Searches for New Physics at DØ

Introduction

Lepton compositeness: e*

Resonances in Z+γ

Randall-Sundrum gravitons

Large extra dimensions: single photon

New gauge bosons: W'

Leptoquarks: all generations

Conclusions

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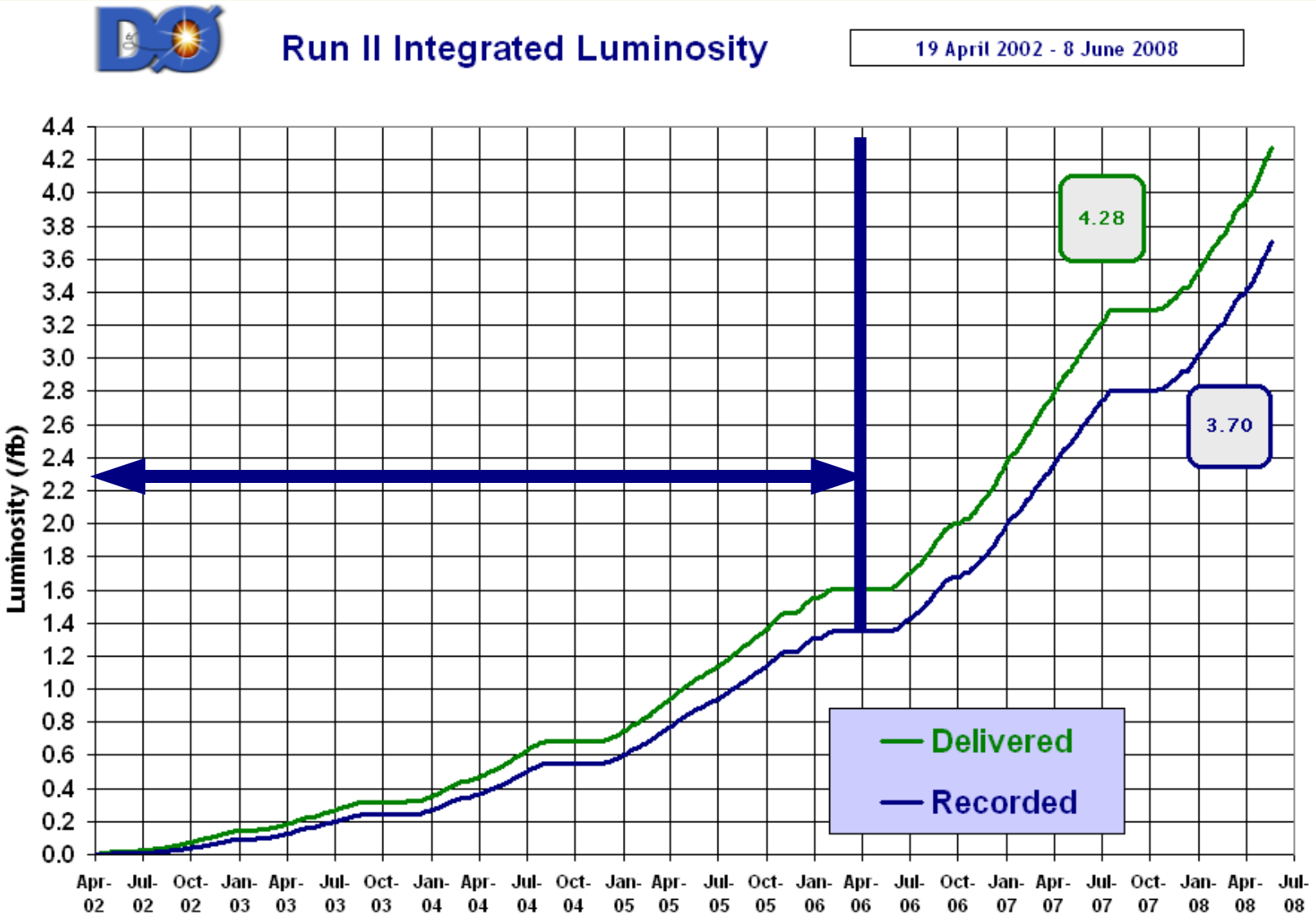
The Physics Landscape

Beyond SUSY, there are many other possible models of new physics that could easily produce results in 1 fb^{-1}.

While SUSY may be popular, all that is certain is a high probability for some sort of new physics “just around the corner”:

- Radiative corrections to the Higgs mass
- If there is one
- Gravitation?
- Unification of couplings?
- Three generations?
- Dark matter?
- .....

Data Set = “Run IIa”

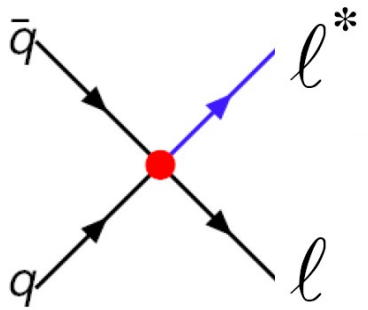


Results based on Run IIa data set

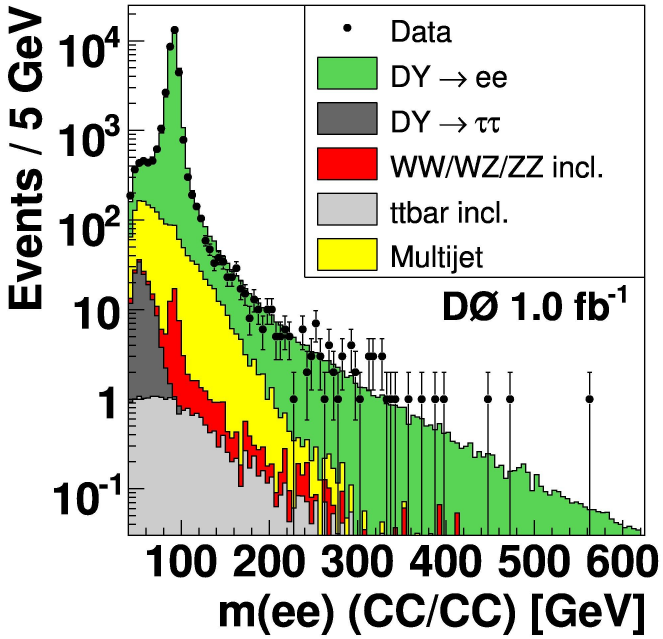
All limits are at 95% CL

Lepton Compositeness: e*

- Learning from thousands of years of history, quarks and leptons may be made of smaller pieces ("preons")
  - Allows excited states (e^*, μ^*, q^*)
  - Describe as contact interaction (compositeness scale Λ)
  - Decay: gauge interaction ($e^* \rightarrow e\,\gamma$, ν W, e Z) or CI ($e^* \rightarrow$ e f f)



- Search in e e γ

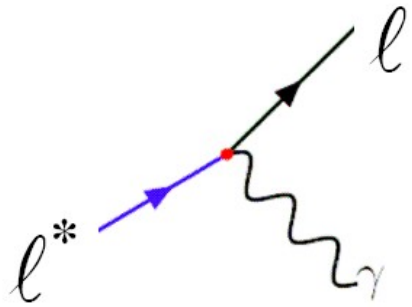


Two isolated electrons with

E_T > 25 GeV, 15 GeV

Next: isolated photon with

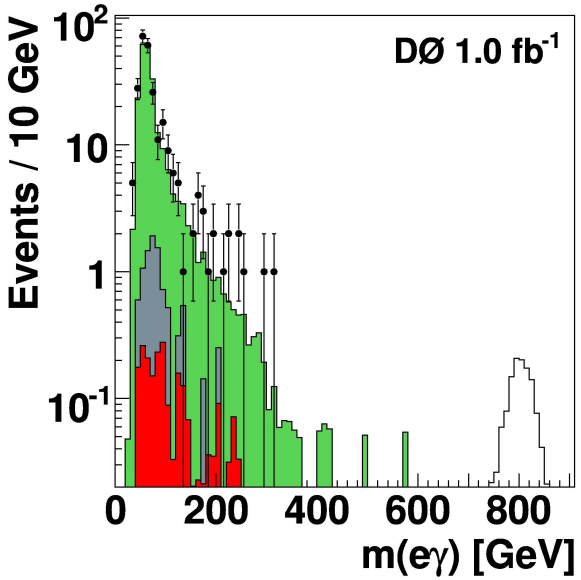
E_T > 15 GeV

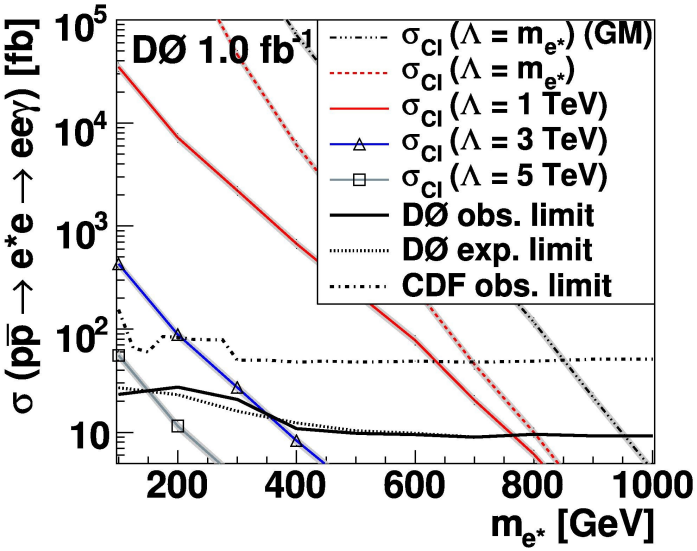


Excited Fermions: e*

arXiv:0801.0877
Phys. Rev. D 77 , 091102 (2008)

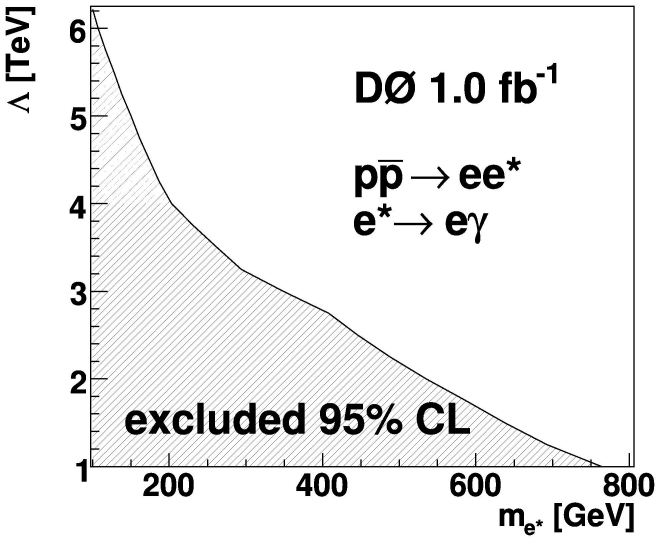
- Observe **259 events with expectation 239 ± 26 events**
- Search for peak in e+γ invariant mass
- Optimize selection criteria
  - Combination e1+γ or e2+γ
  - Mass window / single sided cut
  - |η| acceptance and separation (for small m(e*))
- Find 0 or 1 event in data for all e* masses, with small expected SM background





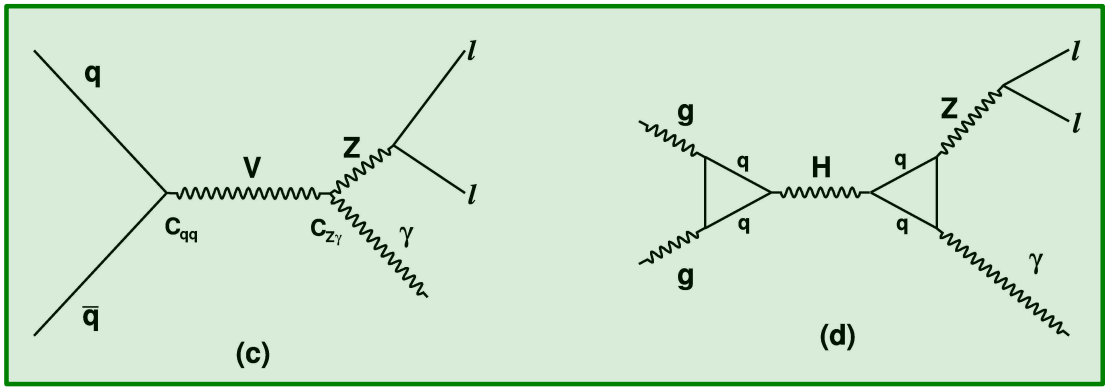
Limit: **m(e*) > 756 GeV for Λ = 1 TeV**

For comparison: m(e*) > 989 GeV when neglecting CI decays, for Λ = m(e*), and using the same theory cross sections as CDF

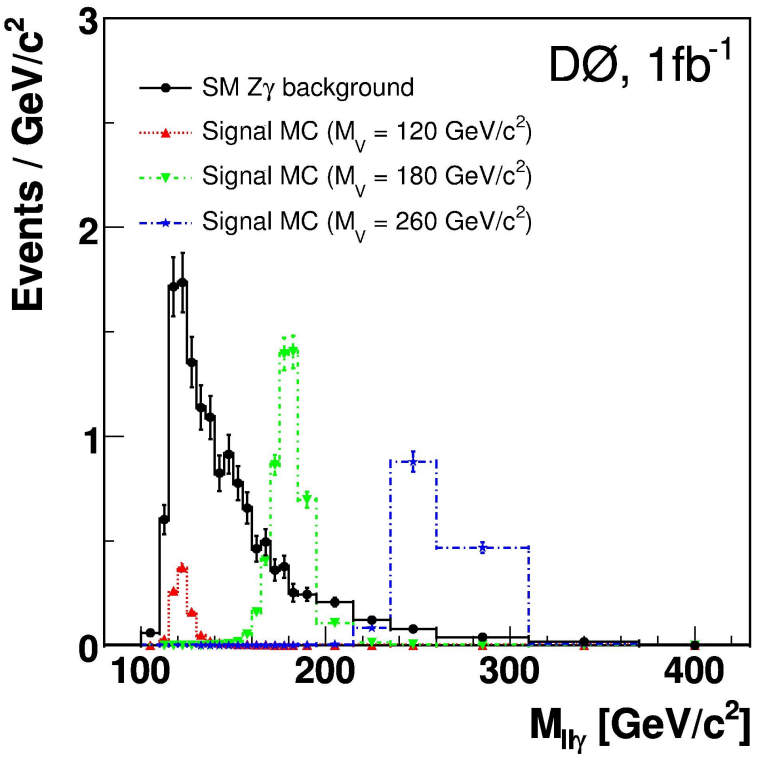


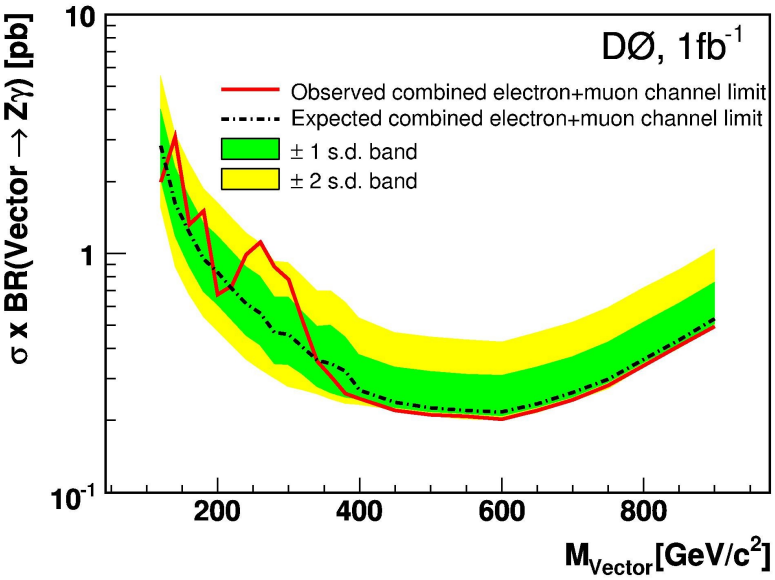
Resonances in Z+γ

New



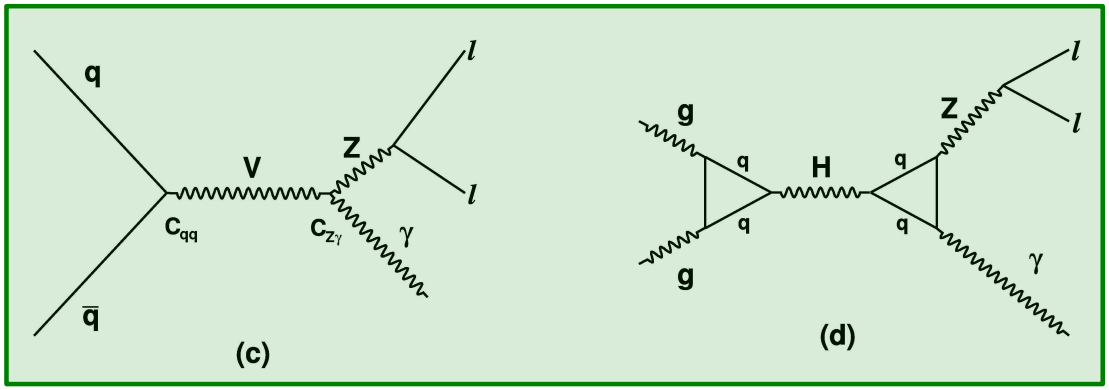
- **Scalar or vector narrow resonance decaying into Z+γ, with Z → ee or $\mu\mu$**
- Isolated e, μ, γ with p_T > 15 – 25 GeV
- llγ mass resolution 4% – 8% (mass constraint to Z for muon channel)
- M_{ll} > 80 GeV after optimization against background (Z+γ and Z+jet dominant)
- **Find 49(50) events in e(μ) channel, compatible with SM expectation of 42 ± 7 (46 ± 7) events**





Resonances in Z+γ

arXiv:0806.0611
submitted to Phys.Lett.B



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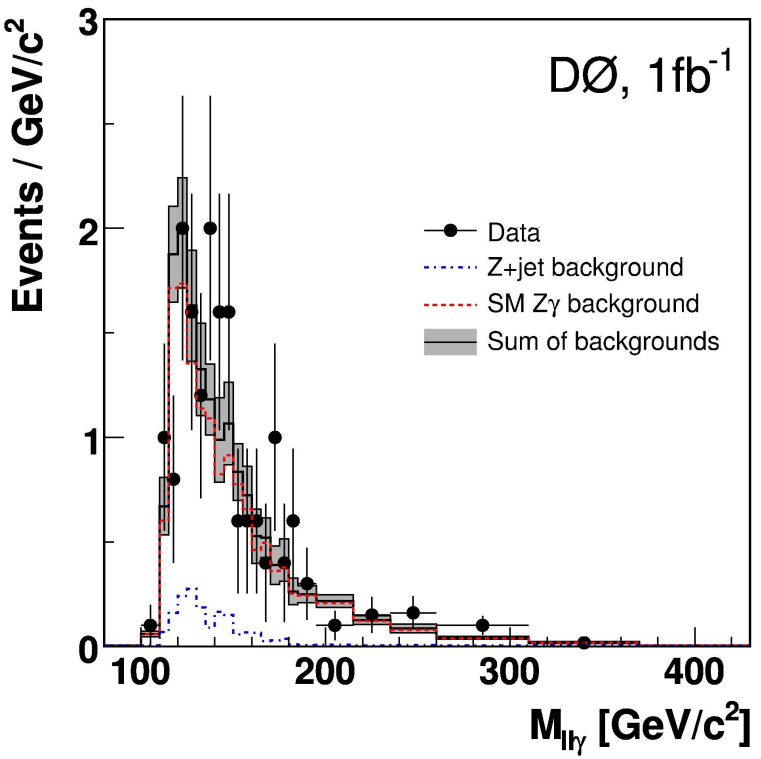
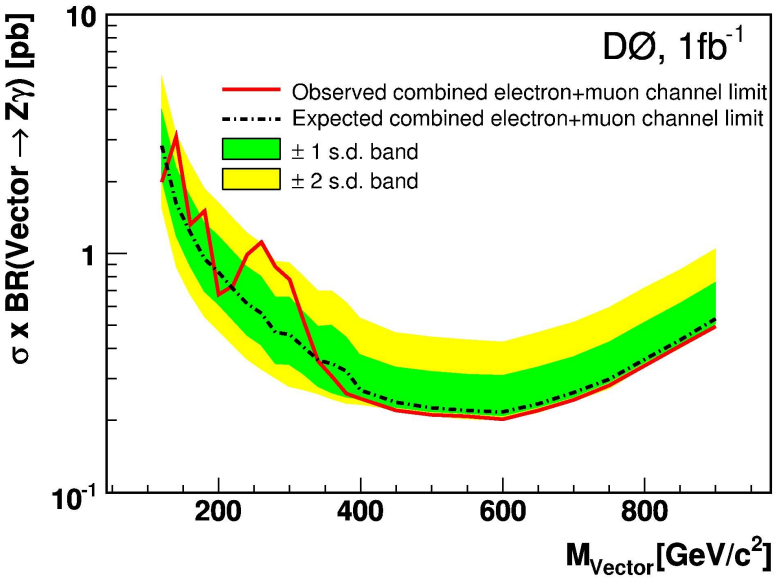




Randall-Sundrum Gravitons

arXiv:0710.3338
PRL 100, 091802 (2008)

Use extra dimensions to address hierarchy problem

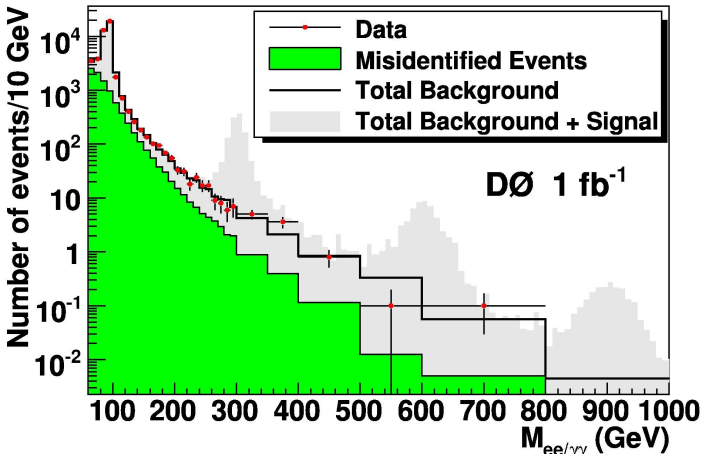
RS model:

One 5th (infinite) ED with warped geometry

Gravity is localized on a brane other than the SM

KK excitations have spacings of order TeV

Signature: **narrow, high mass resonances**



Two model parameters: **Mass and coupling (κ/M_{Pl})**

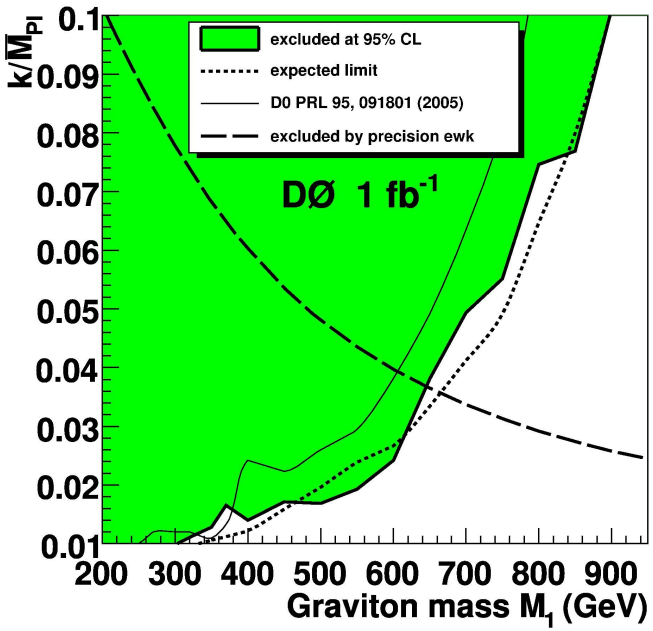
Combined ee + γγ: (BF in γγ = 2 x ee)

– 2 central ($|\eta|<1.1$) electromagnetic objects with $E_T > 25$ GeV

– Background: DY and di-photon

– QCD background estimated from data

– Sliding mass window

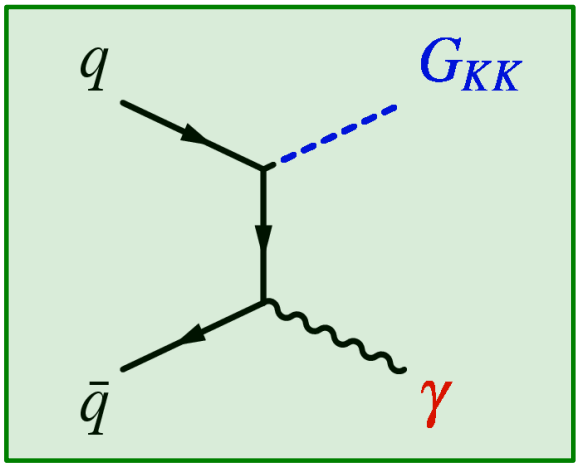


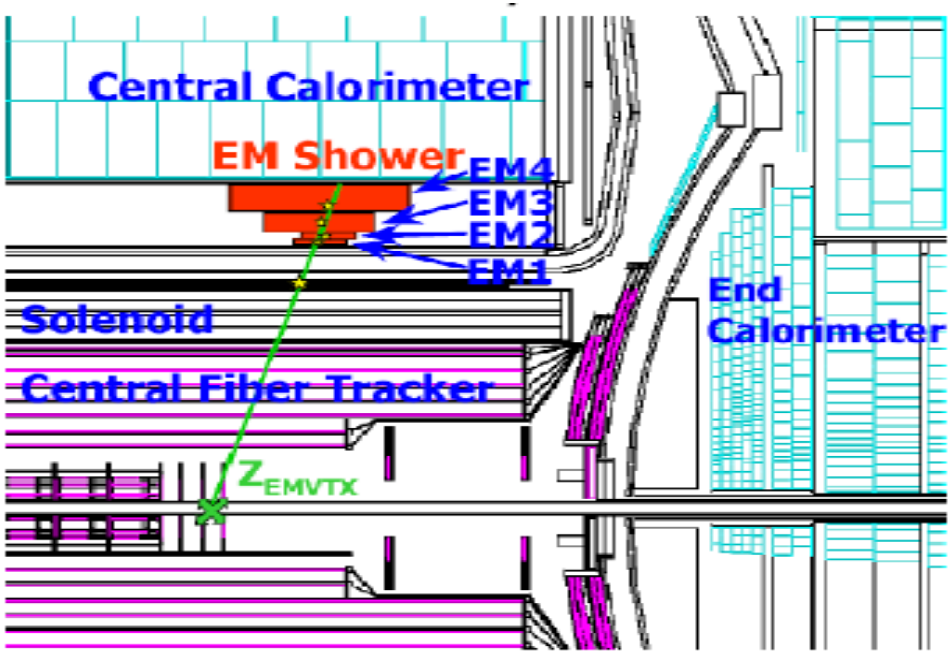
(Previously: 785 GeV based on 260 pb^{-1})

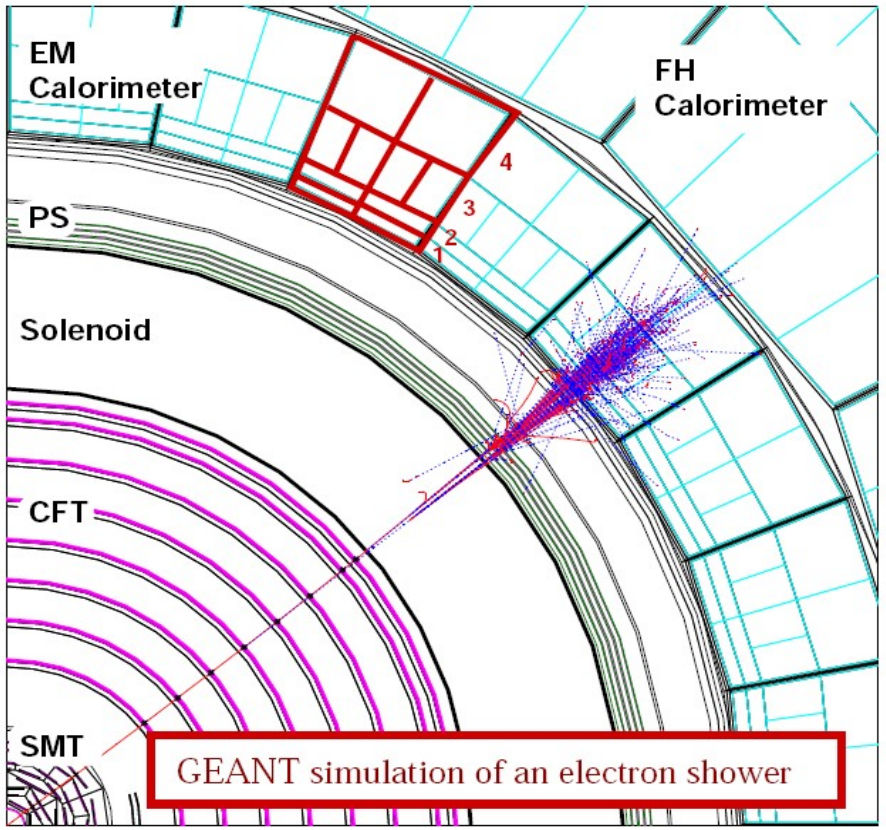
For $\kappa/M_{Pl} = 0.1$: $M_1 > 900$ GeV

Large Extra Dimensions: γ+MET

- LED can explain why gravity is weak: $1/G \sim M_{Pl}^2 \sim M_D^{n+2} R^n$
- Can solve the hierarchy problem: $M_D \sim M_W$
- Here: search in **monophoton** final state – complementary to "monojets"
- Finely segmented EM calorimeter, central preshower for photon pointing



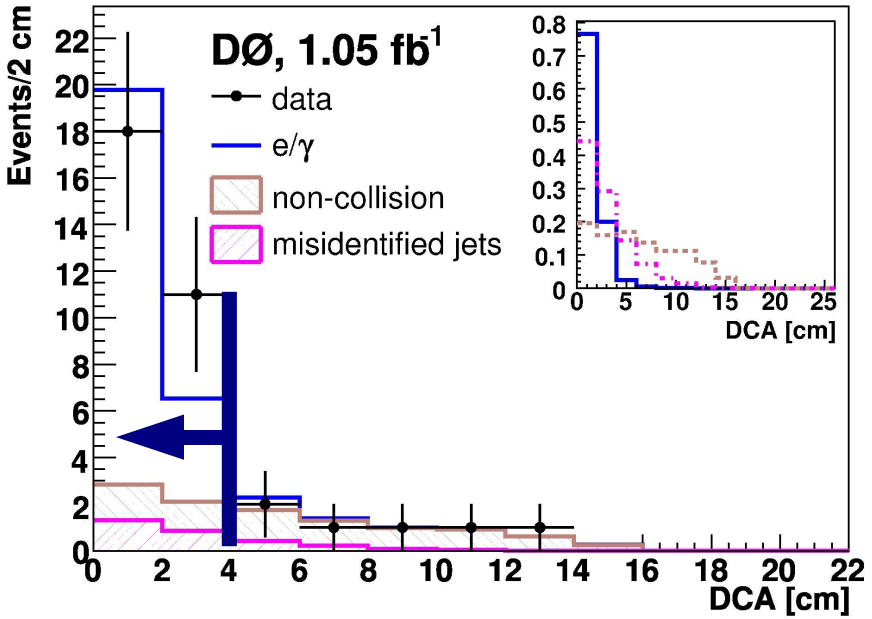


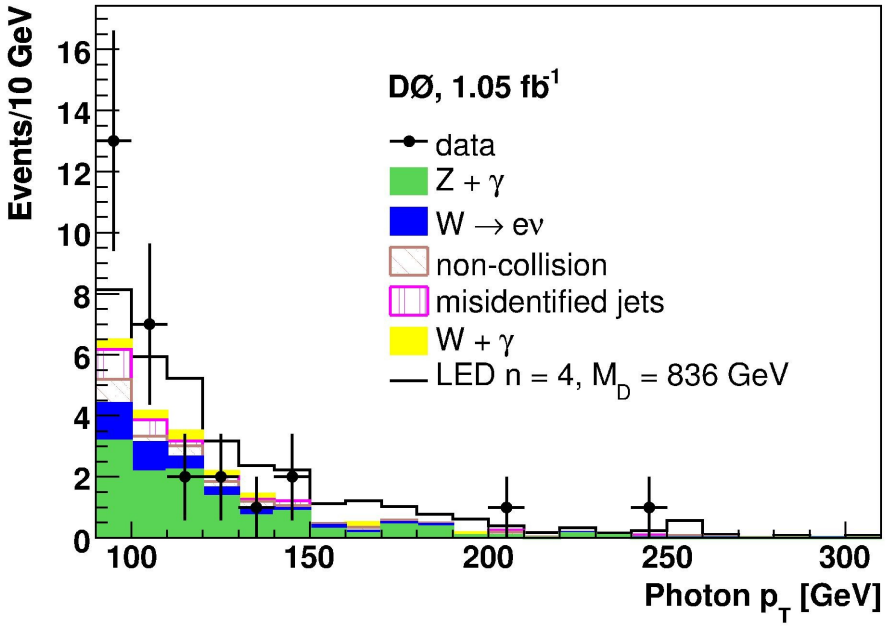


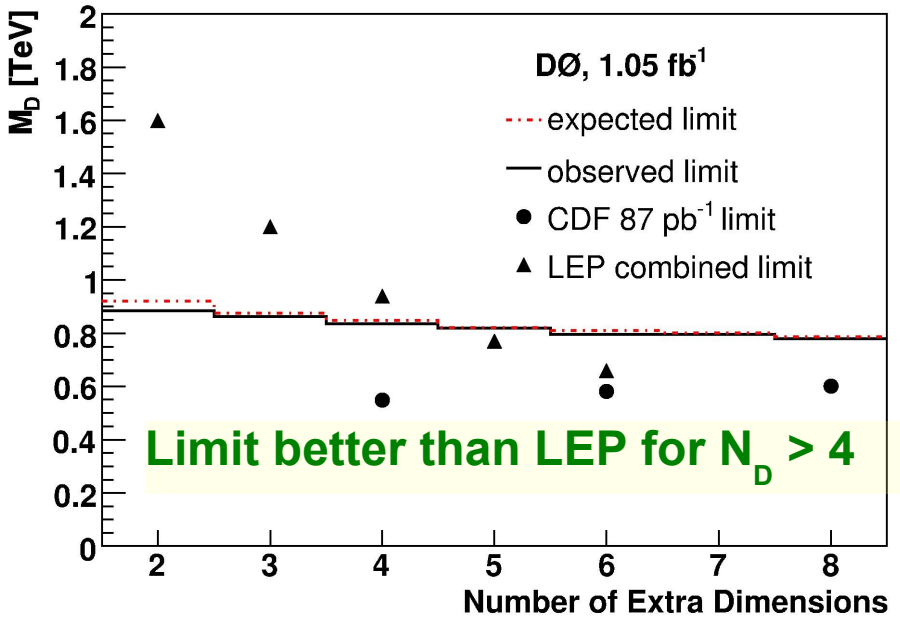
LED: γ+MET

arXiv:0803.2137
submitted to Phys.Rev.Lett.

- Exactly one photon with E_T > 90 GeV and $|\eta|$ < 1.1
- MET > 70 GeV
- Backgrounds from fit of templates to dca
- **Find 29 events in data (expect 22.4 ± 2.5)**



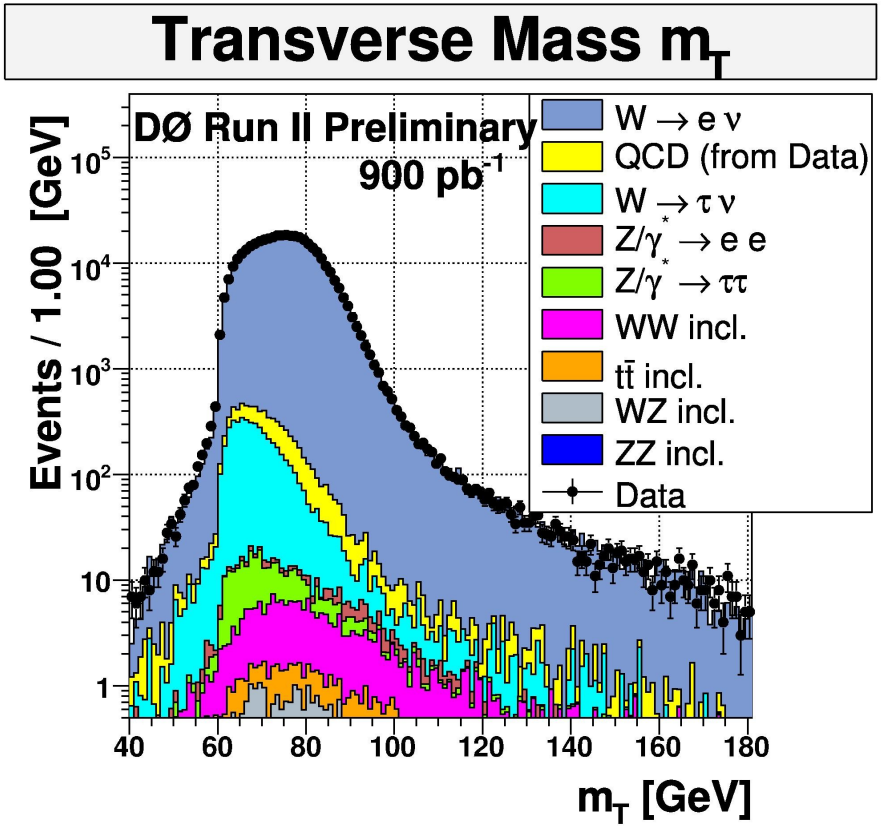




New Gauge Bosons: W' → e ν

- Predicted in many beyond-SM scenarios, GUT's, e.g. left-right symmetric models ($SU(2)_L$ x $SU(2)_R$)
- Benchmark: a SM-like W'
- Selection: isolated central electron with E_T>30 GeV
- MET > 30 GeV, M_T > 140 GeV
- Estimate QCD background from low M_T region

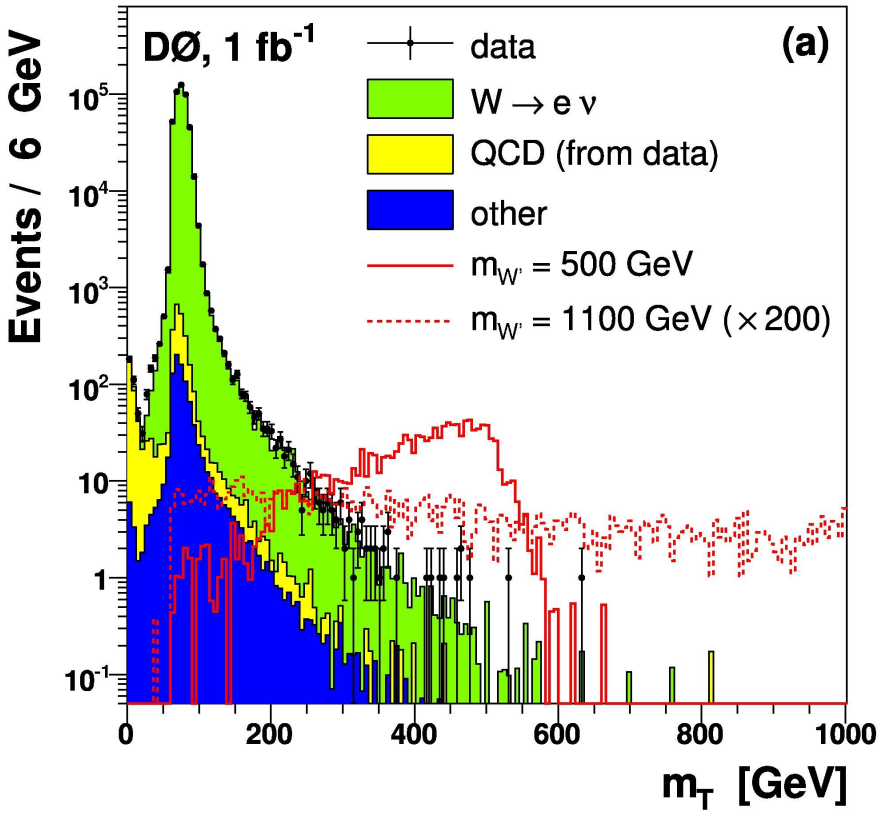
$$M_T = M(p_T(e), \text{MET})$$

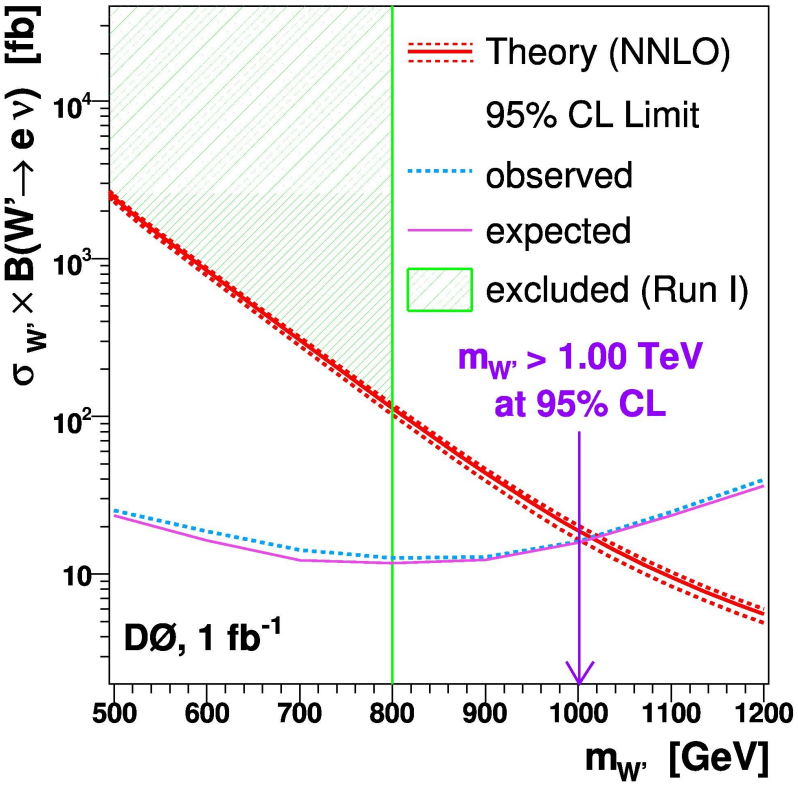


W' – Result

arXiv:0710.2966
Phys.Rev.Lett. 100, 031804 (2008)

- Data (for M_T > 140 GeV):
  967 events
- Standard Model expectation:
  959 ± 21 (stat) ± 90 (syst) events
- Use M_T distribution to derive limits



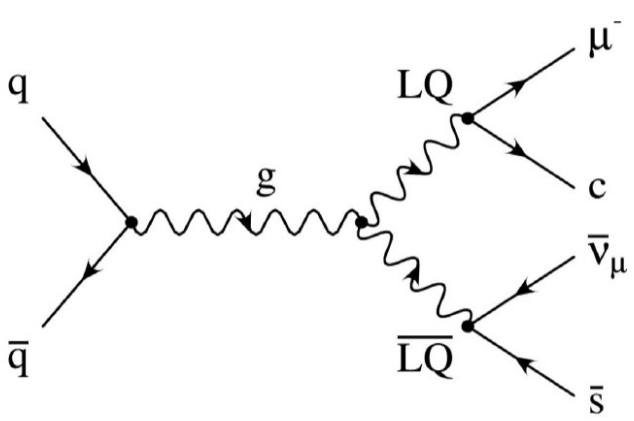


M(W') > 1.00 TeV

First direct search with sensitivity beyond 1 TeV

Leptoquarks

- Couples directly to a quark and a lepton
- Carry both a baryon number and a lepton number
- Predicted in GUT's, Extended Technicolor, Compositeness
- Spin-0 or spin-1
- Charge Q = 1/3, 2/3, 4/3
- Minimal Buchmüller-Rückl-Wyler model: small LQ masses (large cross section) in reach of Tevatron
- Pair production via qq or gg
- Scalar LQ production calculated to NLO

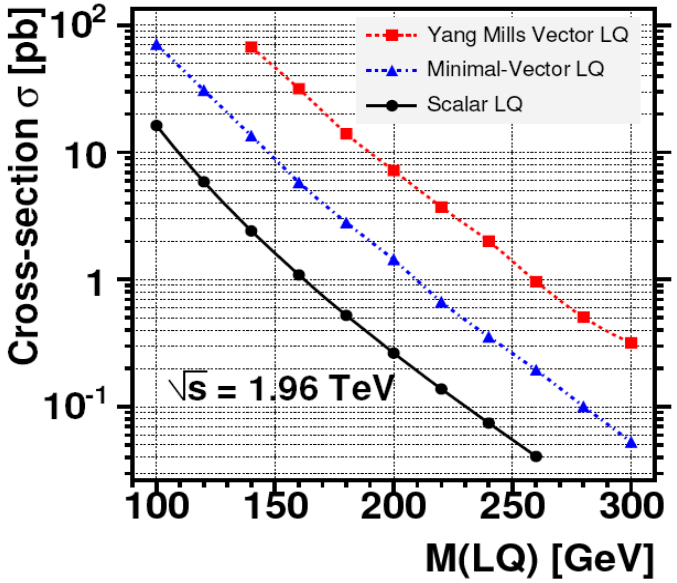


$\beta := \mathrm{BF}(\mathrm{LQ} \rightarrow l\mathrm{j})$

$\sigma \times \mathrm{BF}(\nu\nu\mathrm{jj}) \propto (1-\beta)^2$

$\sigma \times \mathrm{BF}(ll\mathrm{jj}) \propto \beta^2$

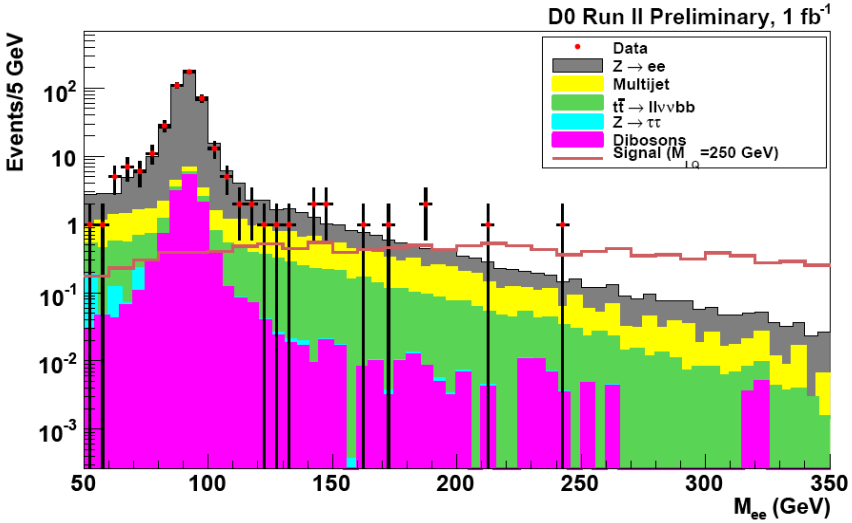
$\sigma \times \mathrm{BF}(l\nu\mathrm{jj}) \propto 2\beta(1-\beta)$



Leptoquarks: 1st Generation – eejj

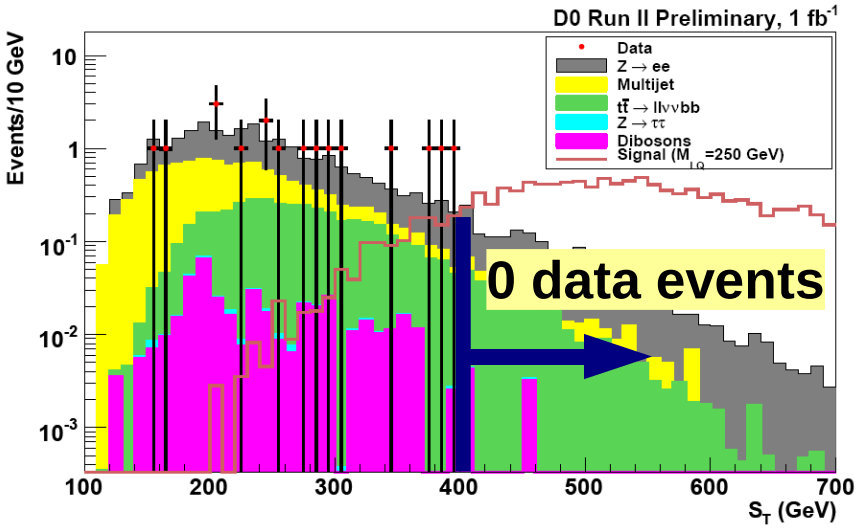
New

- Pair production of LQ1
- At least 2 electrons and 2 jets
  - Electrons: central-central ($|\eta| < 1.1$) or central-forward ($|\eta| < 1.1$, 1.5-2.5), $E_T > 25$ GeV
  - Jets: $E_T > 25$ GeV, $|\eta| < 2.5$
- Further cuts to improve sensitivity
  - Limits on scalar and vector LQ
- $S_T = E_T(e1) + E_T(e2) + E_T(j1) + E_T(j2)$
- Best expected limits (M(LQ) = 290 GeV) for M(ee) > 110 GeV and $S_T > 400$ GeV
- Use $\langle M_{ej} \rangle = (M_{ej}1 + M_{ej}2) / 2$ distribution to set limits ($M_{ej}1$ and $M_{ej}2$ chosen such that LQ and $\overline{\text{LQ}}$ difference minimal)



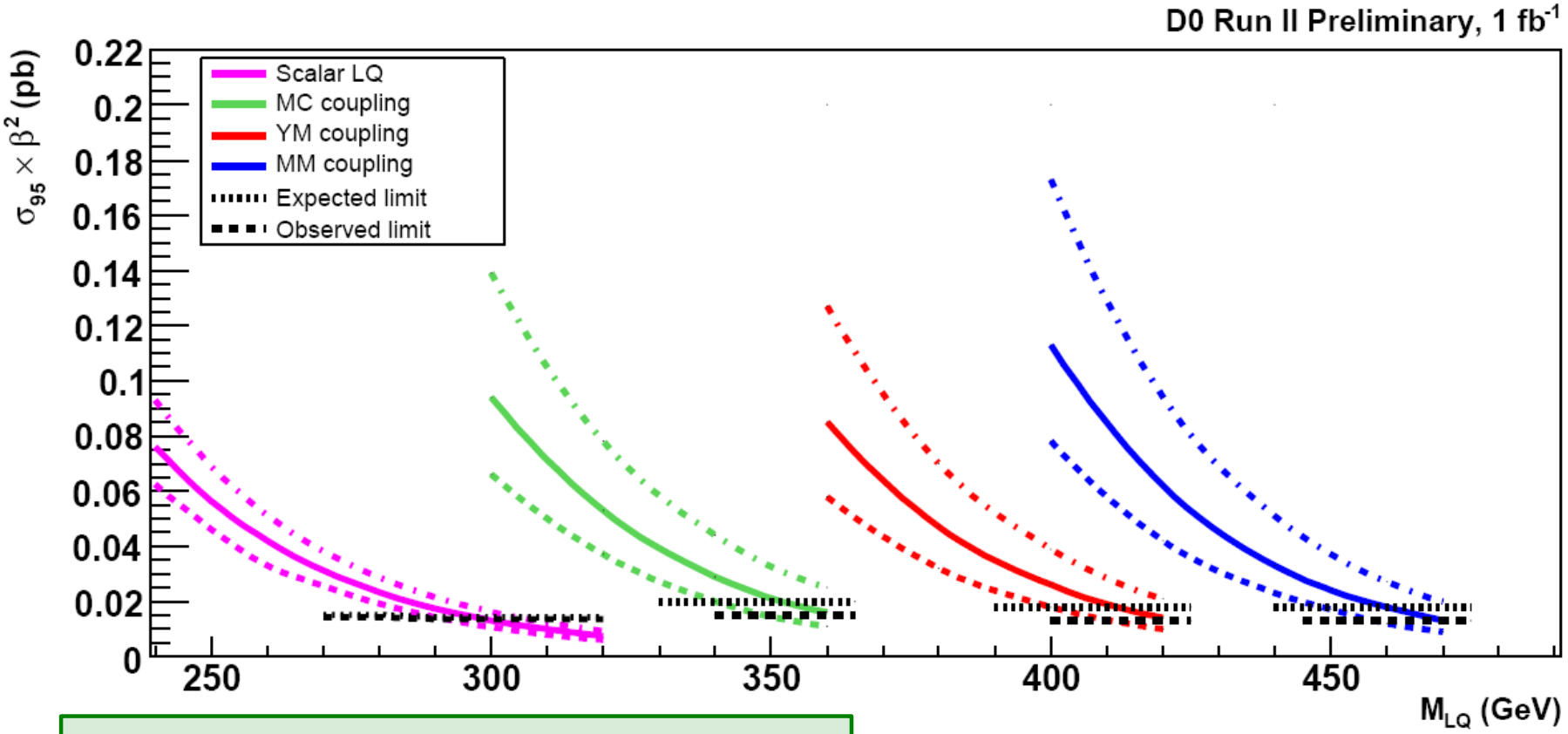
M(ee) in events with ≥2 jets

S_T after M(ee) > 110 GeV cut



LQ1 – Results

Preliminary
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm



Scalar LQ M(LQ1) > 292 GeV

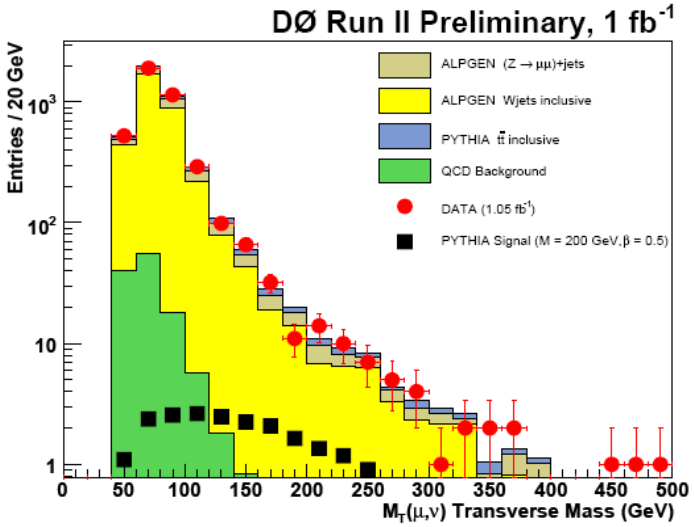
Vector LQ:

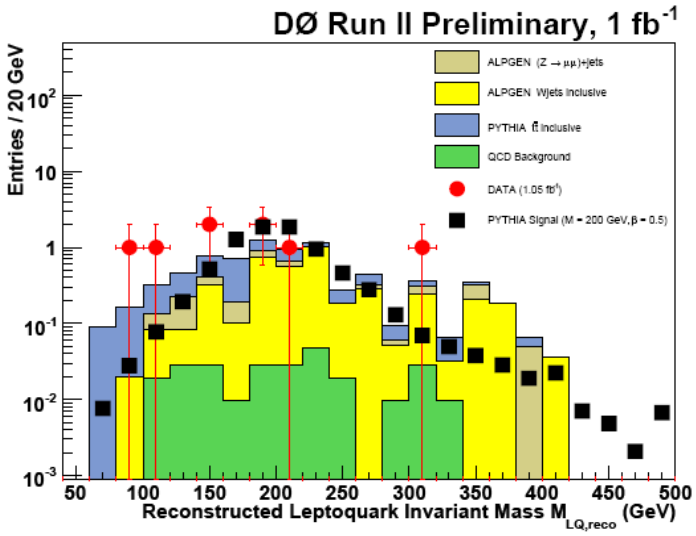
M(LQ1) > 350 GeV	(Q=1/3, T_3= -1/2, κ_G=1, λ_G=0)
M(LQ1) > 410 GeV	(Q=1/3, T_3= -1/2, κ_G=0, λ_G=0)
M(LQ1) > 458 GeV	(Q=1/3, T_3= -1/2, κ_G=-1, λ_G=-1)

Leptoquarks: 2nd Generation – $\mu\nu jj$

Basic selection:

- Exactly one muon with p_T>20 GeV, at least 2 jets with p_T>25 GeV, MET > 25 GeV
- MET not aligned with muon to minimize mis-measured MET
- $M_T(\mu, \nu)$ > 50 GeV to reject QCD background





Optimize for m(LQ) = 200 GeV:

- $M_T(\mu, \nu)$ > 160 GeV – remove background from W production
- Scalar transverse energy $S_T = p_T(\mu) + p_T(\text{jet1}) + p_T(\text{jet2}) + \text{MET} > 350$ GeV
- $M_T(\nu, \text{jet1})$ > 150 GeV – correlated with LQ mass
- |M(LQ)_rec – M(LQ)_gen| < 100 GeV for the μ-jet combination closest to searched LQ

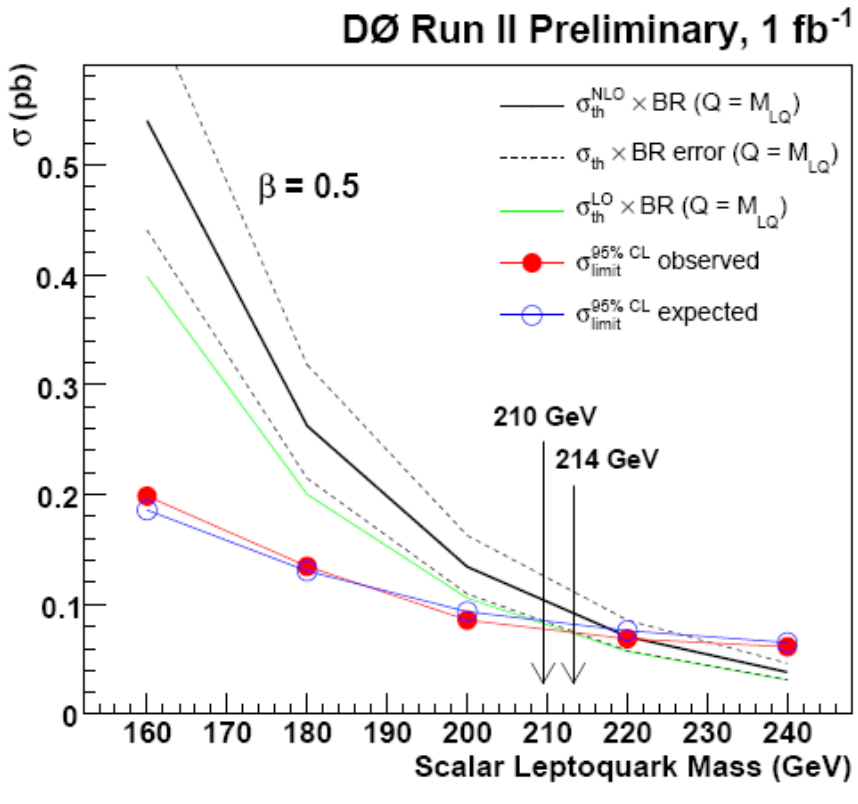
LQ2 – Results

Preliminary
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

Samples	
$W(+jets) \rightarrow l\nu + jets$	$3.2 \pm 0.6 \pm 0.7$
$Z/\gamma^*(+jets) \rightarrow \mu\mu + jets$	$0.68 \pm 0.19 \pm 0.09$
$t\bar{t}$ (inclusive)	$2.3 \pm 0.2 \pm 0.5$
QCD	$0.22 \pm 0.05 \pm 0.04$
Total Background	$6.4 \pm 0.7 \pm 0.8$
Data	6
$\varepsilon_{\mathbf{signal}}$	$0.079 \pm 0.001 \pm 0.007$

Dominant remaining backgrounds: W+jets, ttbar

(m(LQ) = 200 GeV, others similar)



m(LQ) > 214 GeV for β = 0.5

For publication, update including $\mu\mu$jj channel underway

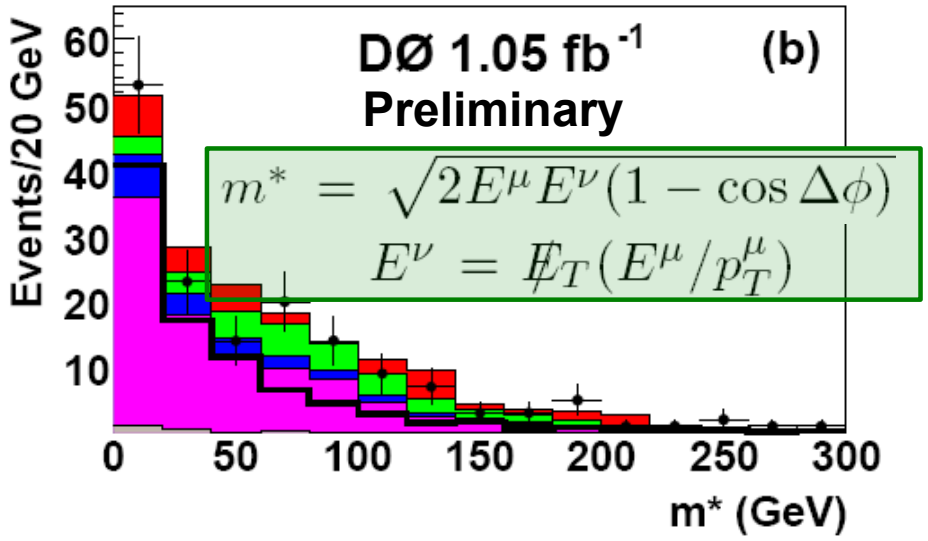
Leptoquarks: 3rd Generation – ττbb

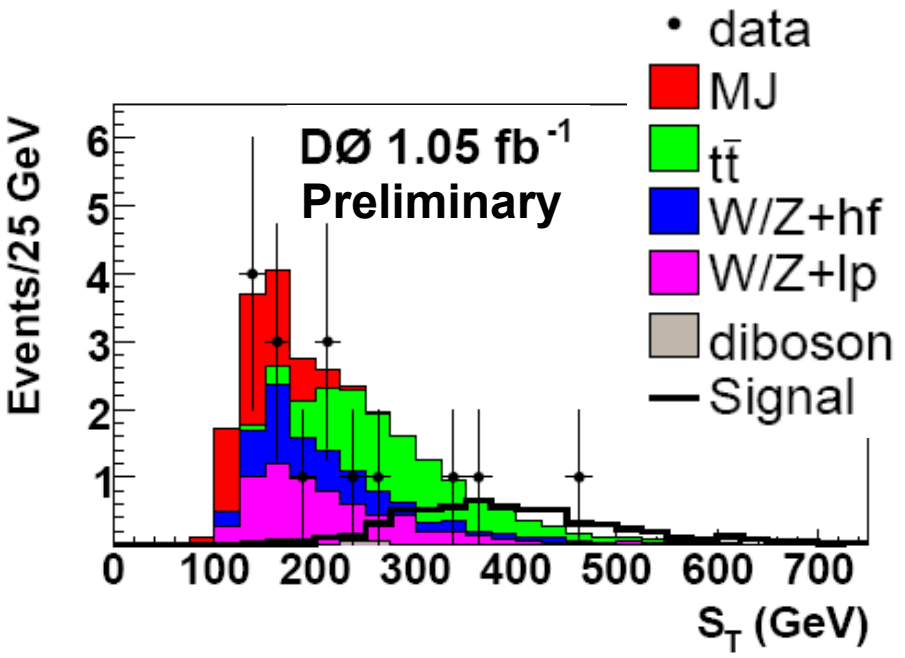
New

$$LQ_3\,\overline{LQ_3} \rightarrow \tau^- b\,\tau^+ \bar{b}$$

$$\tau_1 \rightarrow \mu\,\bar{\nu}\,\nu\,, \tau_2 \rightarrow \nu + hadrons$$

- Pair production of LQ3
- 2 opposite-sign taus and 2 jets
  - Tau 1: μ p_T> 15 GeV, $|\eta|$ < 2.0
  - Tau 2: visible p_T> 15 – 20 GeV, identified using NN-algorithm based on tracks and calorimeter information
  - Jets: E_T> 25, 20 GeV, $|\eta|$ < 2.5
  - m* < 60 GeV
  - Two sub-samples: 1 b-tag or 2 b-tags
  - b-tag based on NN, optimized for sensitivity
- Veto extra muons or electrons





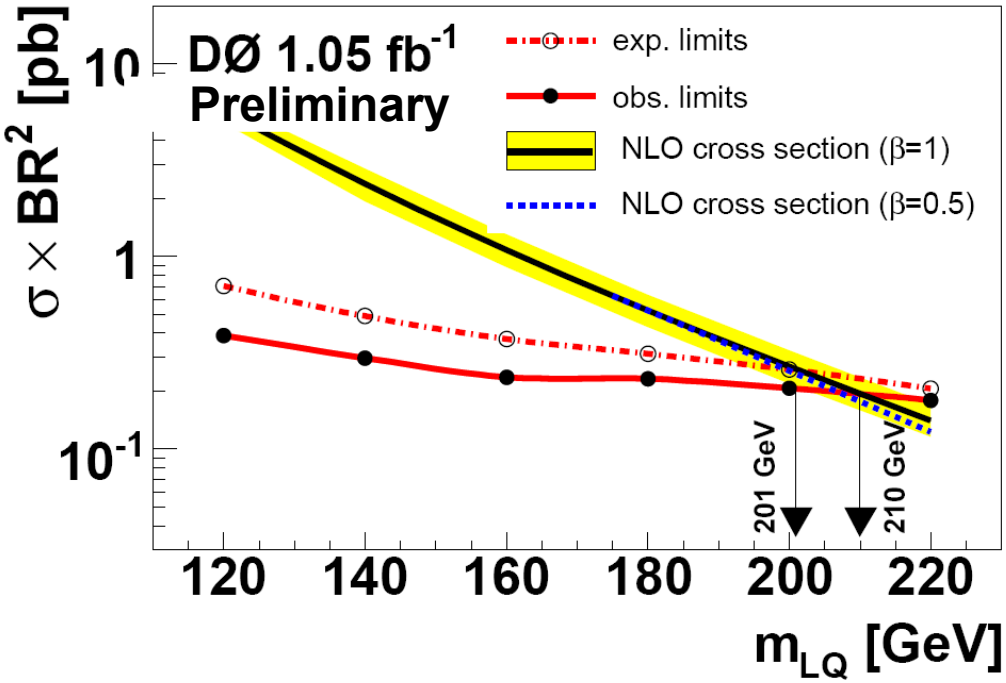
$S_T = p_T(\mu) + p_T(\tau) + p_T(\text{jet1}) + p_T(\text{jet2}) + \text{MET}$

LQ3 – Results

arXiv:0806.NNNN
to be submitted to Phys.Rev.Lett.

Use S_T distribution and both 1 and ≥2 b-tagged samples to obtain limits

- Charge = 4/3, 2/3 LQ, β = 1
- For Q = 2/3, LQ → t ν is allowed, only suppressed by phase space
- BF(LQ → t ν) = (1 – β) x f_{ps}



Source	$1b$-tag	$\geq 2b$-tag
W + lp	1.0±0.4	< 0.1
$W + c\bar{c}$	0.4±0.1	< 0.1
$W + b\bar{b}$	0.4±0.1	< 0.1
Z + lp	5.0±0.2	0.1±0.0
$Z + c\bar{c}$	1.7±0.2	0.1±0.1
$Z + b\bar{b}$	1.8±0.1	0.4±0.1
$t\bar{t}$	5.2±0.1	3.1±0.1
Diboson	0.3±0.1	< 0.1
MJ	4.0±2.5	0.8±1.0
Sum Bknd	19.6±2.5	4.8±1.0
Data	15	1
LQ pair signal	3.4±0.1	2.6±0.1

(Uncertainties in Table are statistical only)

m(LQ) > 201 GeV for β = 1

Conclusions

- A vibrant program searching for non-SUSY new phenomena continues – have shown new(er) results in the areas of compositeness and leptoquarks, (large) extra dimensions, and extra gauge bosons

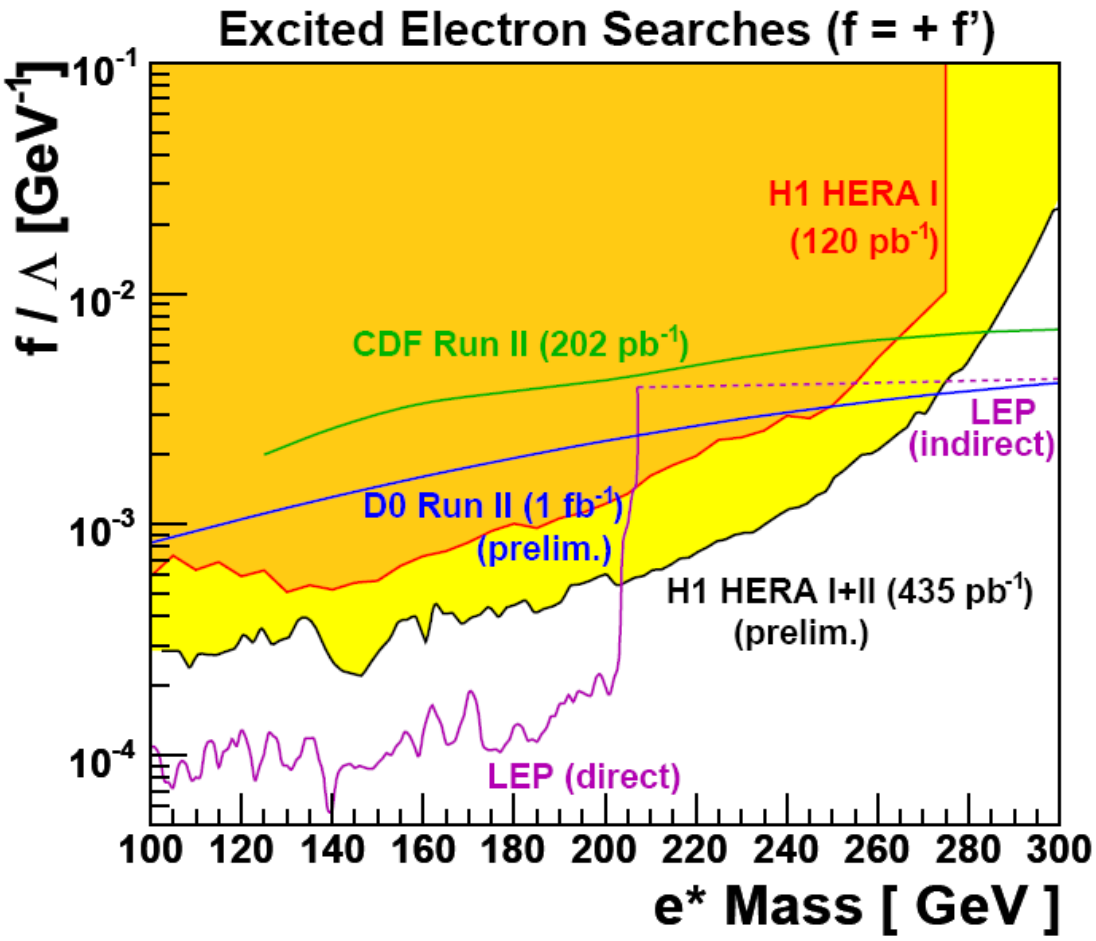
- Most searches based on 1 fb^{-1} of integrated luminosity are now completed

- With almost 4 fb^{-1} collected, updates promising

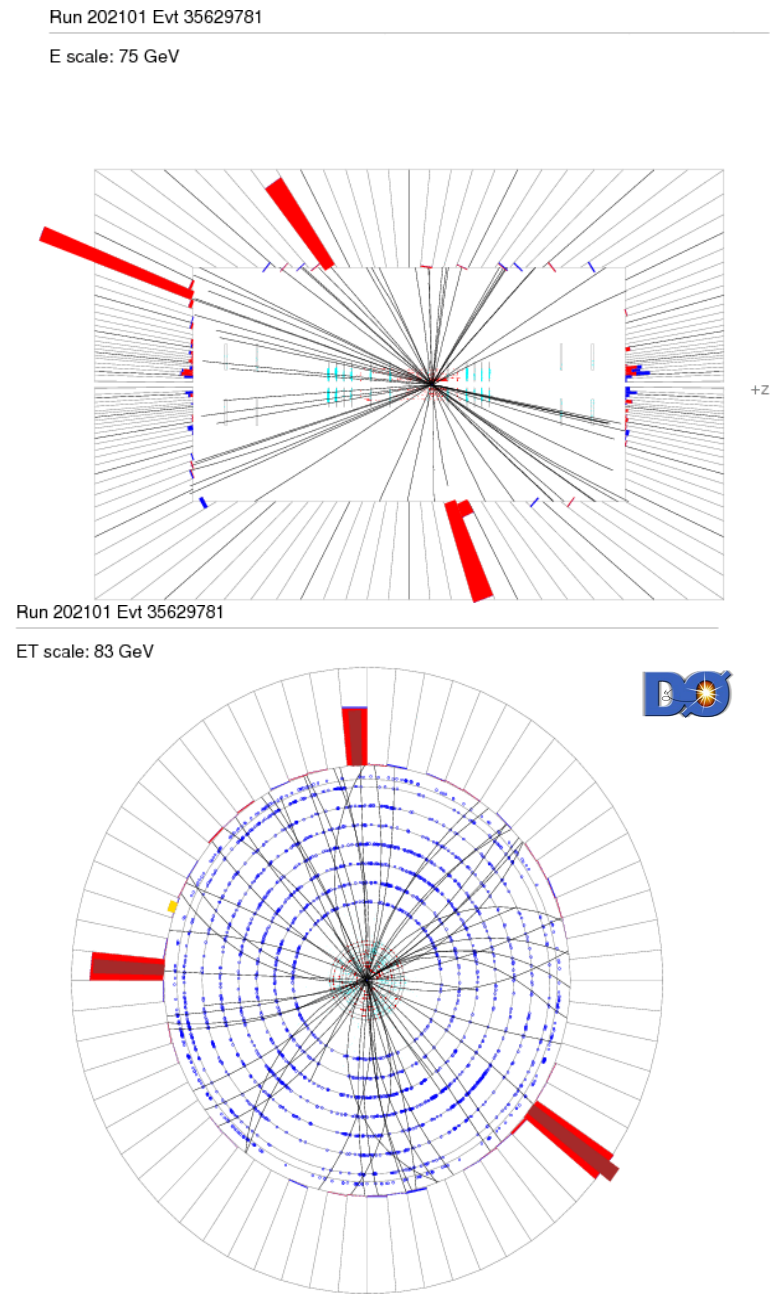
- All results and more available at http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

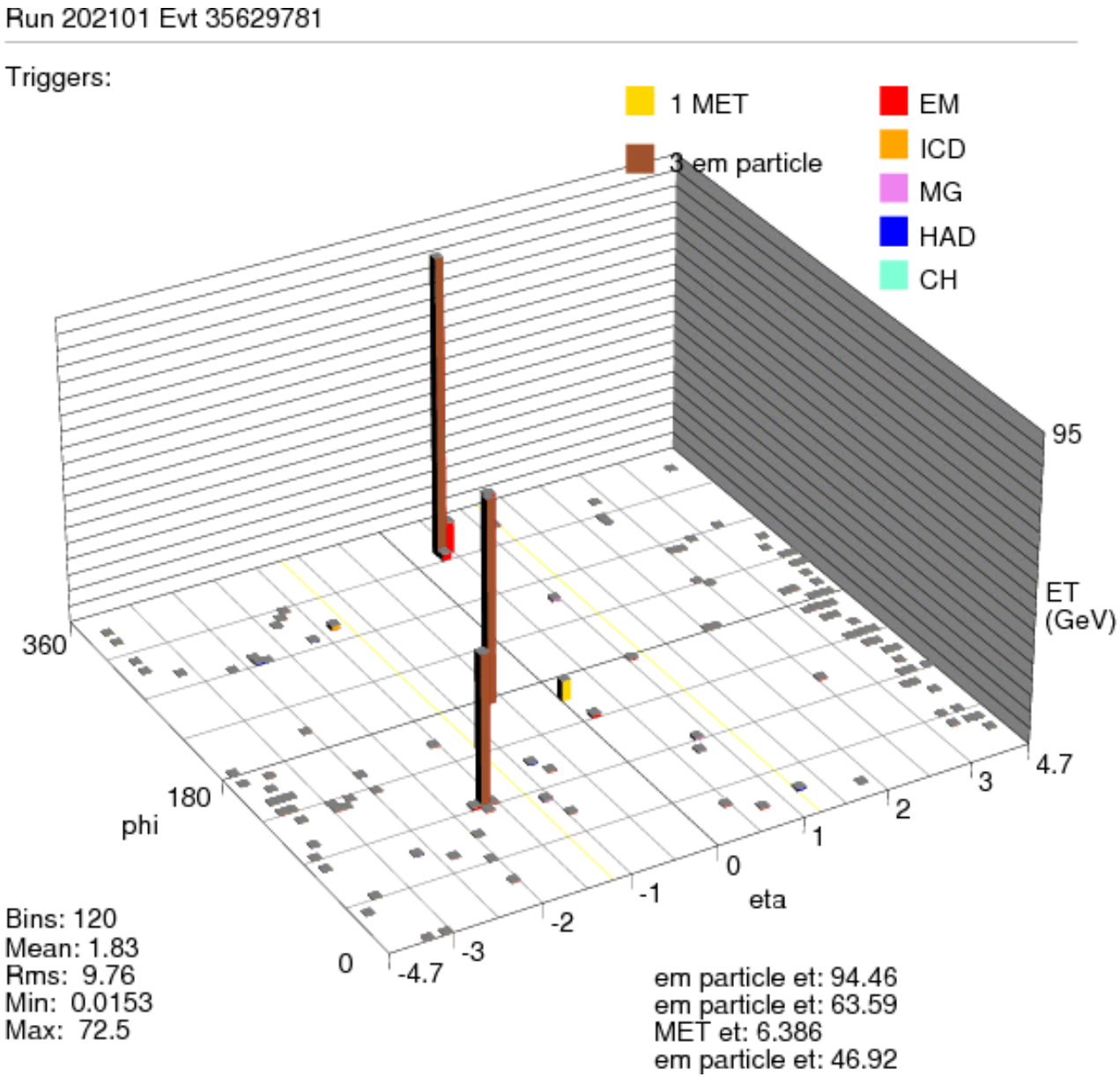
Backup

e*

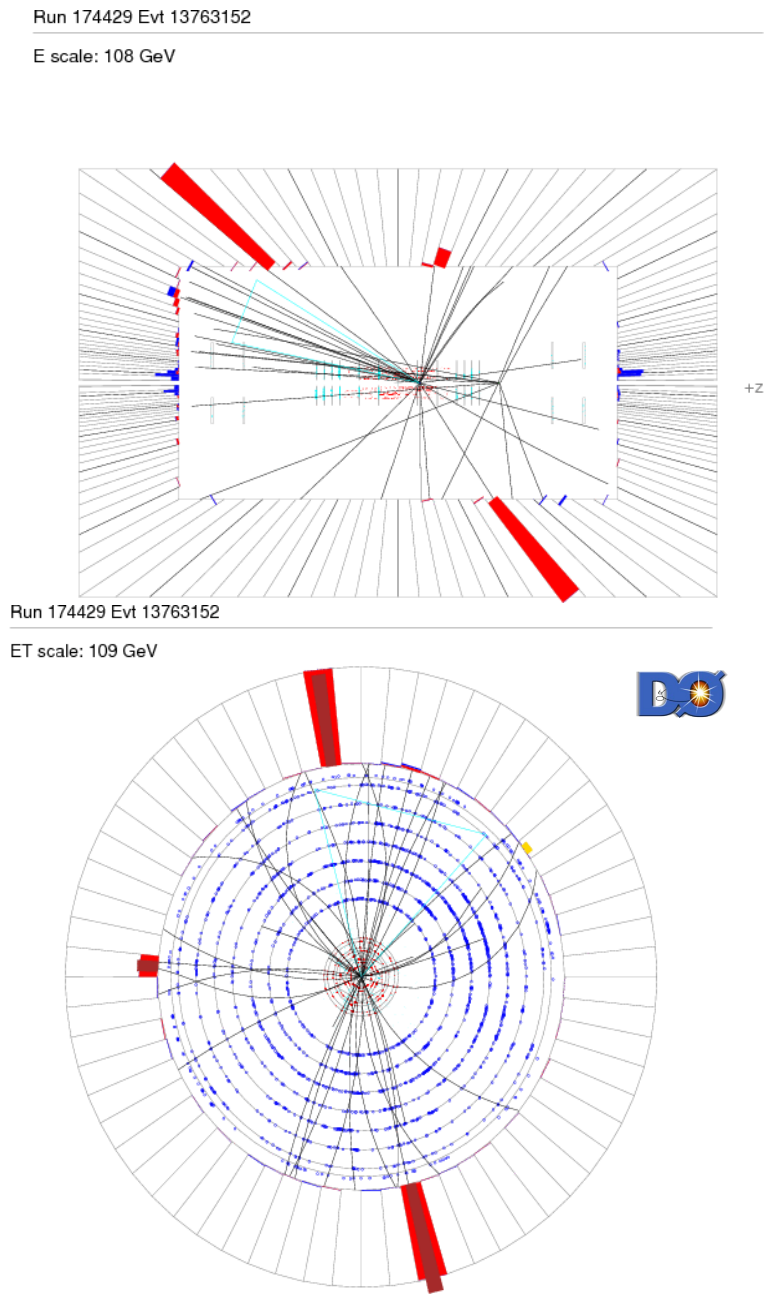

Excited Electron Searches (f = + f')
f / Λ [GeV-1]
10-1
10-2
10-3
10-4
H1 HERA I
(120 pb-1)
CDF Run II (202 pb-1)
LEP
(indirect)
D0 Run II (1 fb-1)
(prelim.)
H1 HERA I+II (435 pb-1)
(prelim.)
LEP (direct)
100 120 140 160 180 200 220 240 260 280 300
e* Mass [GeV]

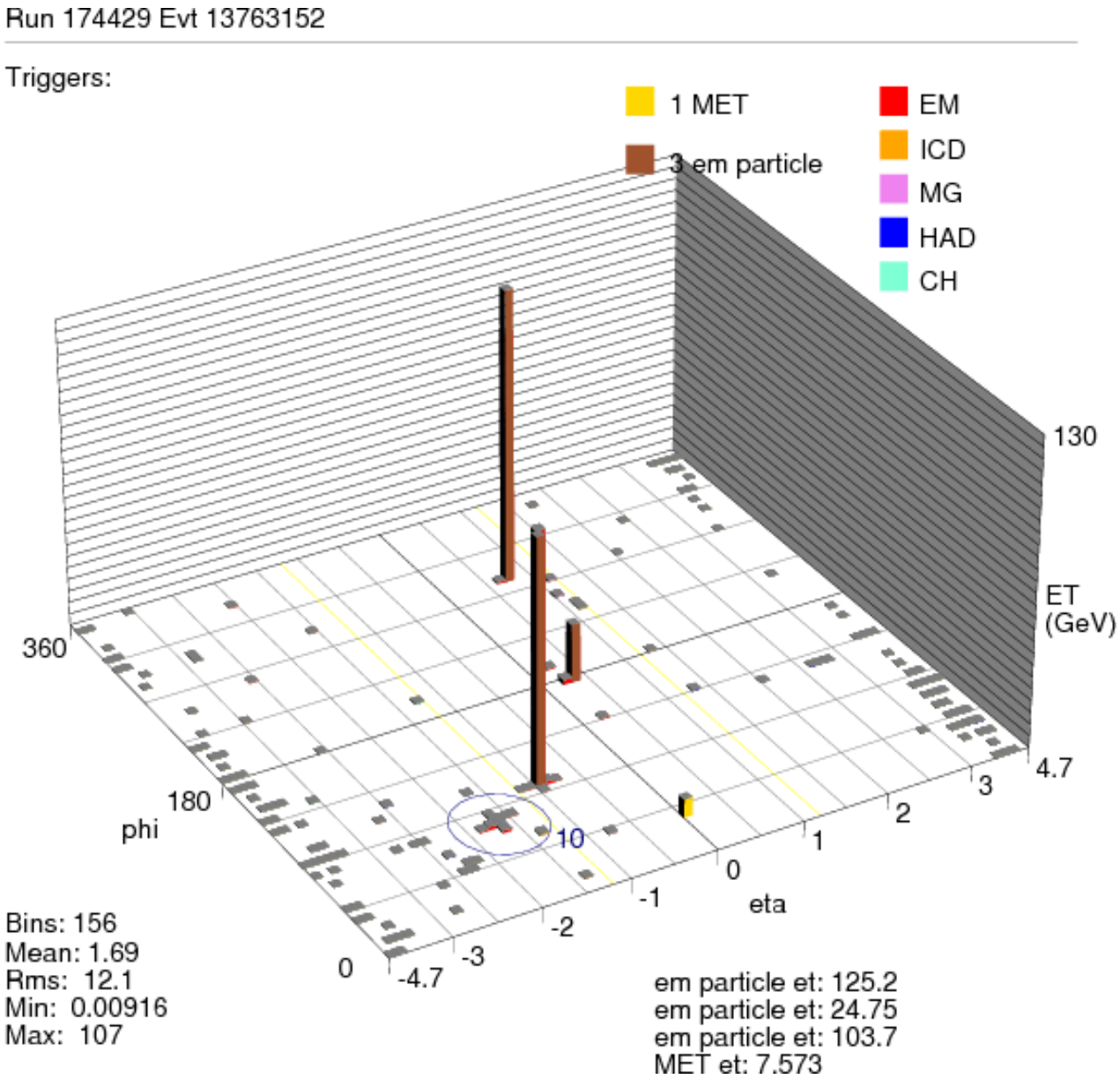
Candidate Event I





Candidate Event II





Candidate Events

	$m_{e^*} = 200$ GeV	$m_{e^*} = 300$ GeV
Run number	202101	174429
Event number	35629781	13763152
$e1$: p_T, η, ϕ, q	63.7 GeV, -0.800, 3.105, $+$	124.1 GeV, 0.606, -1.334, $-$
$e2$: p_T, η, ϕ, q	46.9 GeV, -1.768, 1.599, $-$	24.8 GeV, 0.128, 3.067, $+$
γ: p_T, η, ϕ	94.1 GeV, 0.199, -0.675	103.1 GeV, -1.073, 1.714
$m(e^*$ candidate$)$	194.6 GeV	310.6 GeV
$m(e1, e2)$	92.8 GeV	93.6 GeV
$m(e1, \gamma)$	167.8 GeV	310.6 GeV
$m(e2, \gamma)$	194.6 GeV	90.3 GeV
$m(e1, e2, \gamma)$	273.2 GeV	336.8 GeV