BSM Physics At the TeVatron Searches & Signs

Fermilab User's Meeting

June 2010

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On behalf of the D0 and CDF Collaborations

Topics

Resonances:

- Randall - Sundrum
- High mass lepton pairs
- Dibosons (W^+W^-, $W^\pm Z$)

Signature driven:

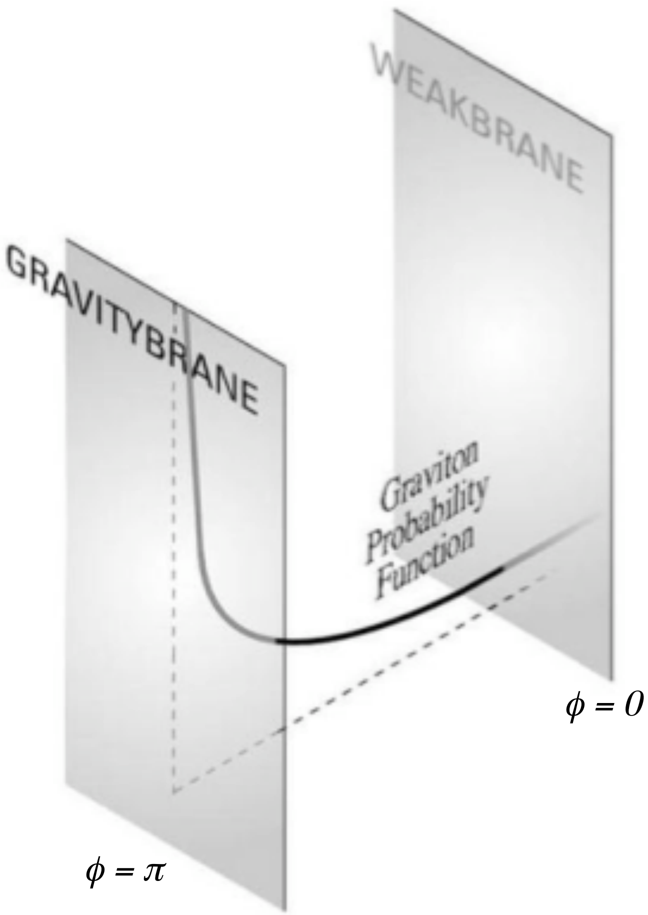
- $\gamma\gamma X$
- jjE_T(MISSING)

SUSY & LQ

4th fermion generation

Excitement in Flavor Physics

Randall-Sundrum Gravitons



$$ds^2 = e^{-2kr_c\phi}\underbrace{\eta_{\mu\nu}dx^\mu dx^\nu}_{\boxed{\text{SM fields at } \phi = 0}} + r_c^2 d\phi^2$$

$kr_c \approx$* 11-12 gives observed *M_P / M_{EW}

Predicted spin-2 graviton spectrum:

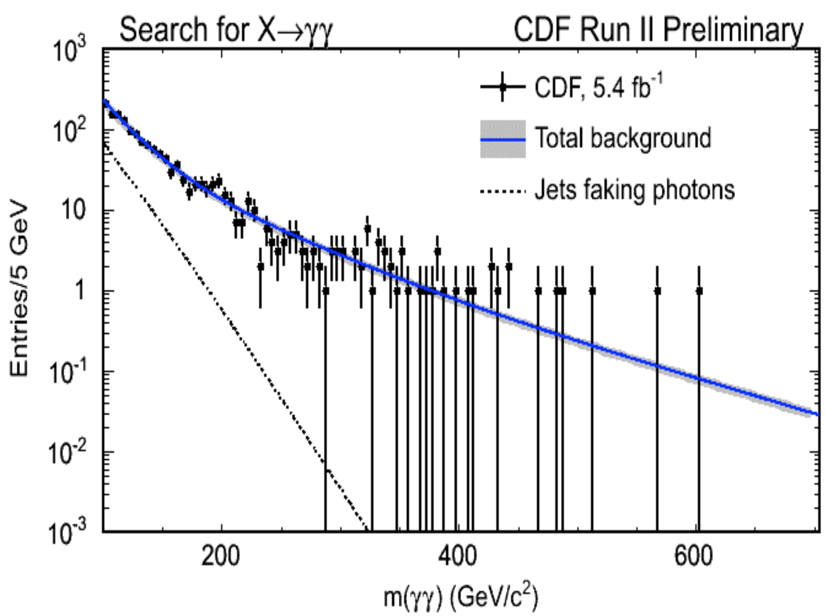
$$m(G) = \begin{bmatrix} 2.405 \\ 5.520 \\ 8.654 \\ \vdots \end{bmatrix} \left(\frac{k}{\overline{M}} = \frac{k\sqrt{8\pi}}{M_P} \right) \Lambda_\pi$$

$$Br(G \rightarrow \gamma\gamma) \,/\, Br(G \rightarrow e^+e^-) = 2$$

Randall-Sundrum Gravitons

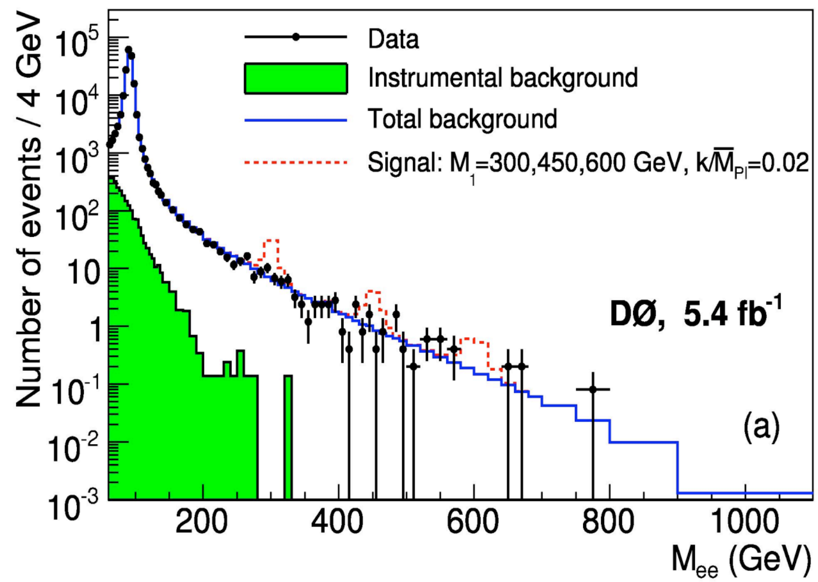
At high γγ mass, major backgrounds are $Z/\gamma^* \rightarrow ee$,
SM continuum production of γγ
Both are modeled by fitting MC (PYTHIA, DIPHOX)
to a smooth function

G→γγ



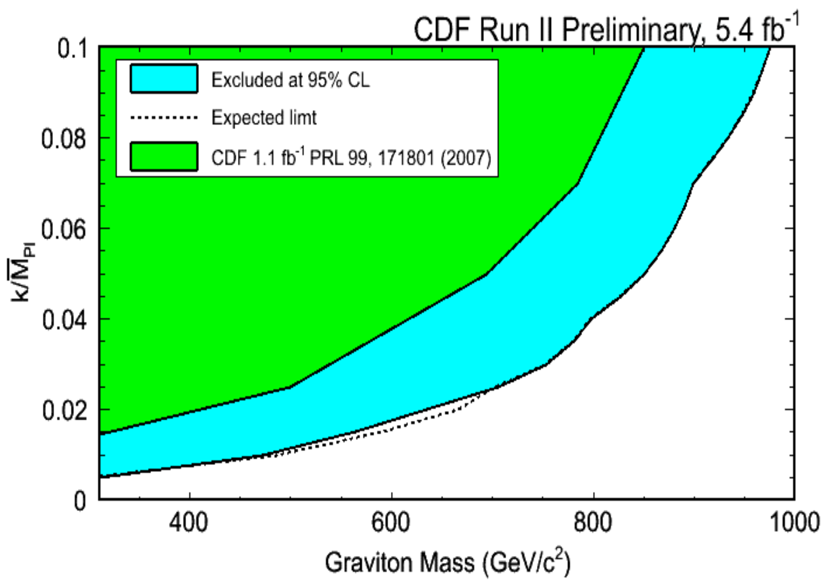
Public note 10158

G→e⁺e⁻

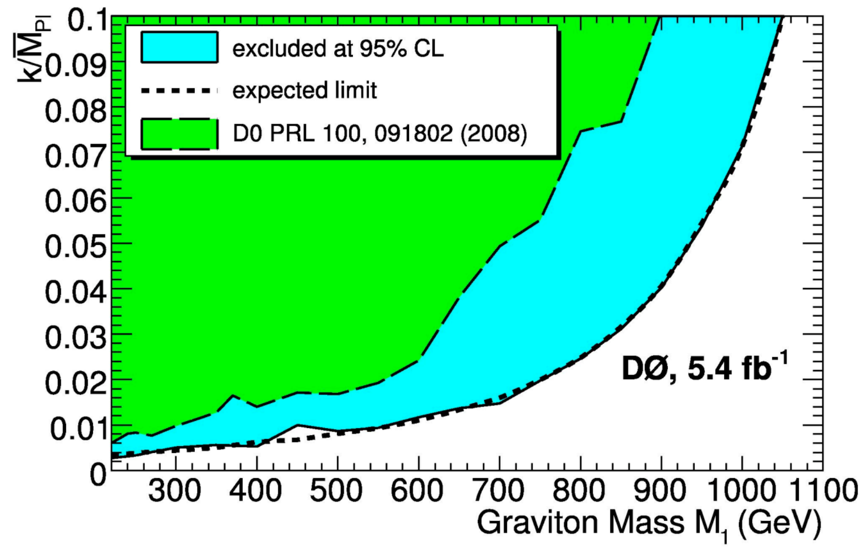


Randall-Sundrum Gravitons

$G \to \gamma\gamma$

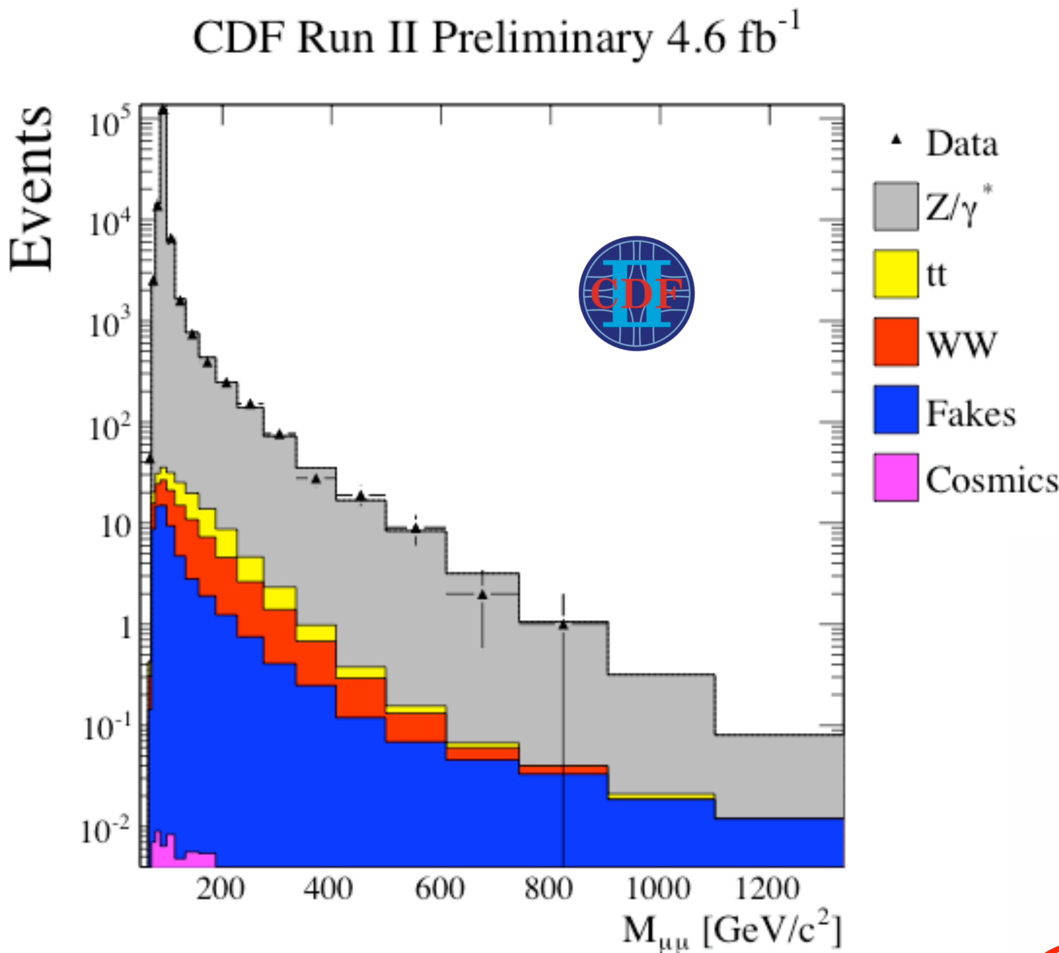


$G \to \gamma\gamma$, $G \to e^+e^-$



Accepted by PRL
arXiv:1004.1826

Dimuon Resonances

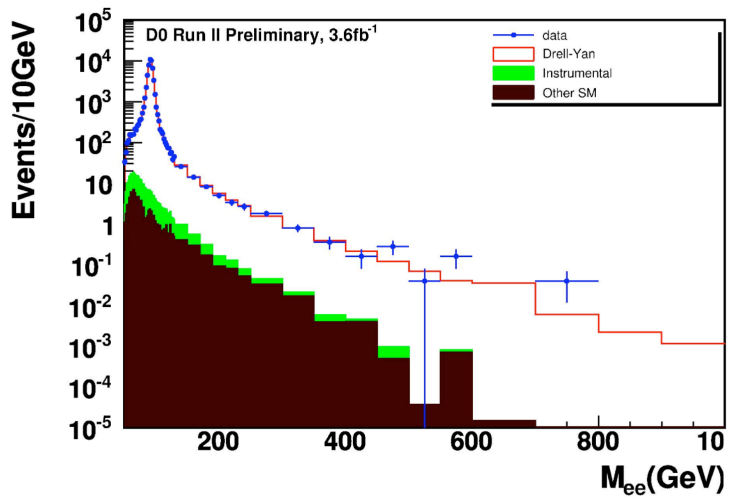


Wide range of models have another spin 1 boson decaying to $\mu^+\mu^-$

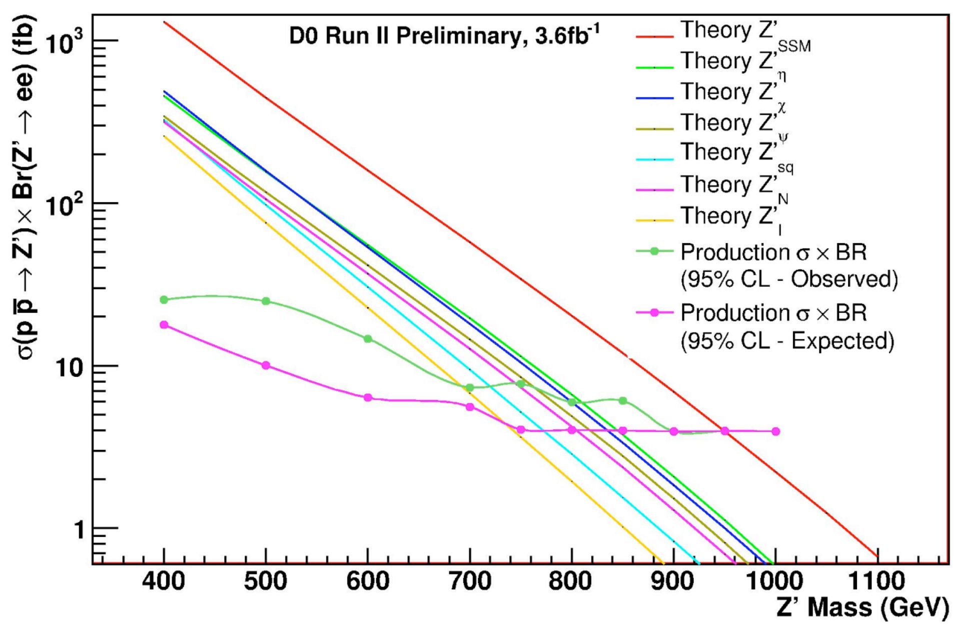
Matrix-element method improves sensitivity 20% over earlier result

Model	Mass Limit (GeV/c^2)
Z'_l	817
Z'_{sec}	858
Z'_N	900
Z'_ψ	917
Z'_χ	930
Z'_η	938
Z'_{SM}	1071

Dielectron Resonances



Mass limits in a wide range of models with spin 1 and spin 2 bosons range from 692 to 950 GeV



Public Note 5923-CONF

DiBoson Resonances

The production of W^+W^-, $W^{\pm}Z$, and ZZ has become an important part of the TeVatron program:

- SM tests (triple gauge couplings, cross-section)
- Validation & development of Higgs search techniques
- Background for BSM searches

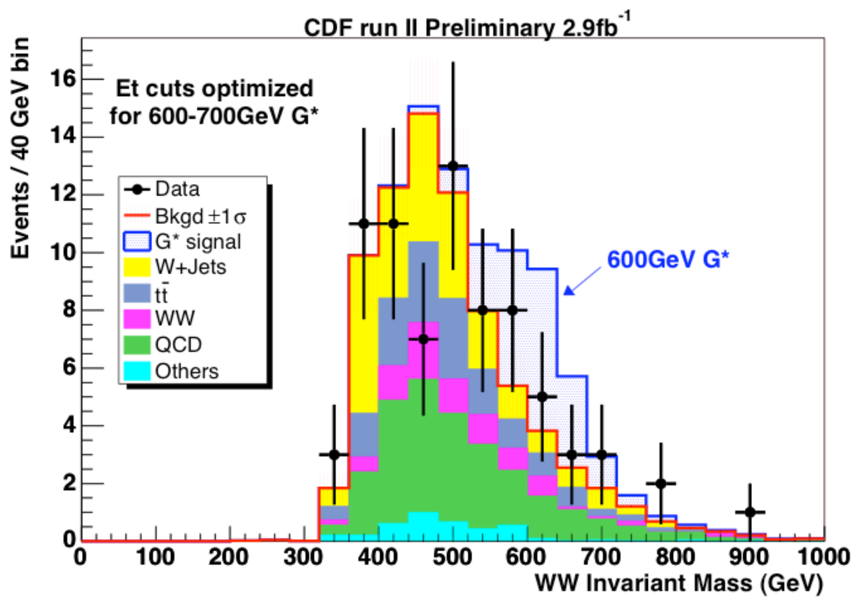
Many models predict resonances in diboson production:

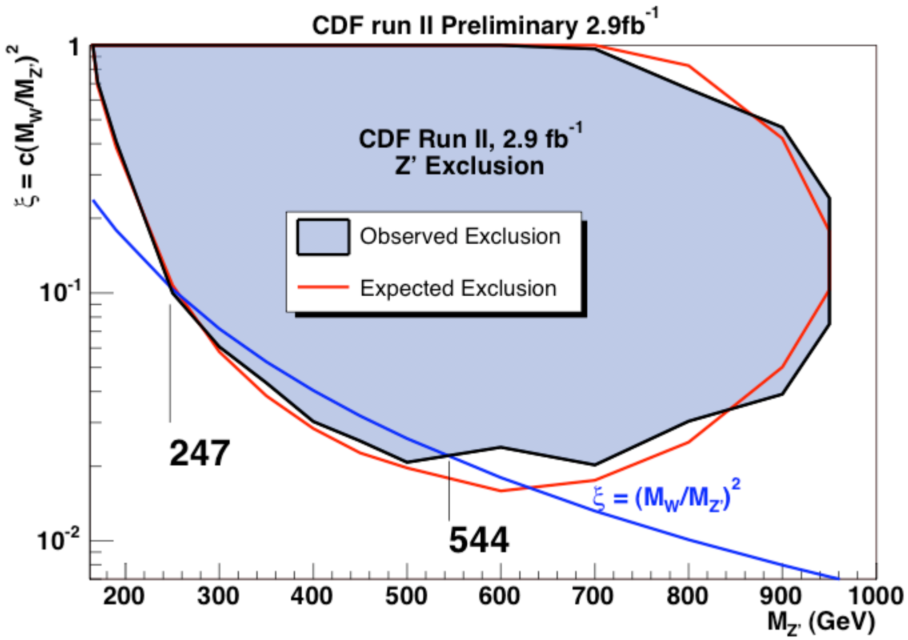
- Randall-Sundrum gravitons, technicolor, sequential bosons . . .

Neutral final states (W^+W^-, ZZ) well studied at LEP but only up to 207GeV

Diboson Resonances

Reconstruct 2 jets - require mass consistent with $m(W)$
Require also an electron with > 30GeV E_T & missing E_T > 30GeV
Then only one $\nu \Rightarrow$ can solve for P_z (quadratic ambiguity)





95% C.L. lower limit on mass $G(k/M_P=0.1)\rightarrow WW$ of 632GeV

Change $65 < M(jj) < 95$GeV cut to $70 < M(jj) < 105$ GeV cut $284 < m(W' \rightarrow WZ) < 515$ GeV

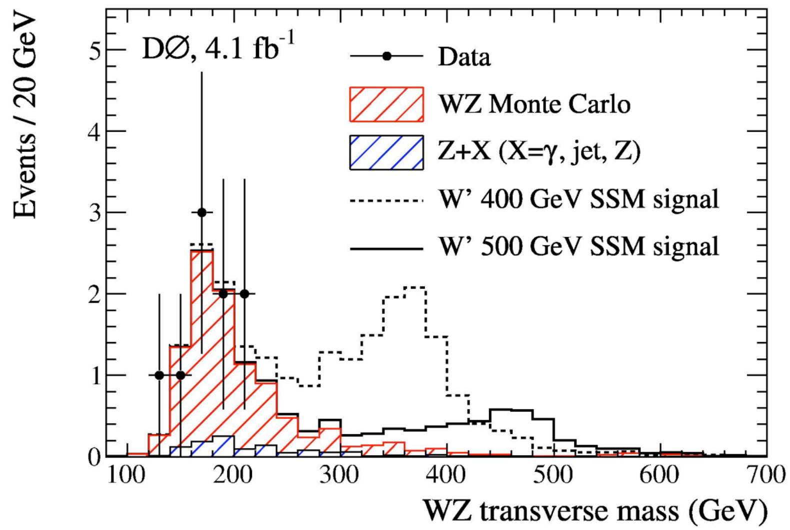
Accepted by PRL
arXiv:1004.4946

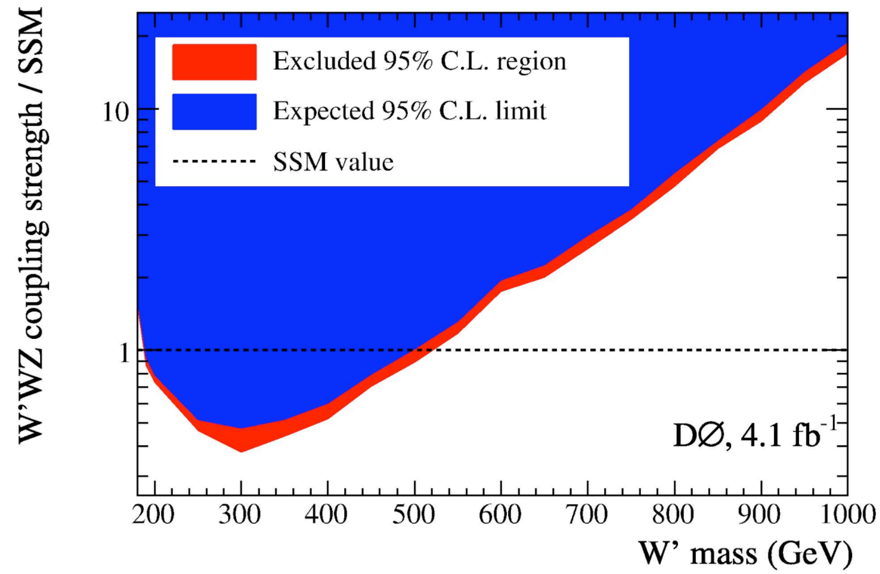
$W^{\pm}Z$ Resonances

$$p\bar{p} \to W^{\pm}Z \to \left(\ell^{\pm}\nu\right)\left(\ell^{+}\ell^{-}\right)$$

$$\ell \in \{e, u\}$$

A very clean channel - trilepton events are rare at the TeVatron





$$M_T = \sqrt{\left(E_T^Z + E_T^W\right)^2 - \left(p_x^Z + p_x^W\right)^2 - \left(p_y^Z + p_y^W\right)^2}$$

$188 < m(W'_{SM}) < 520$ GeV 95% C.L.

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

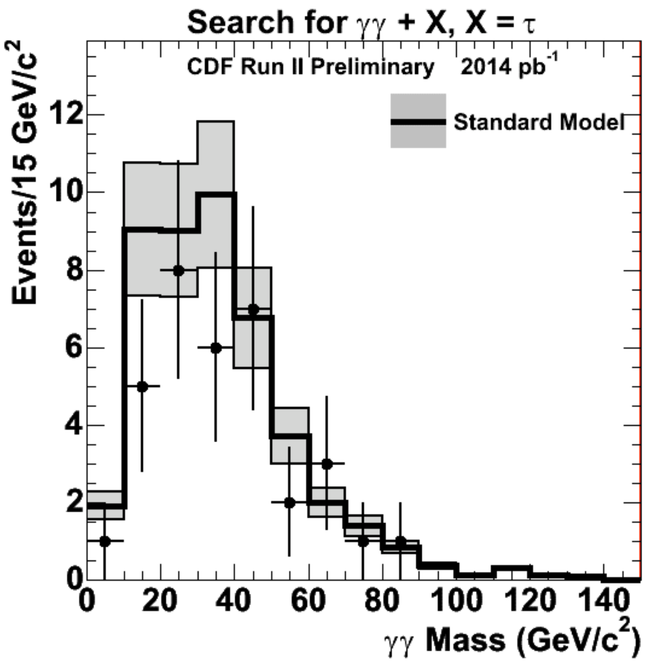
Low-scale Technicolor limits
$208 < m(\rho_T) < 408$ GeV
for $m(\rho_T) < m(\pi_T) + m(W)$

Signature Driven

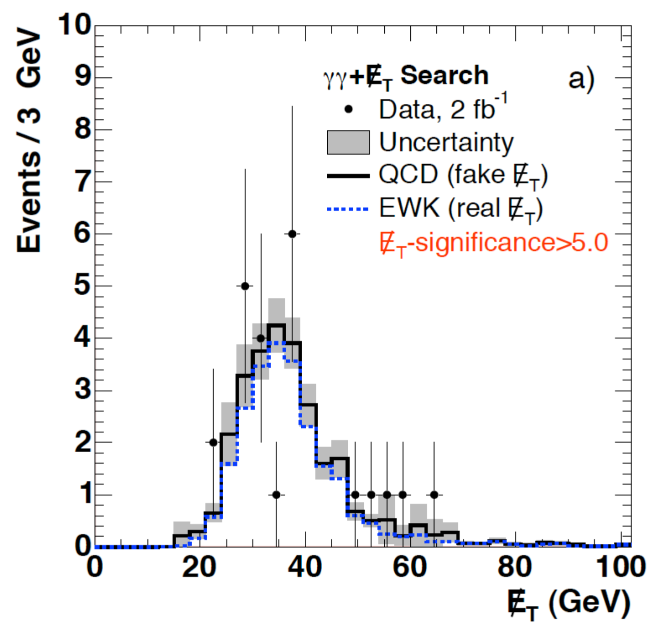
$$p\bar{p} \rightarrow \gamma\gamma\, X,\ \ X \in \{e^{\pm}, \mu^{\pm}, \tau^{\pm}, \not{E}_T\}$$

Require 2γ with $E_T > 13$ GeV in $0.05 < |\eta| < 1.05$

	electrons	muons
$Z\gamma\gamma$	0.82 ± 0.08	0.50 ± 0.05
$W\gamma\gamma$	0.15 ± 0.02	0.08 ± 0.01
$\ell\gamma + e\rightarrow\gamma$	2.26 ± 0.46	0.004 ± 0.004
$\ell\gamma + jet\rightarrow\gamma$	0.44 ± 0.26	0.12 ± 0.08
Fake $\ell + \gamma\gamma$	0.12 ± 0.05	0.004 ± 0.004
Total bkgd	3.79 ± 0.54	0.71 ± 0.1
Data	1	0



Submitted to P.R.D.
arXiv:0910.5170



Consistent with Standard Model

Signature Driven

$$p\bar{p} \rightarrow jj\ \not{E}_T$$

Many SM extensions require pair-production of new particles (prevents large contributions to well measured SM processes)

Decays to jet + non-interacting particle occur in many models

Look for events with 2 jets and large missing E_T

Backgrounds are W, Z production at high p_T with jets

Cut-and-count:

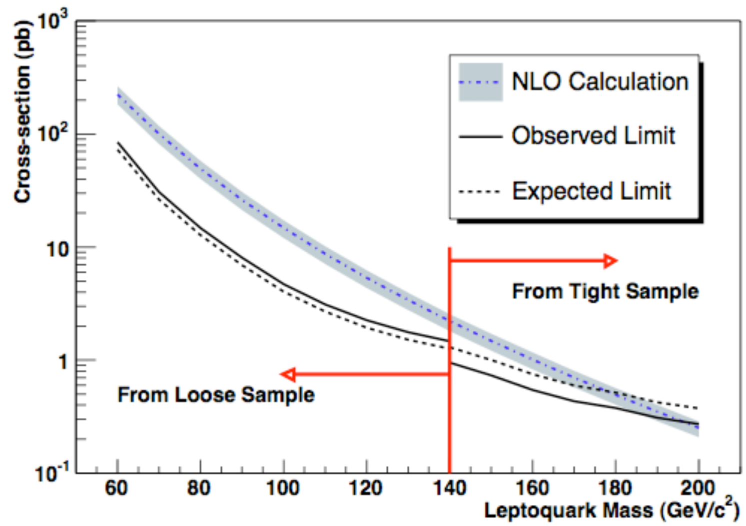
No extra jets with $E_T > 15$ GeV
No isolated tracks with $p_T > 10$ GeV

Loose sample:

$E_T^{(1)} + E_T^{(2)} > 125$ GeV
$\not{E}_T > 80$ GeV
2506 observed *vs* 2443 ± 151 expected

Tight sample:

$E_T^{(1)} + E_T^{(2)} > 225$ GeV
$\not{E}_T > 100$ GeV
186 observed *vs* 211 ± 30 expected



$m(\text{scalar LQ} \rightarrow q\nu) > 187$ GeV

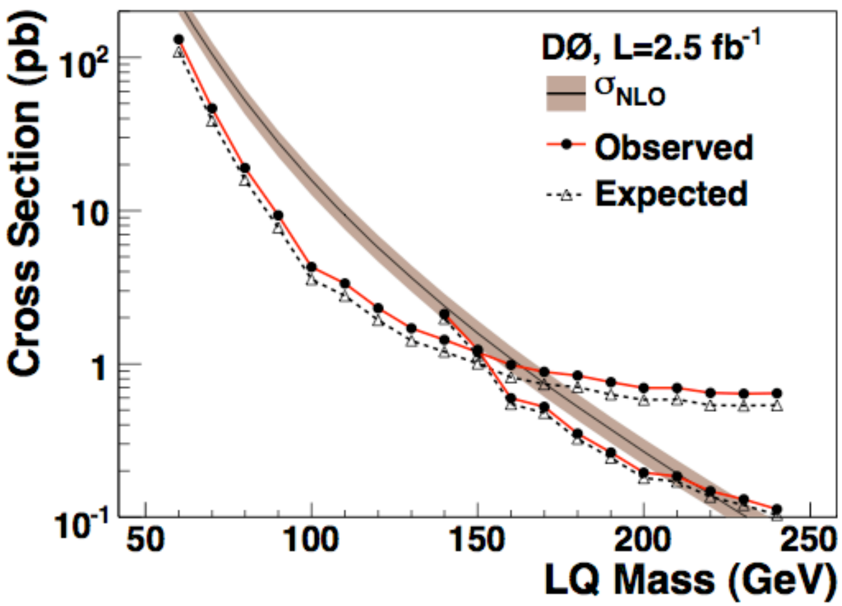
Submitted to P.R.L
arXiv:0912.4691

Signature Driven

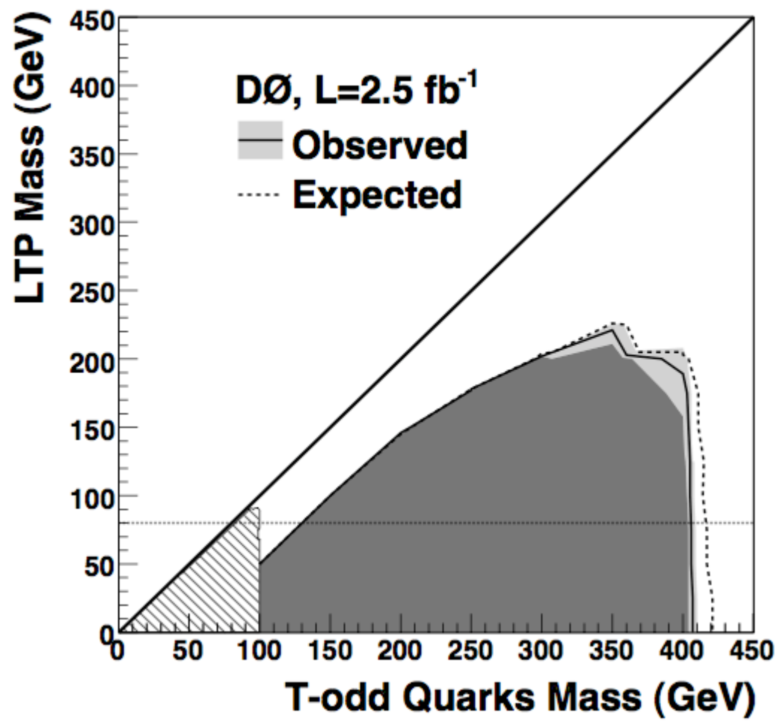
$$p\bar{p} \rightarrow jj \,\not{E}_T$$

P.L. **B668**, 357

Little Higgs model

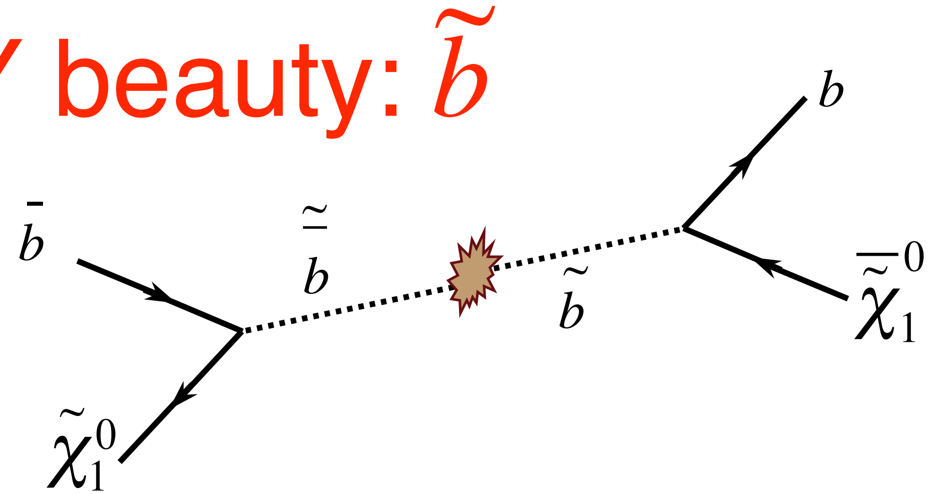


$m(\text{scalar LQ} \rightarrow q\nu) > 205$ GeV

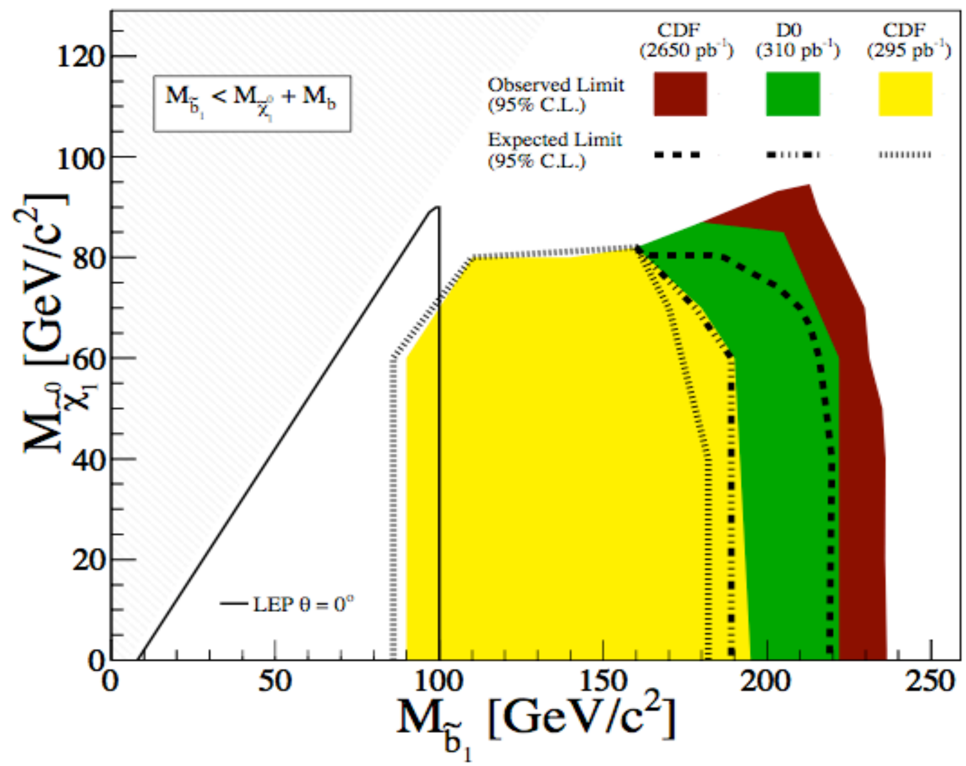


SUSY beauty: $\tilde{b}$

$$p\bar{p} \rightarrow bb \not{E}_T$$

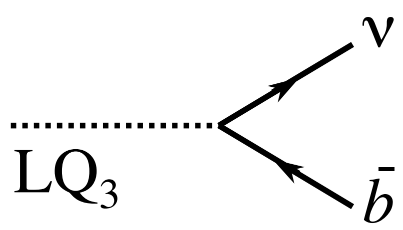


$E_T^{(1)}$, $E_T^{(2)} > 15$ GeV
$\not{E}_T > 10$ GeV
At least 1 b-tagged jet!
No extra jets with $E_T > 15$ GeV
Isolated track veto
$|\eta^{(jet1)}| < 1.1, \quad |\eta^{(jet2)}| < 2.0$



Submitted to P.R.L.
arXiv:1005.3600

Leptoquarks & $\tilde{b}$

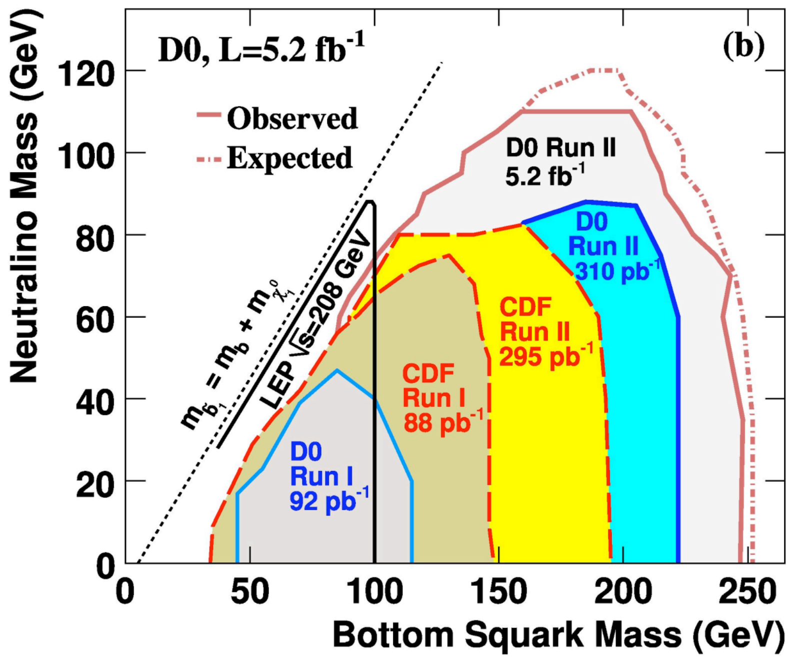


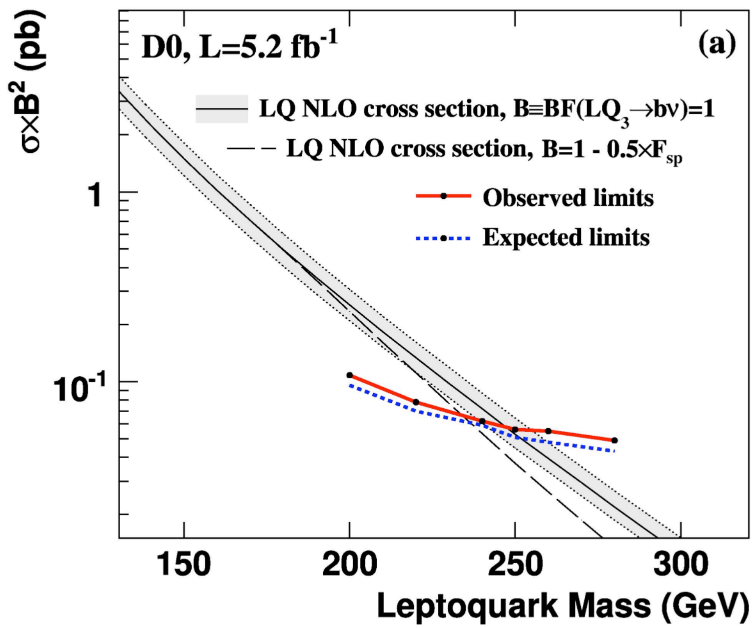
$$p\bar{p} \rightarrow LQ_3\,\overline{LQ_3} \rightarrow b\bar{b}\,\nu\bar{\nu}$$

Very similar to

$$p\bar{p} \rightarrow \tilde{b}_1\tilde{b}_1 \rightarrow b\bar{b}\,\tilde{\chi}_1^0\,\overline{\tilde{\chi}_1^0}$$

signal is 2 b jets with E_T^{MISS}





Submitted to P.L.B.
arXiv:1005.2222

4th SM fermion generation

Cancellation of gauge anomalies requires either all 4 fermions or none at all!

Direct searches:

$m(\nu'_{\mathrm{MAJ}}) > 80.5$ GeV
$m(\nu'_{\mathrm{DIRAC}}) > 90.3$ GeV
$m(\tau') > 100.8$ GeV

EW Precision Constraints

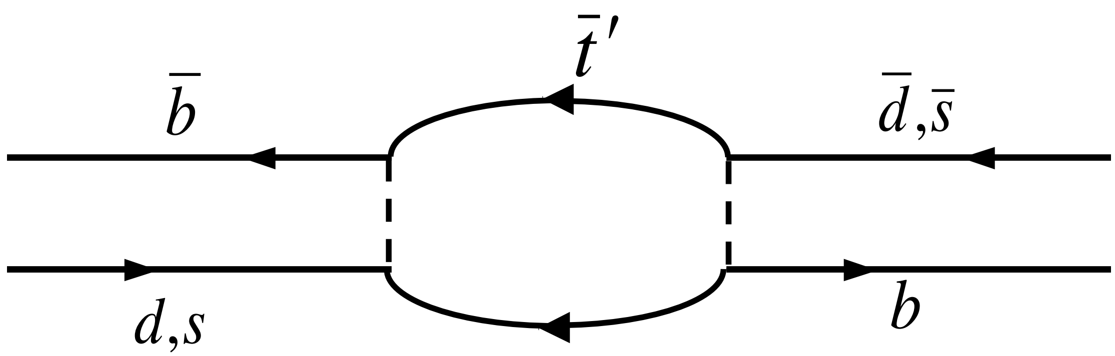
$$m(\tau') - m(\nu') \approx 60 - 85\, GeV$$

$$|m(t') - m(b')| \leq 30\ GeV$$

$$m(f') - m(\exp.\mathrm{limit})\ \mathrm{small}$$

$q' \rightarrow q^{(3)} + W$

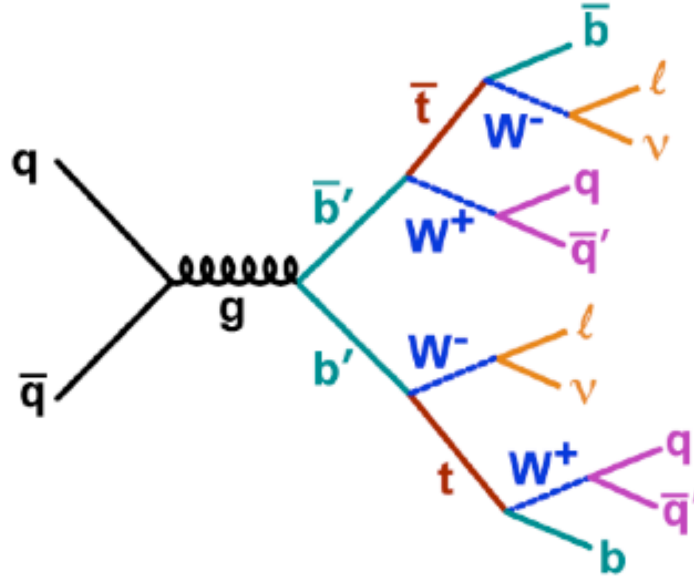
See also arXiv:1005.3505
arXiv:1005.1077
arXiv:1003.3211
arXiv:1002.0595



Combined TeVatron limits on m_H arXiv:1005.3216

4th SM fermion generation

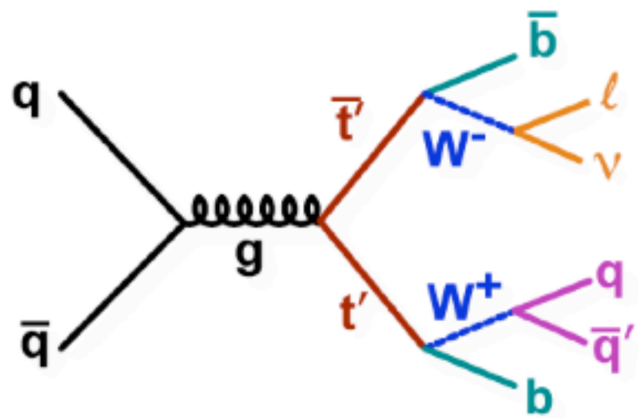
- b′: look for LS dilepton+jets +MET events



$m(b')$ > 338 GeV
if Br($b' \rightarrow tW$) = 1
CDF 2.7 fb^{-1}

P.R.L. 104, 091801

- t′: look for lepton+jets +MET events

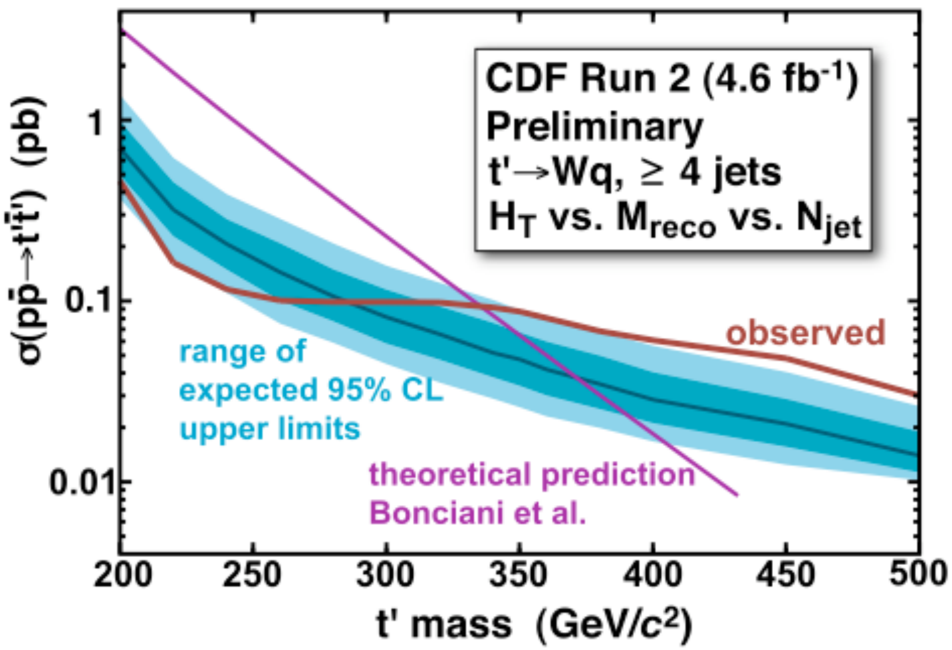


Like the search for top but:

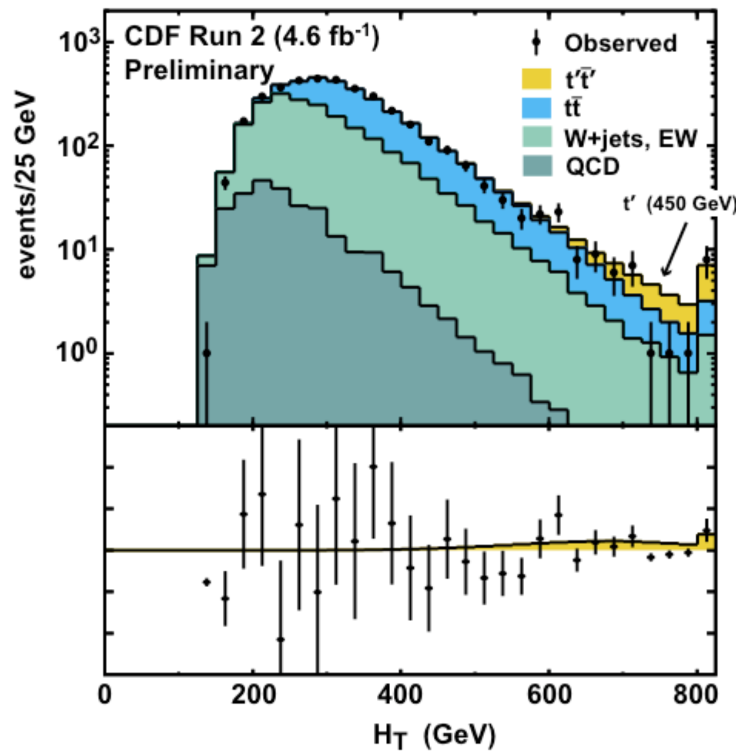
- **Reduce sensitivity to CKM mixing by NOT *b*-tagging**
- **Large t' mass ⇒ large scalar sum of E_T**

t' Search

- In each event, a fit assigns reconstructed jets to partons, resolves 2-fold ambiguity in $E_z(\nu)$ and assigns $m_{\text{RECO}}(t')$
- Then use $m_{\text{RECO}}(t')$ and $H_T = \Sigma E_T$ distributions from data and linear combination of background distributions in likelihood fits

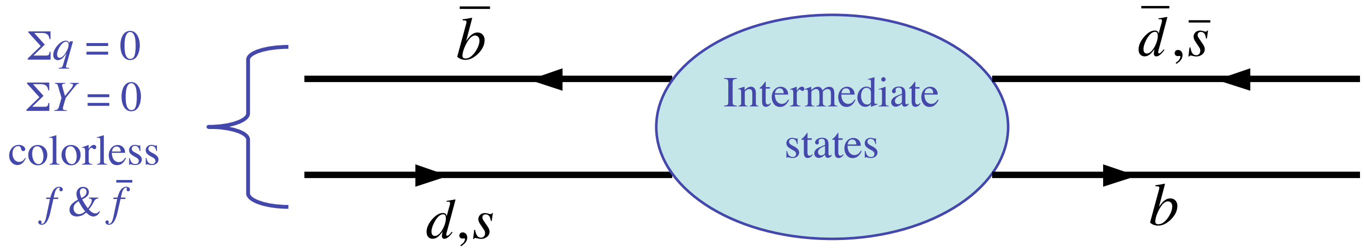


$m(t') > 335$ GeV @ 95% C.L.



Signs of New Physics

Neutral meson mixing simplified:



$$i \frac{\partial}{\partial t} \begin{bmatrix} |B^0\rangle \\ |\bar{B}^0\rangle \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} |B^0\rangle \\ |\bar{B}^0\rangle \end{bmatrix}$$

To get $H_{12} = M_{12} - (i/2)\Gamma_{12}$ right, you need to know all the intermediate states; and if you got H_{12} wrong, there might be new-physics intermediate states that you don't know about!

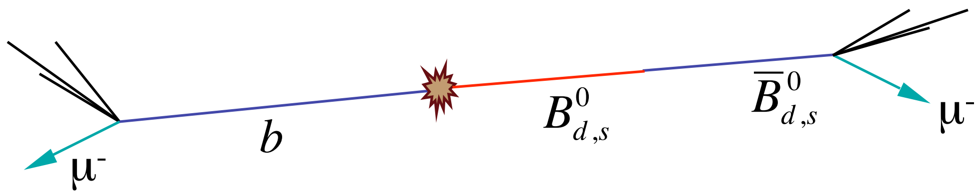
If $arg(M_{12}/\Gamma_{12}) \neq 0$, rate ($B^0_{d,s} \rightarrow \bar{B}^0_{d,s}$) $\neq$ the rate ($\bar{B}^0_{d,s} \rightarrow B^0_{d,s}$)

Then $$\frac{\Gamma\left(\bar{\mathrm{B}}^0_{\mathrm{q}} \rightarrow \mu^+ X\right) - \Gamma\left(\mathrm{B}^0_{\mathrm{q}} \rightarrow \mu^- X\right)}{\Gamma\left(\bar{\mathrm{B}}^0_{\mathrm{q}} \rightarrow \mu^+ X\right) + \Gamma\left(\mathrm{B}^0_{\mathrm{q}} \rightarrow \mu^- X\right)} \neq 0$$

Inclusive muon charge asymmetry

New Physics from Flavor Physics

Dimuon charge asymmetry



There are few other sources of like-sign dimuons

From the signal process, dimuon and inclusive muon asymmetries will be equal

Combining both inclusive and like-sign dimuons works best (backgrounds are correlated)

Submitted to P.R.D.
arXiv:1005.2757
FNAL Pub 10/114-E

$$A^b_{sl} = \left(-9.57\ \pm 2.51_{\mathrm{STAT}}\ \pm 1.46_{\mathrm{SYST}}\right)\times 10^{-3}$$

$$A^b_{sl}\left[SM\ \ prediction\right] = \left(-0.23\ {}^{+0.05}_{-0.06}\right)\times 10^{-3}$$

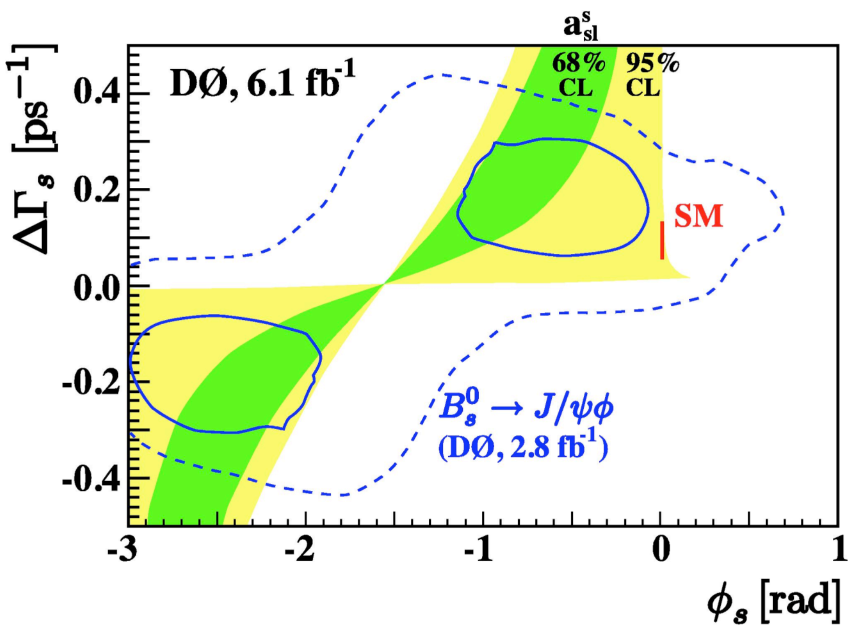
3.2σ (99.8% C.L.) disagreement with SM

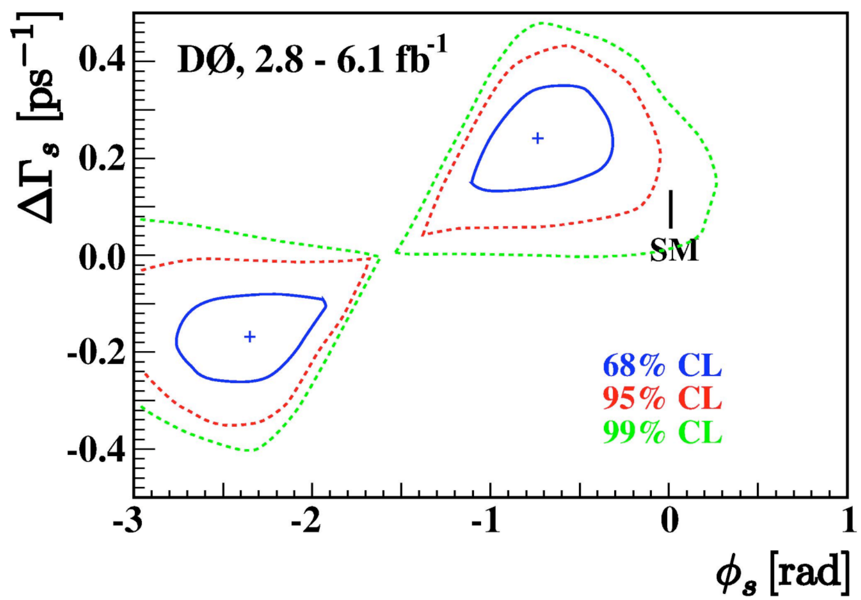
Using Lenz & Nierste, JHEP 0706:072 (2007)
Grossman et.al. PRL 97, 151801(2006)

New Physics from Flavor Physics

Constrain the CP violation parameters $\phi_s \approx -2\beta$ and $\Delta\Gamma_s$

Compare against values from $B_s \rightarrow J/\psi\ \phi$





>95% C.L.
disagreement with SM!

Summary

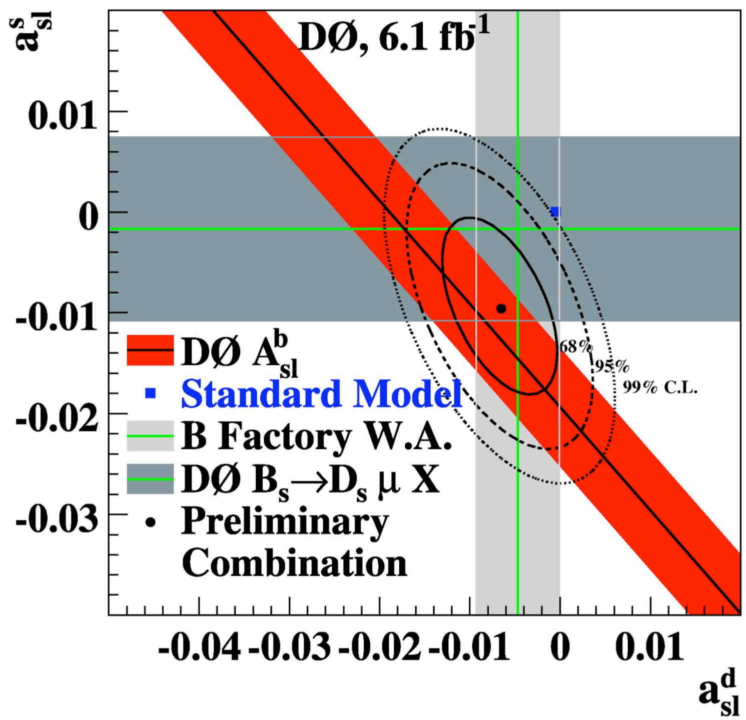
The TeVatron has a wide-ranging program of searches for new phenomena; I have been able to cover only the most recent work

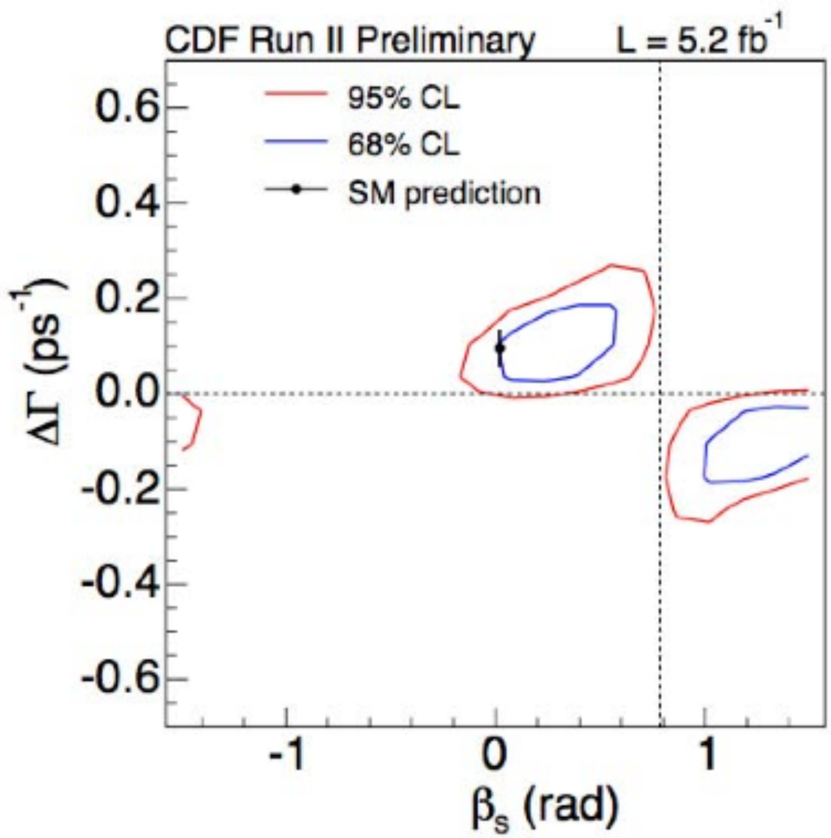
We have signs of, if not proof of, interesting new physics from B_s mixing

http://www-cdf.fnal.gov/physics/physics.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

Thanks to:
Arnaud Duperrin, G. Brooijmans, O. Gonzalez, Tom Wright, Todd Adams, J. Conway, our conference organizers, and the many people whose efforts made these results possible

Extra Slides


DØ, 6.1 fb-1
a_{sl}^s
0.01
0
-0.01
-0.02
-0.03
DØ A_{sl}^b
Standard Model
B Factory W.A.
DØ $B_s \rightarrow D_s\, \mu\, X$
Preliminary Combination
68%
95%
99% C.L.
-0.04 -0.03 -0.02 -0.01 0 0.01
a_{sl}^d

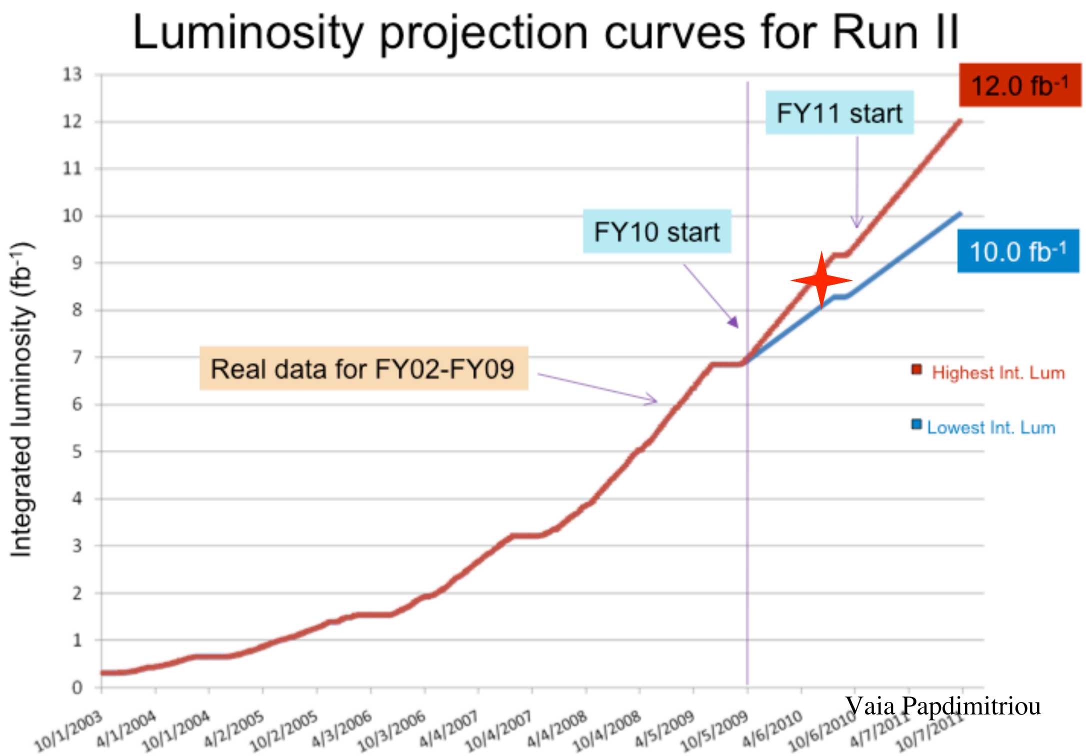

CDF Run II Preliminary
L = 5.2 fb-1
95% CL
68% CL
SM prediction
$\Delta\Gamma$ (ps-1)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-1
0
1
β_s (rad)

TeVatron Performance

Large data samples:
~ 8.6 fb^{-1} already

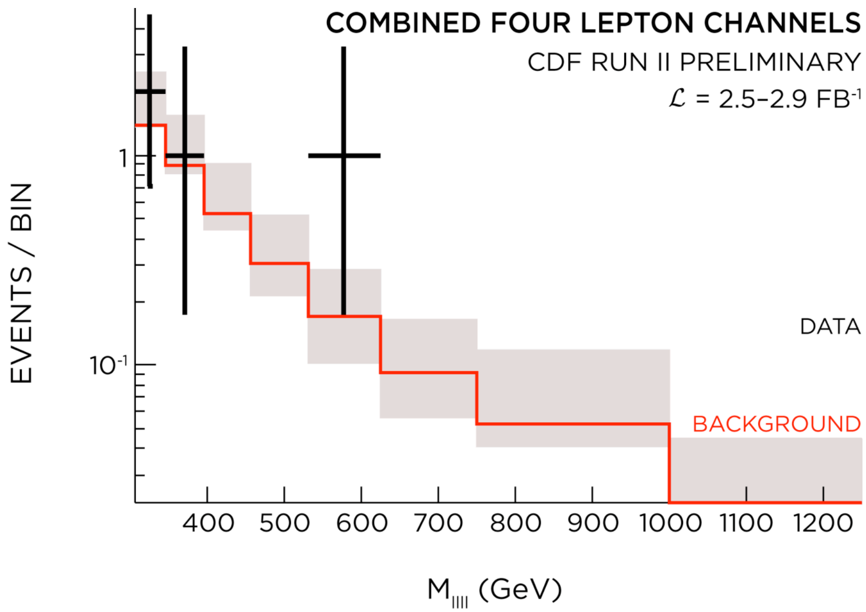
multi-years running
⇒ CDF & D0 detectors
are well-understood

Both detectors measure e, μ, γ, jets, τ and E_T^{MISS} well and tag τ, b, c with vertex detectors



http://www-cdf.fnal.gov/physics/physics.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

ZZ Resonances



$$p\bar{p} \to X \to ZZ \to eeee$$
$$\to eejj$$
$$\to \mu\mu jj$$
$$\to ee\mu\mu$$
$$\to \mu\mu\mu\mu$$

RS Graviton ($k/M_P = 0.1$)
mass > 491 GeV