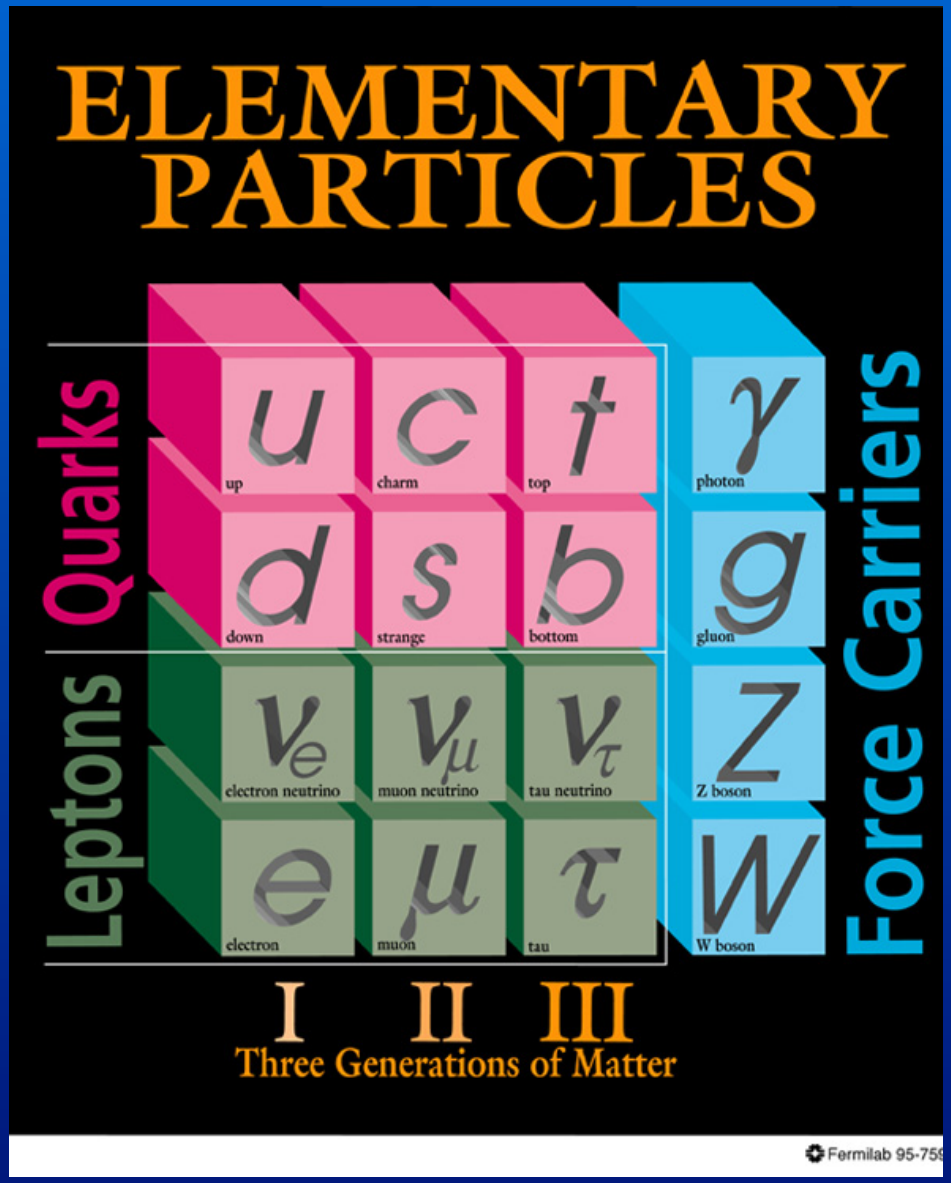
leptoquark pair production



Leptoquarks

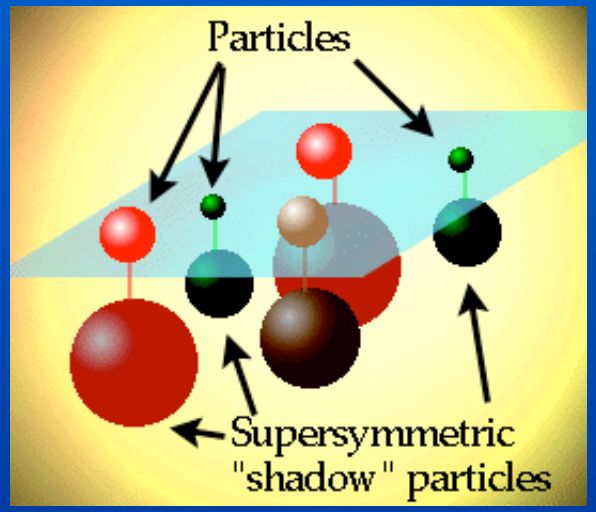
- Hypothetical particles that carry
  - lepton number
  - baryon number
  - fractional charge
- Appear naturally in grand unified theories
  - 3 generations ⇒ 3 types of leptoquarks
- Decays
  - LQ3 → tτ (BR = 1-B)
  - LQ3 → bν (BR = B)

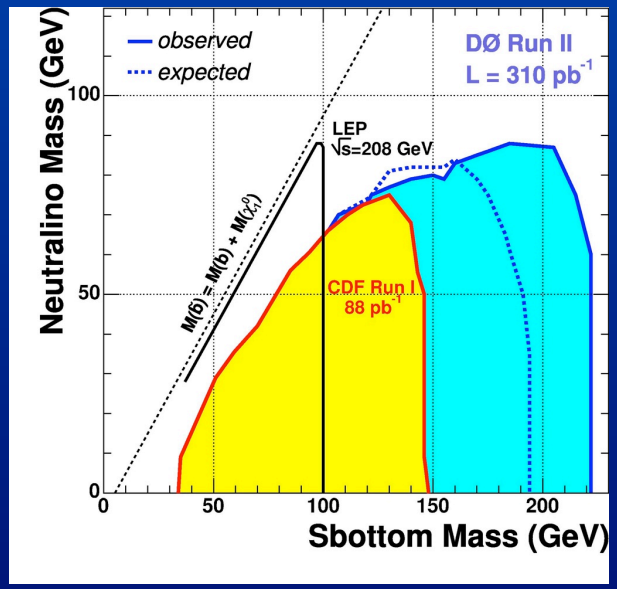




Supersymmetry

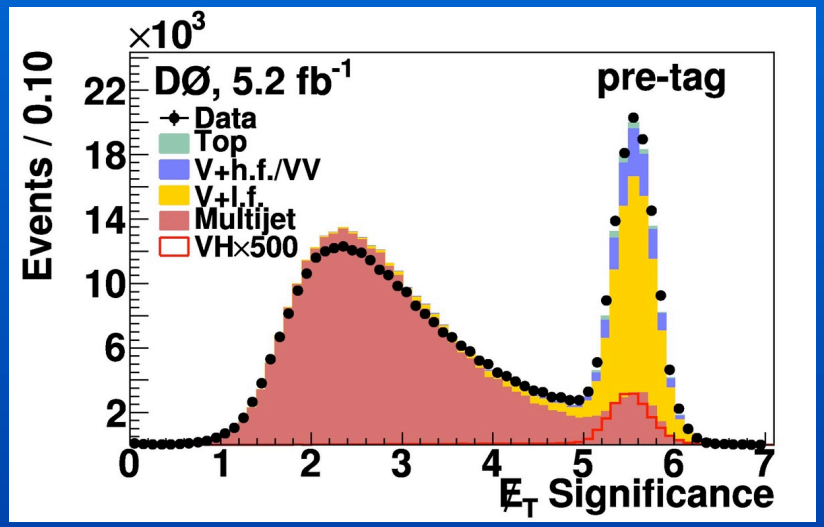
- Additional symmetry between bosons and fermions
- Broken symmetry
  - superpartners must be heavy
- Sbottom can be "light"
  - mass splittings can favor sbottom being one of the lighter squarks
  - higher cross section
- $\tilde{b} \rightarrow \tilde{\chi}_1^0 b$
  - $m(b) + m(\tilde{\chi}_1^0) < m(\tilde{b}) < m(t) + m(\tilde{\chi}^{\pm})$
  - mass relations determine kinematics

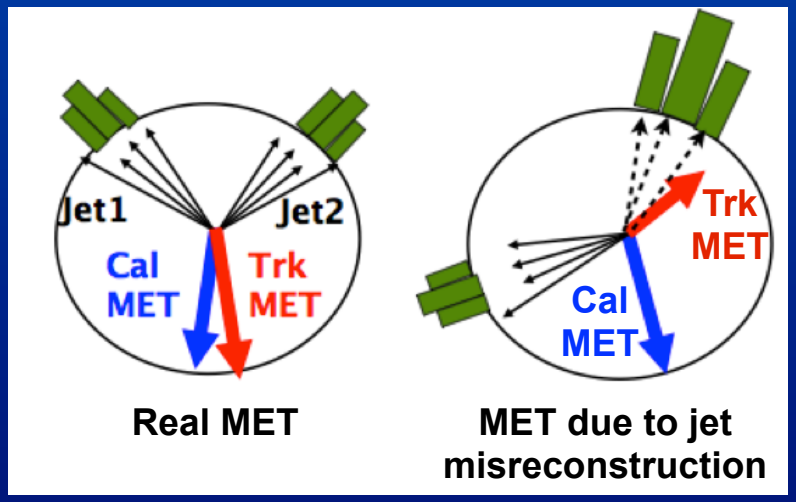




Preselection

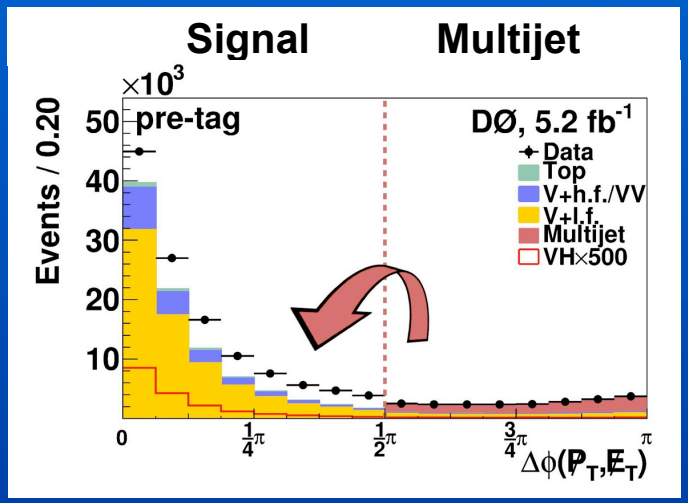
- Primary vertex
  - $|z| < 40$ cm
- ≥ 2 Jets
  - $E_T > 20$ GeV
  - $|\eta| < 2.5$
  - $\Delta\phi$(jet1,jet2) $< 165^o$
- MET > 40 GeV
- MET "significance" discriminant> 5
- MET/GEV > 80 - 40×$\Delta\phi_{min}$(MET, jets)
- veto events with leptons or bad jets
- $\Delta\phi$(MET(cal), MET(track)) $< \pi/2$



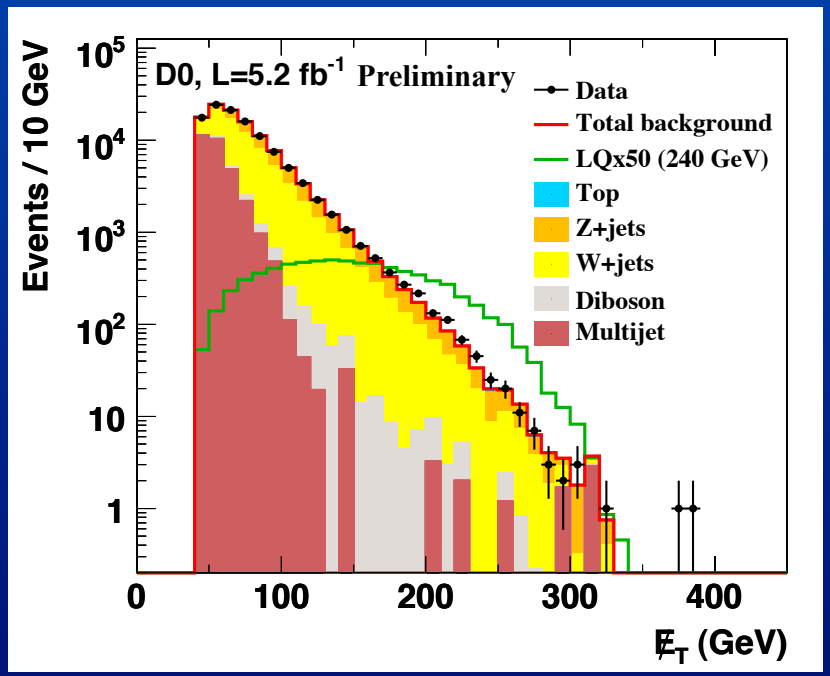


Backgrounds

- Electroweak and top backgrounds modeled with Monte Carlo
- Multijet backgrounds
  - shape
    - $\Delta\phi$(MET(cal), MET(track)) > $\pi/2$
  - normalization
    - MC + multijet = data at preselection

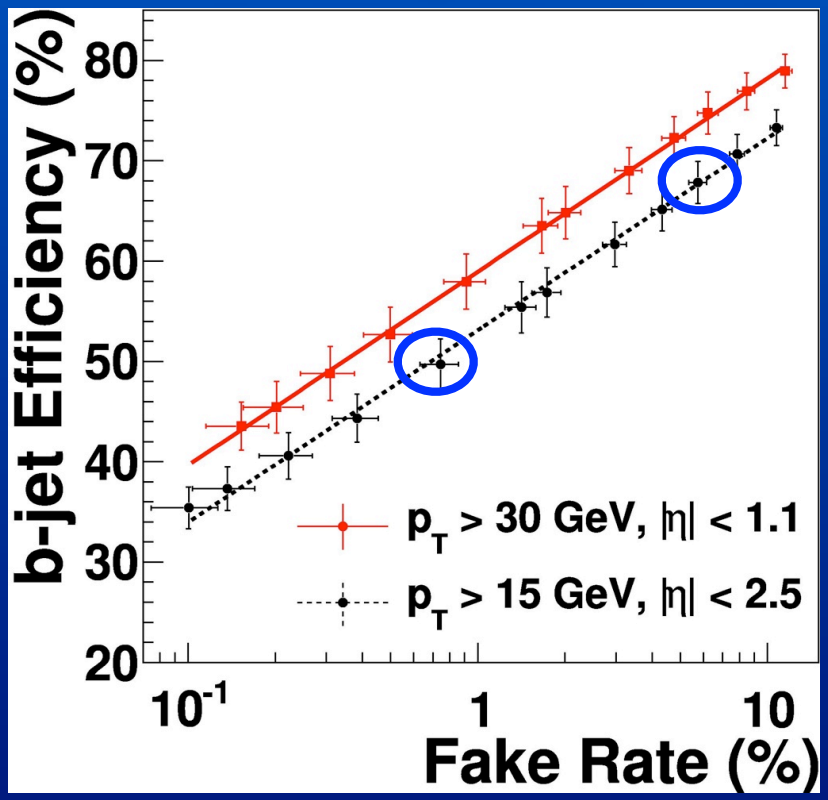


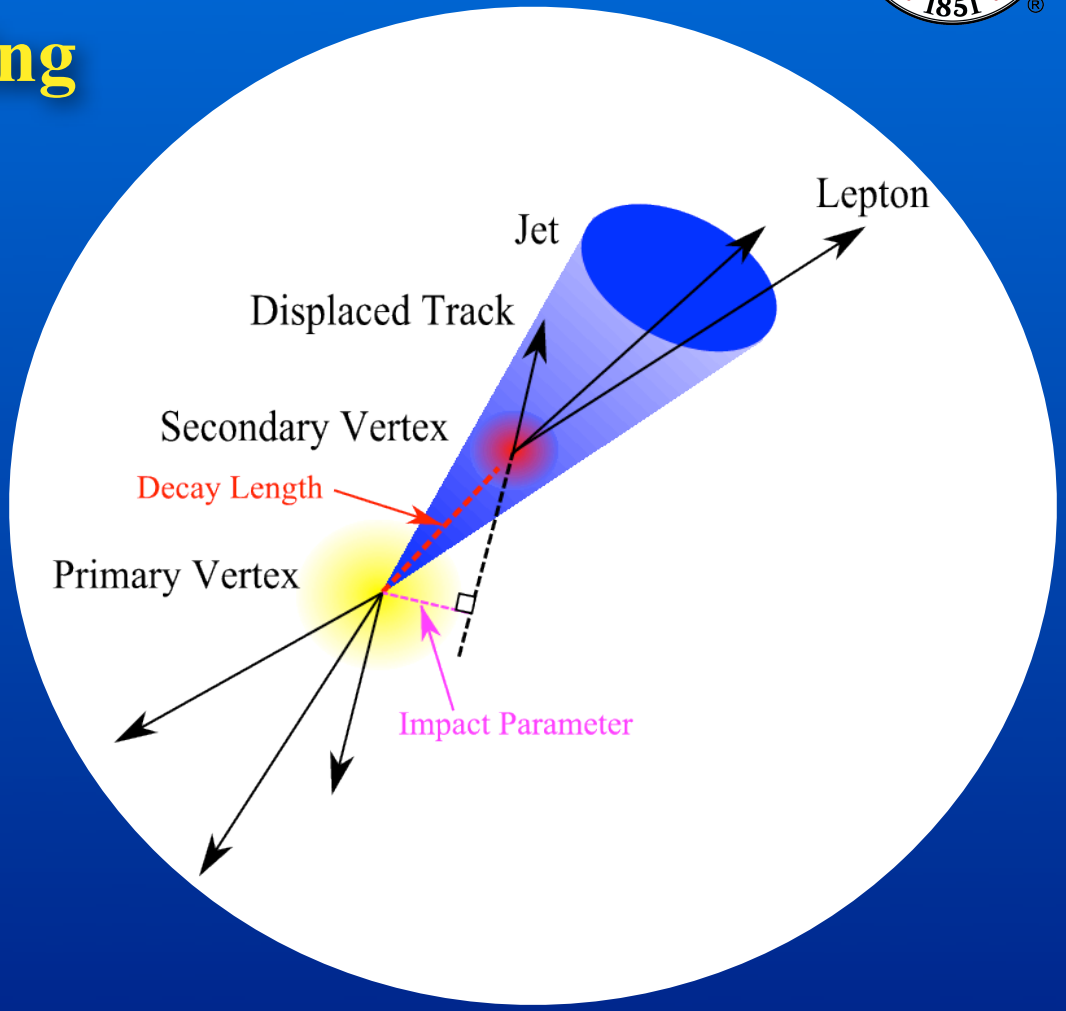
Diboson	2060 ± 12
W (+ light jets)	49251 ± 104
Wcc, Wbb	7792 ± 35
Z (+ light jets)	17663 ± 106
Zcc, Zbb	4526 ± 29
Top	2019 ± 5
Multijet	30243 ± 316
Total Bkgd	113553
Data	113553



b-Jet Tagging

- Multivariate method using
  - impact parameter
  - jet lifetime
  - secondary vertices



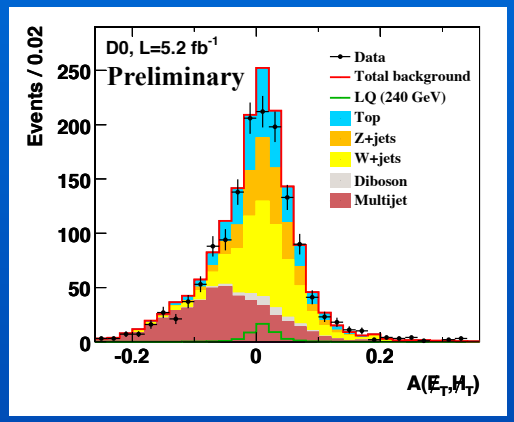


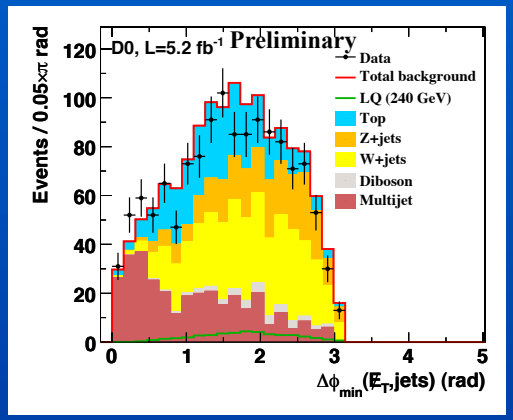
"b-jet identification in the DØ Experiment" to be published in NIM A [arXiv:1002.4224]

Require two b-tagged jets for analysis

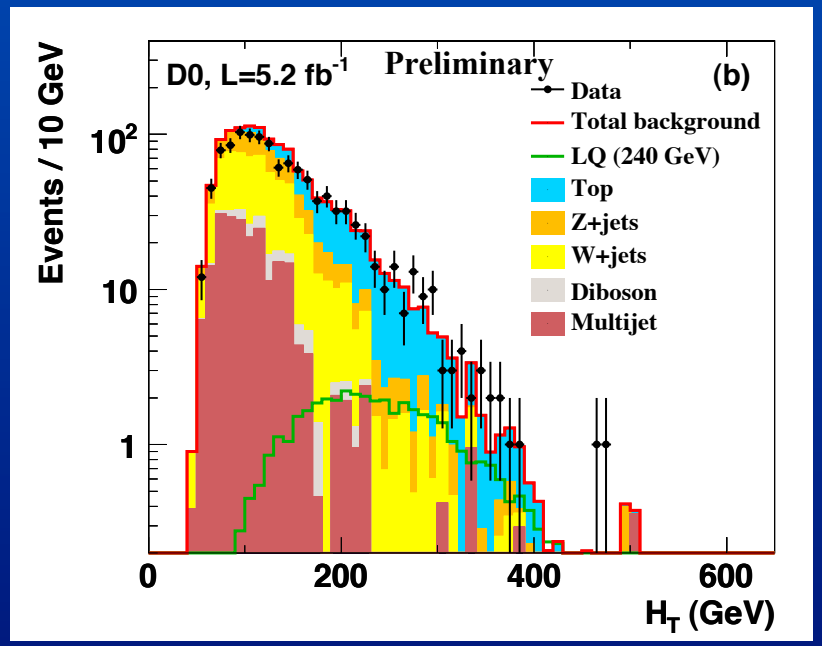
Additional Selection

- Additional selection to reduce multijet background
- $-0.1 < \mathcal{A} < 0.2$
  - $\mathcal{A}$ = (MET - MHT)/(MET + MHT)
- $\Delta\phi$ (MET, jets) > 0.6 rad

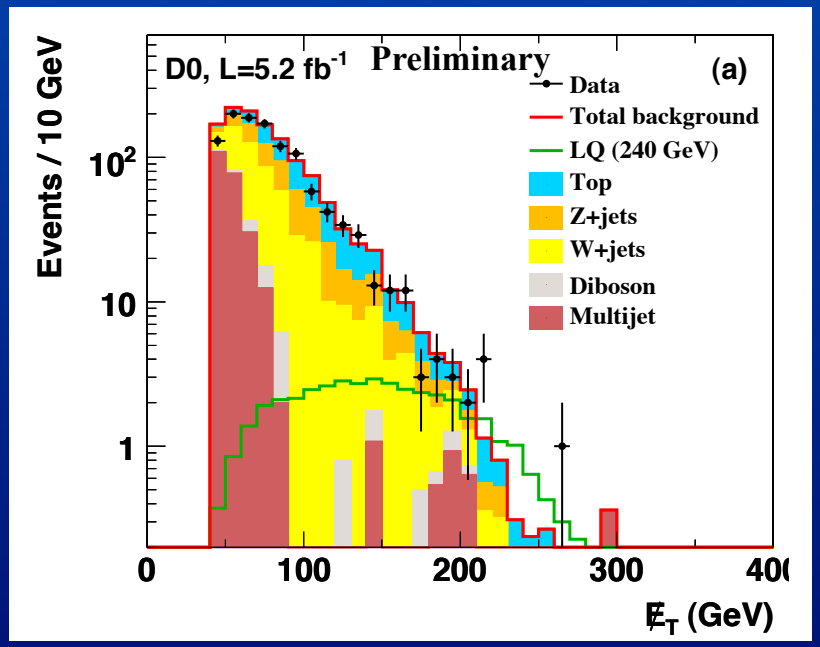




$$MHT = |\Sigma_{jets}\ \vec{p}_T|$$

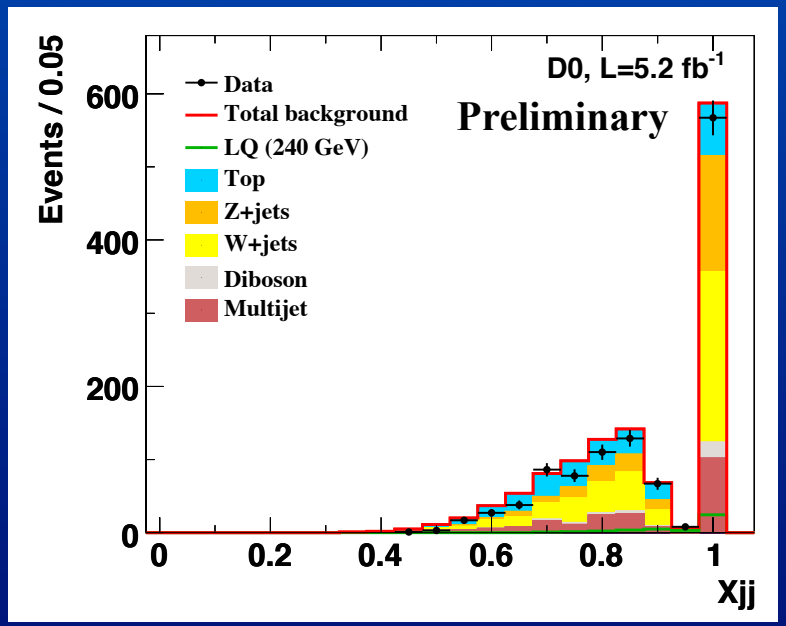


$$H_T = \Sigma_{jets}\ E_T$$



Optimized Selection

- Further optimize selection for each mass point in $(m_{\tilde{b}}, m_{\tilde{\chi}^0})$ space
- $X_{jj} = (E_T^{jet1} + E_T^{jet2})/(\Sigma_{jets} E_T)$
- MET
- H_T
- E_T^{jet1}



Two Sample Mass Points

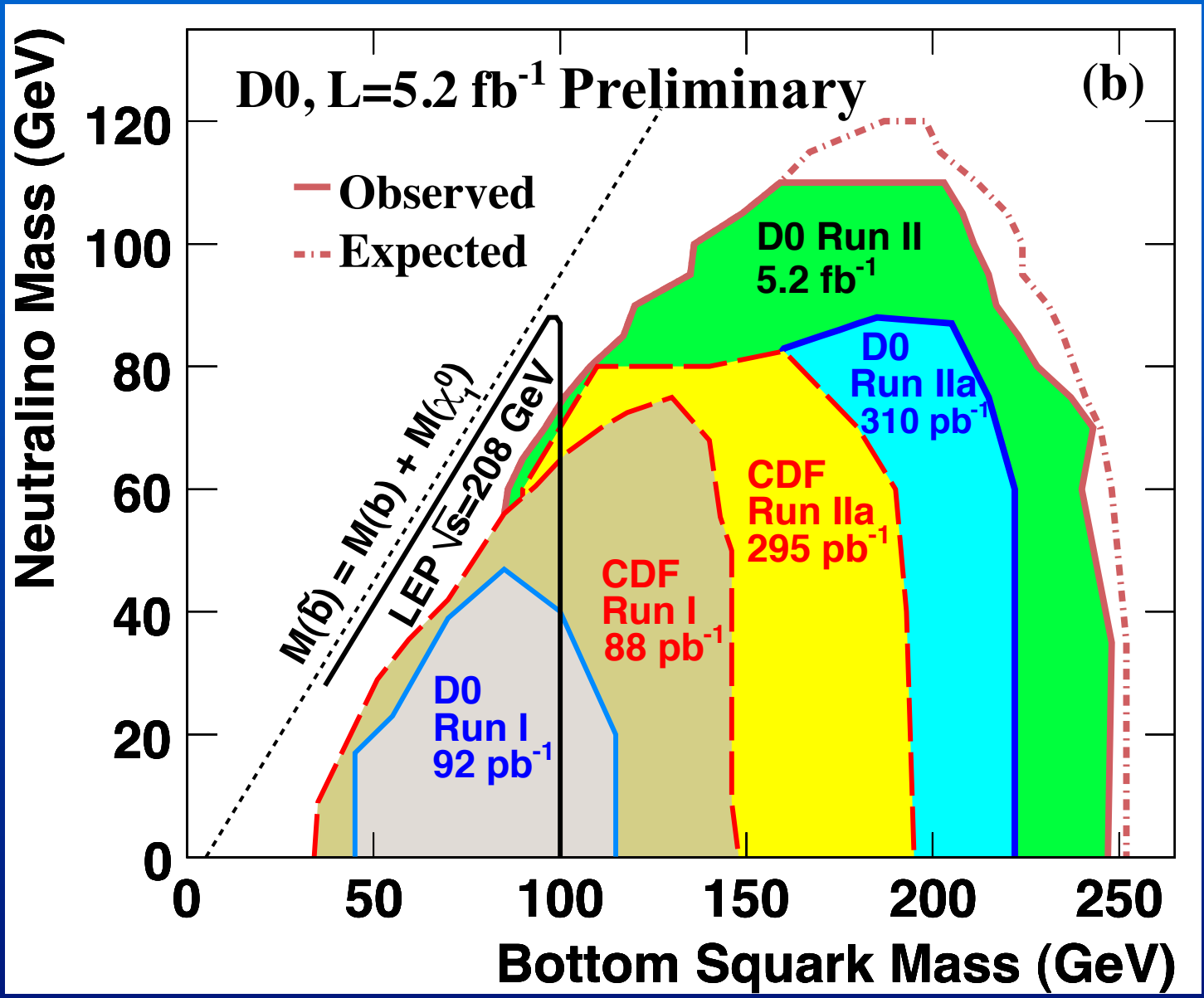
LQ or $(m_{\tilde{b}}, m_{\tilde{\chi}}) = (240,0)$	$(m_{\tilde{b}}, m_{\tilde{\chi}}) = (100,60)$
$X_{jj} > 0.9$ $E_T^{jet1} > 50$ GeV MET > 150 GeV $H_T > 220$ GeV	$X_{jj} > 0.75$ $E_T^{jet1} > 20$ GeV MET > 40 GeV $H_T > 60$ GeV

Final Event Sample

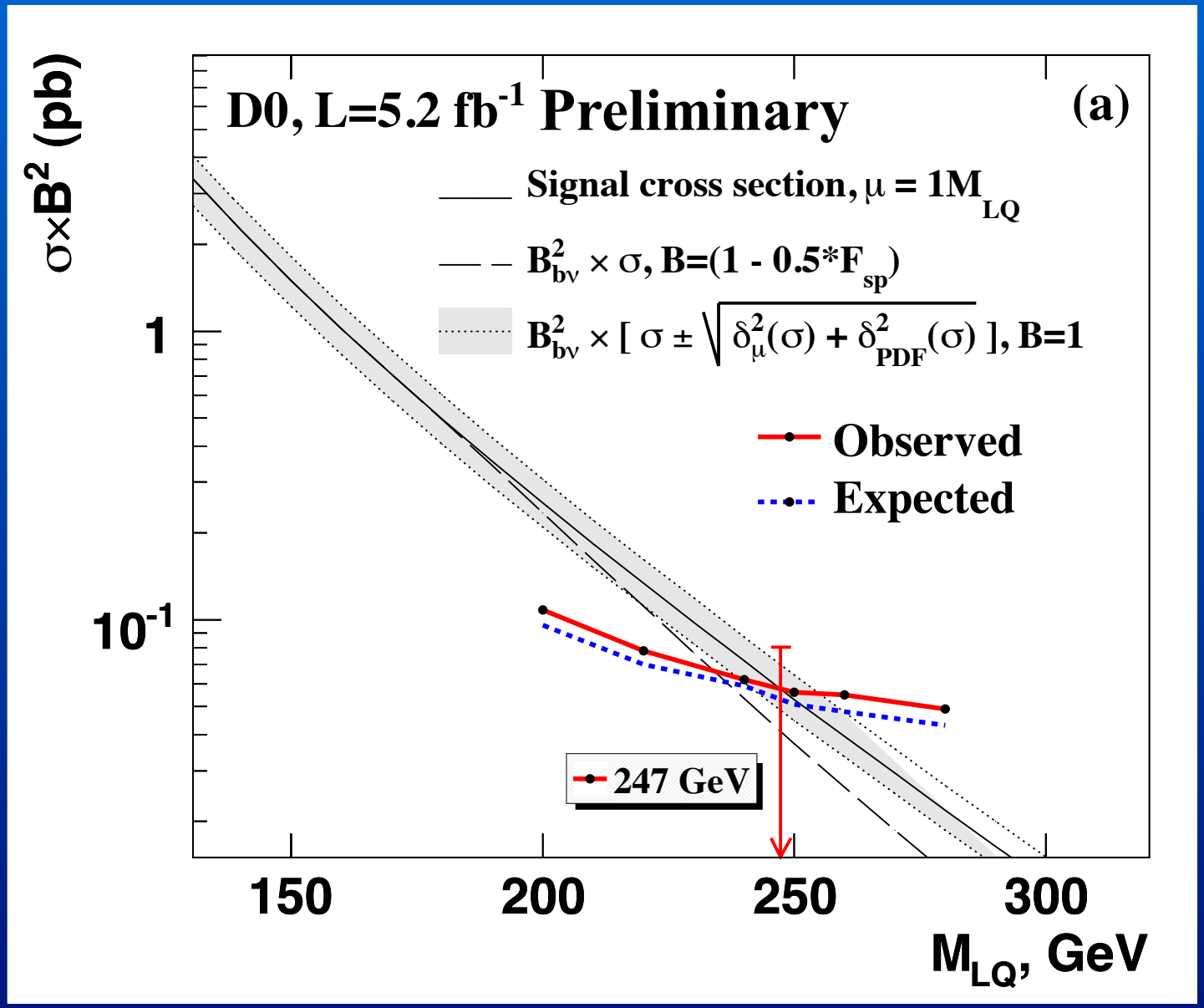
- Comparison of data to expectations for several stages of the analysis

	Pre-tag	b-tag	Additional Selection	Example Low MET	Example High MET
Total Background	113533	1579 ± 22	1242 ± 18	971 ± 17	6.9 ± 0.8
Data	113533	1463	1131	901	7
Signal LQ3 or (m_b,m_χ) = (240,0) GeV	144.6 ± 1.5	43.3 ± 0.8	42.0 ± 0.8		10.5 ± 0.4
Signal (m_b,m_χ) = (100,60) GeV	5478 ± 135	1316 ± 61	1253 ± 60	1109 ± 55	

Sbottom Limits



Scalar Leptoquark Limits



DØ Limits

LQ1 (B=0.5)
$M_{LQ1} > 284$ GeV

LQ2 (B=0.5)
$M_{LQ2} > 270$ GeV

LQ3 (B=1)
$M_{LQ3} > 247$ GeV
(preliminary)

Conclusions

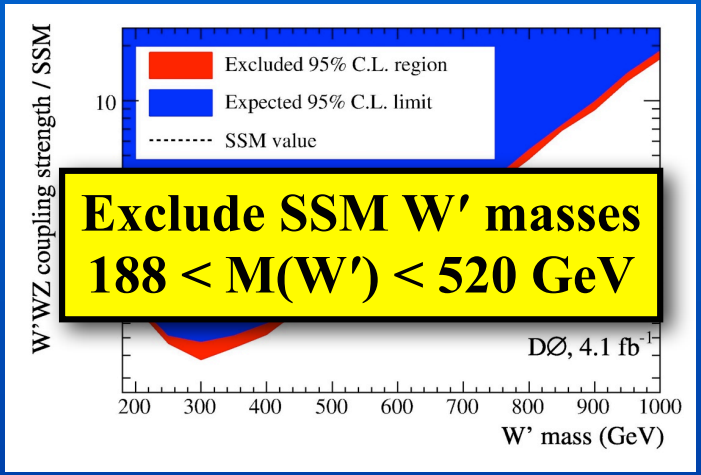
- D0 continues to probe the large, high quality Run II dataset in search of new physics
- Today, we've seen several results with >4 fb^{-1} data
  - $WZ \rightarrow 3l + \nu$ 4.1 fb^{-1}
    - W′
    - technicolor
  - ee, $\gamma\gamma$ 5.4 fb^{-1}
    - Randall-Sundrum gravitons
  - b-jets + MET 5.2 fb^{-1}
    - sbottom
    - 3rd generation leptoquarks
- Other D0 new phenomena results with >4 fb^{-1}
  - dark photons (4.1 fb^{-1}), RPV tau sneutrino (4.2 fb^{-1}, preliminary)

PRL 104, 061801 (2010)

submitted to PRL [arXiv:1004.1826

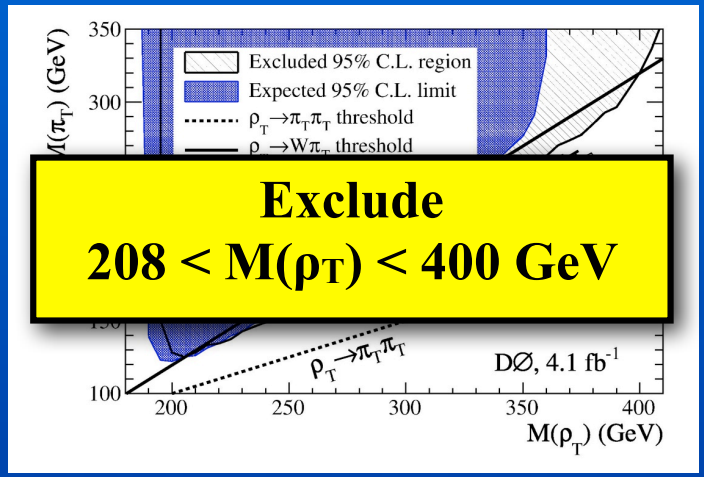
to be submitted soon

Summary

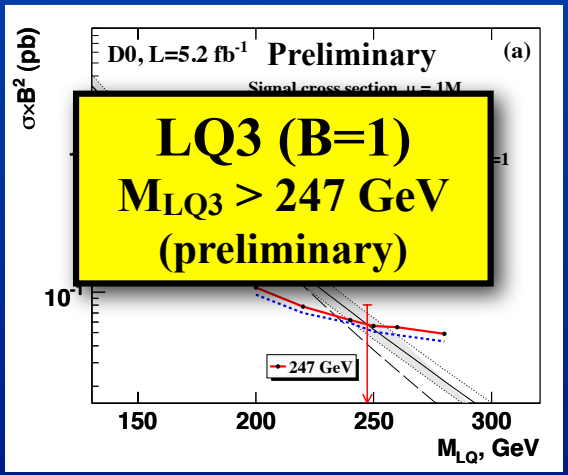


Exclude SSM W′ masses
188 < M(W′) < 520 GeV

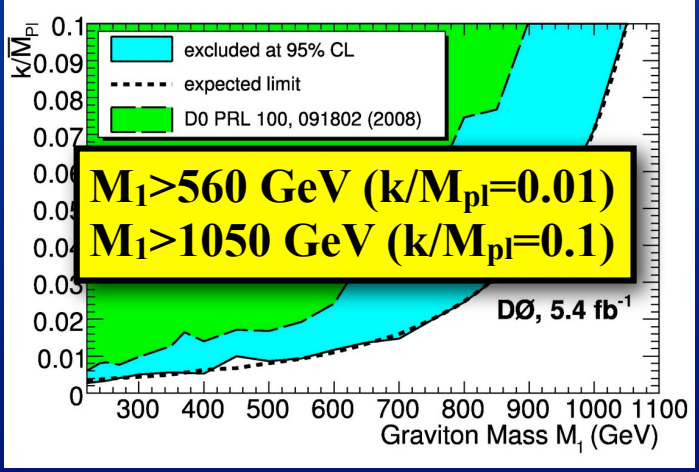
W′
technicolor
RS gravitons
leptoquarks
sbottom



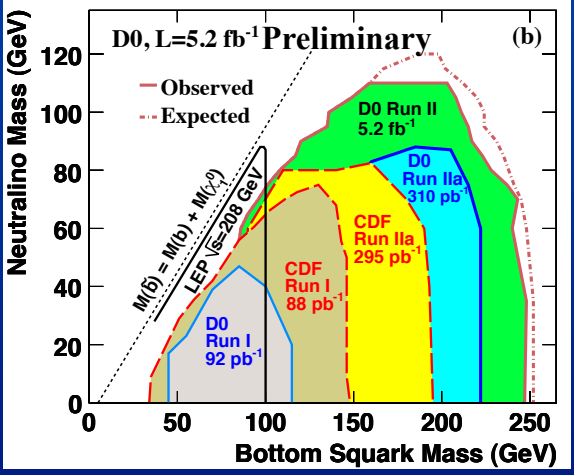
Exclude
208 < M(ρ$_T$) < 400 GeV



LQ3 (B=1)
M_{LQ3} > 247 GeV
(preliminary)

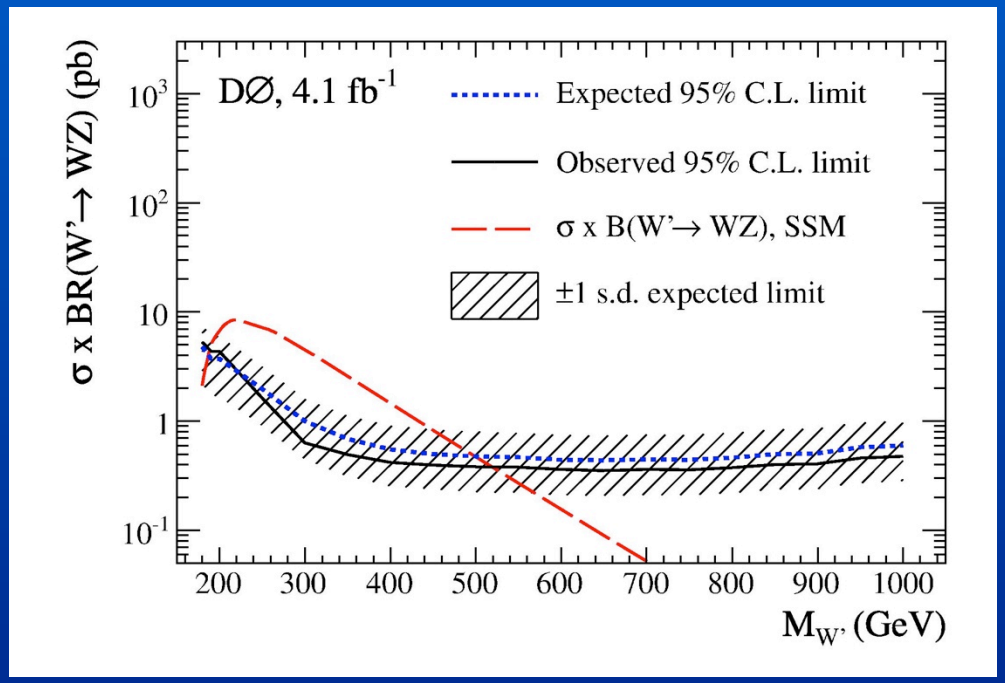


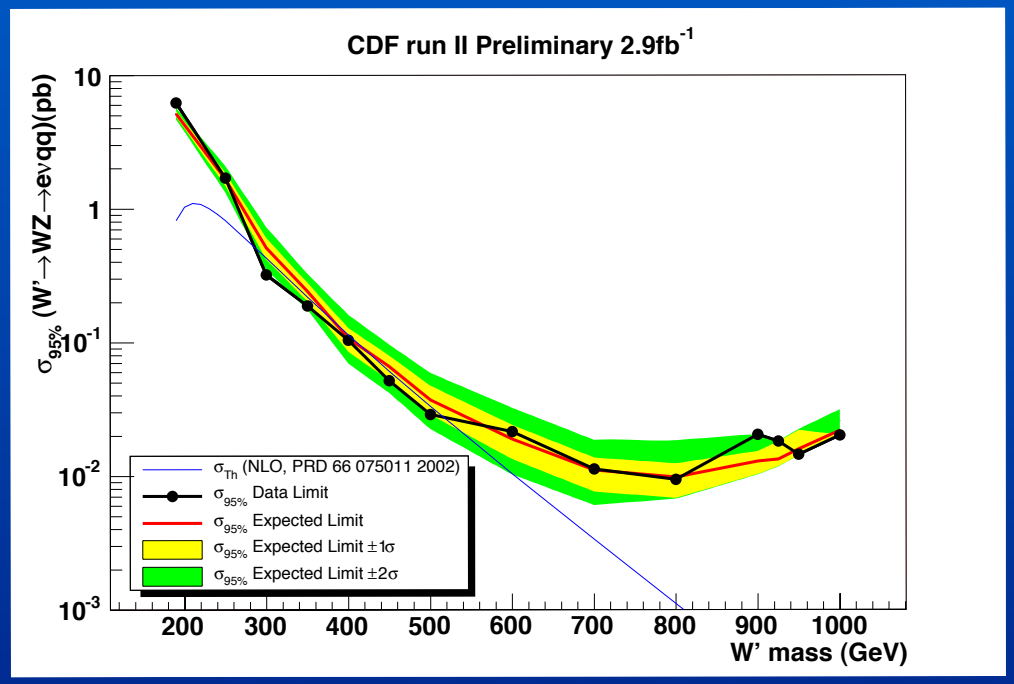
M_1>560 GeV (k/M_{pl}=0.01)
M_1>1050 GeV (k/M_{pl}=0.1)



Backup Slides

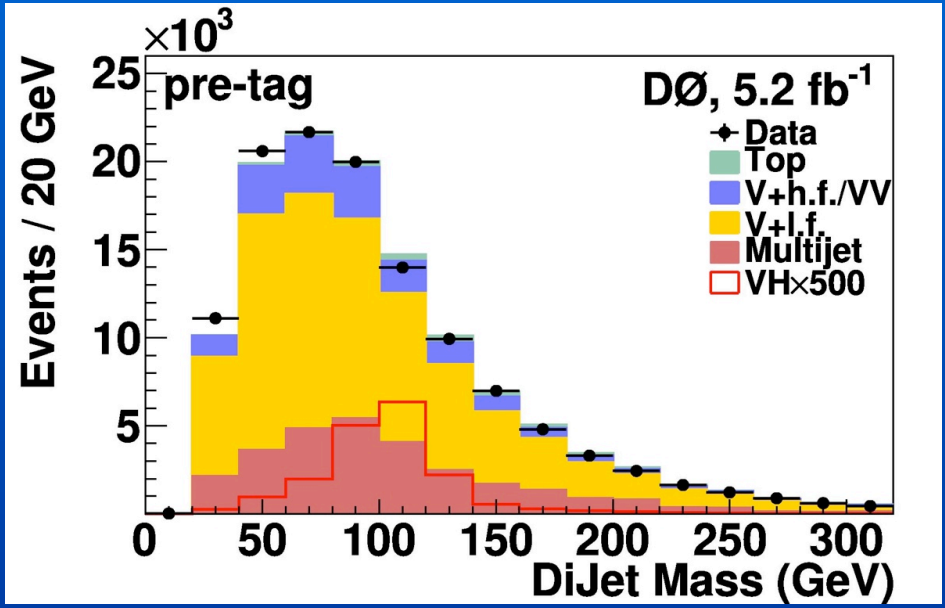
W′ Cross Section Limits

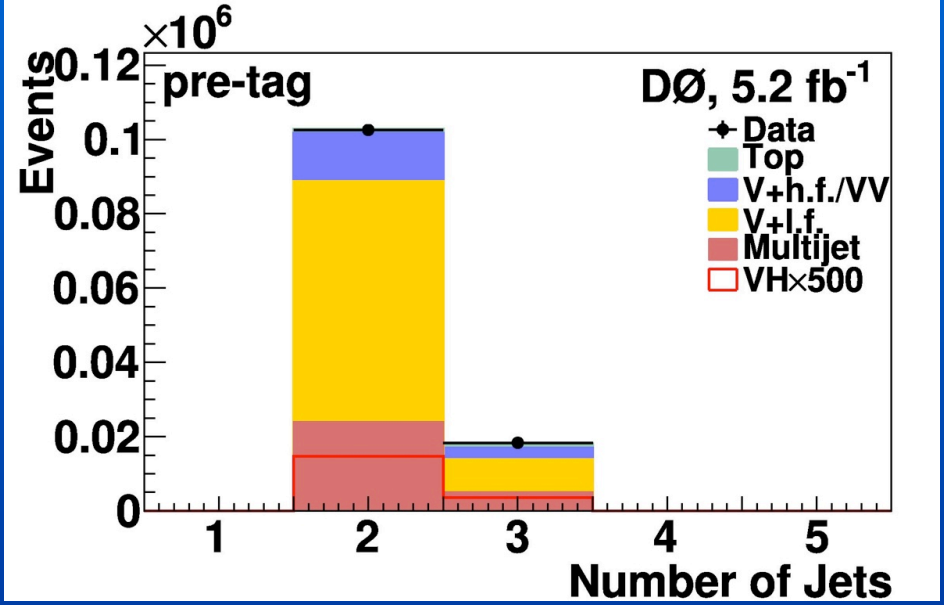


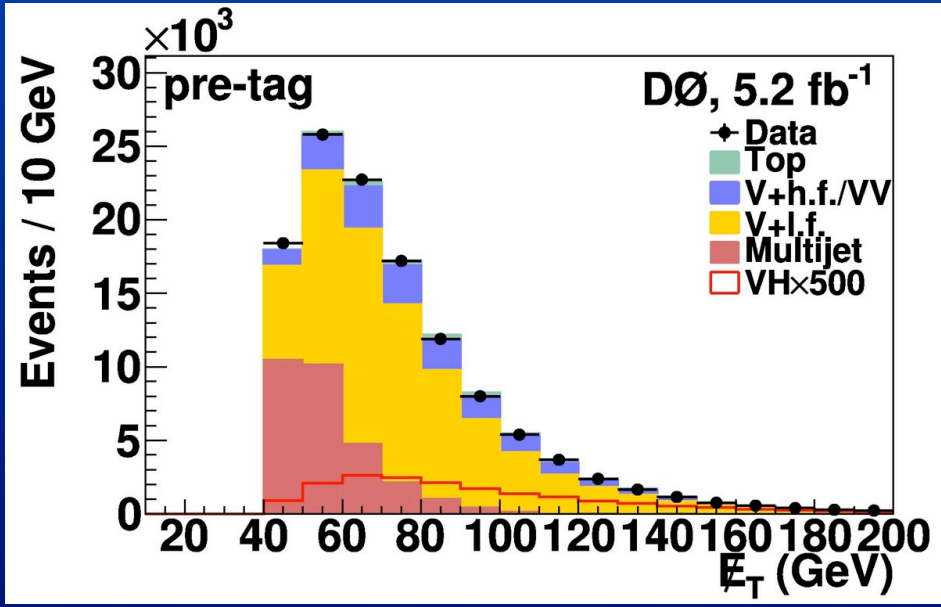


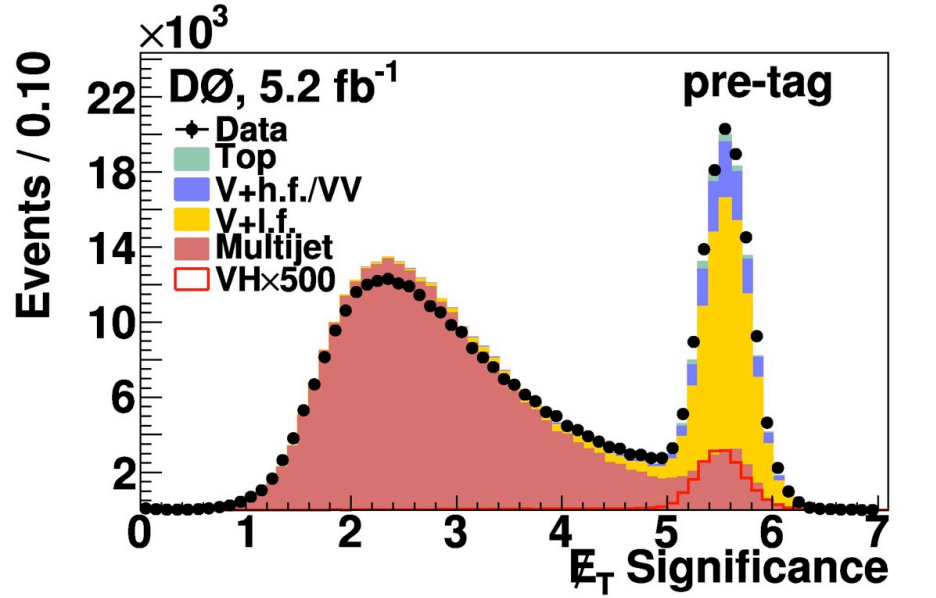
- D0: Exclude SSM W′ masses 188 < M(W′) < 520 GeV (95% C.L.)
- CDF: Exclude W′→ WZ → eνjj (2.9 fb-1 preliminary) 284 < M(W′) < 515 GeV

Pre-Tag


×10^3
pre-tag
DØ, 5.2 fb^-1
Data
Top
V+h.f./VV
V+l.f.
Multijet
VH×500
Events / 20 GeV
DiJet Mass (GeV)


×10^6
pre-tag
DØ, 5.2 fb^-1
Data
Top
V+h.f./VV
V+l.f.
Multijet
VH×500
Events
Number of Jets


×10^3
pre-tag
DØ, 5.2 fb^-1
Data
Top
V+h.f./VV
V+l.f.
Multijet
VH×500
Events / 10 GeV
Ɛ̸T (GeV)


×10^3
DØ, 5.2 fb^-1
pre-tag
Data
Top
V+h.f./VV
V+l.f.
Multijet
VH×500
Events / 0.10
Ɛ̸T Significance