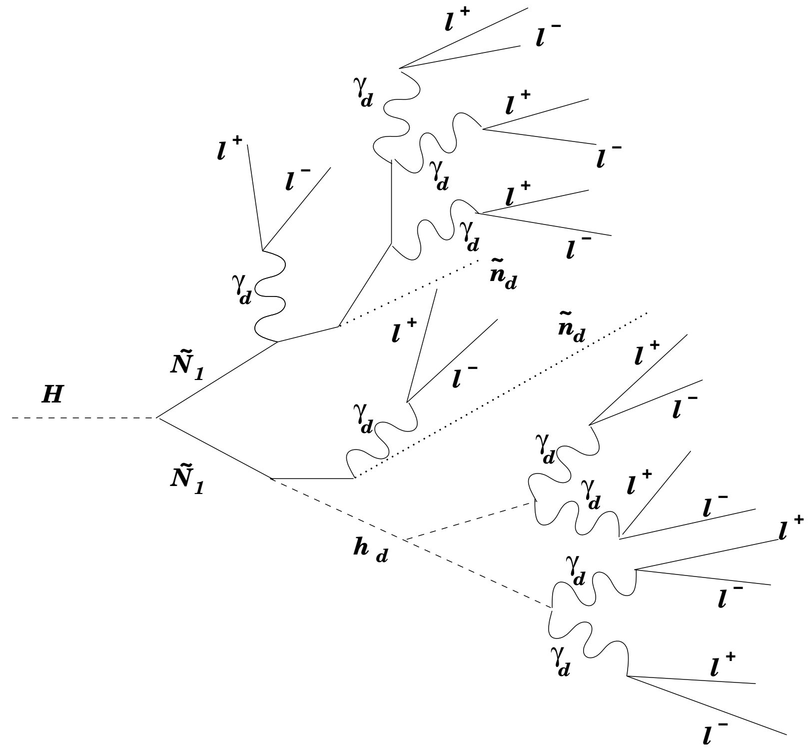
A Search for Low-Energy Leptons and Lepton Jets in W and Z Events at CDF



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On behalf of the CDF Collaboration

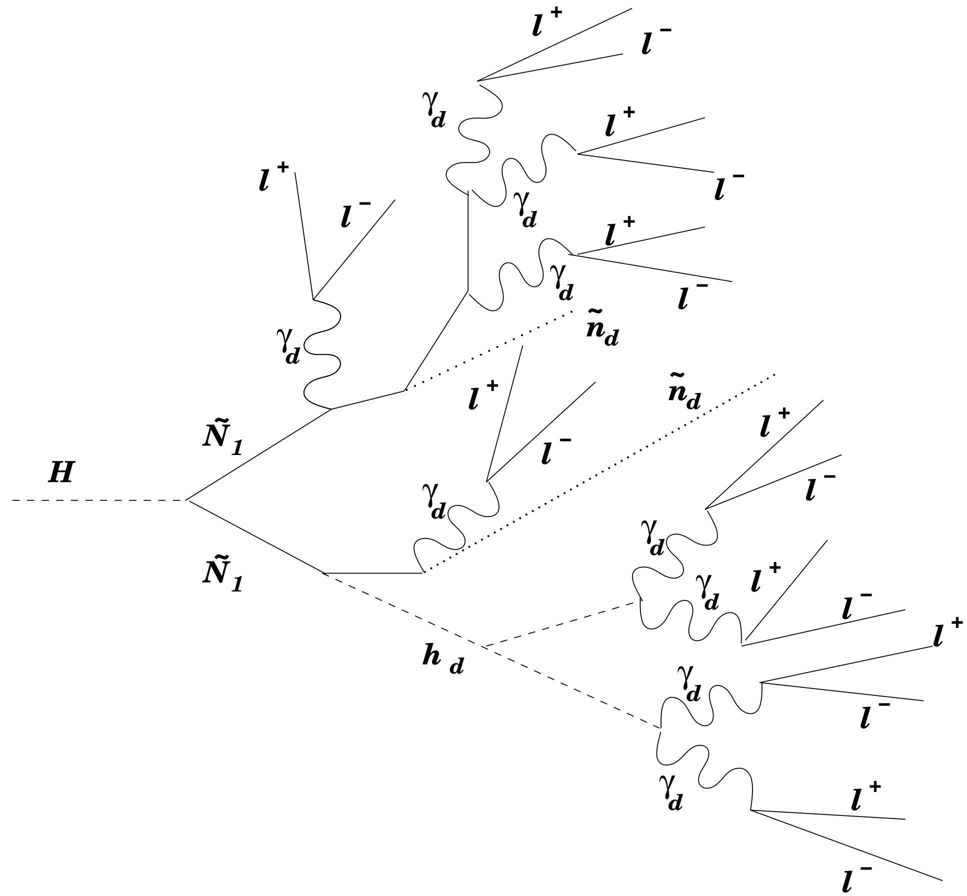
BOOST 2011, Princeton, May 24th

A Model-Independent Search

- Many models predict lepton jets
  - New models can evade previous searches with a different jet shape: A. Falkowski, J. T. Ruderman, T. Volansky, and J. Zupan, arXiv:1007.3496v1 [hep-ph]
  - We don't want to optimize too heavily for one and ignore others
- We perform a very general signature-based search for events with extra leptons
- We choose a representative model to test: Neutralino Benchmark Model from A. Falkowski, J. T. Ruderman, T. Volansky and J. Zupan, arXiv:1002.2952 [hep-ph]
- We also present results in a model-independent way

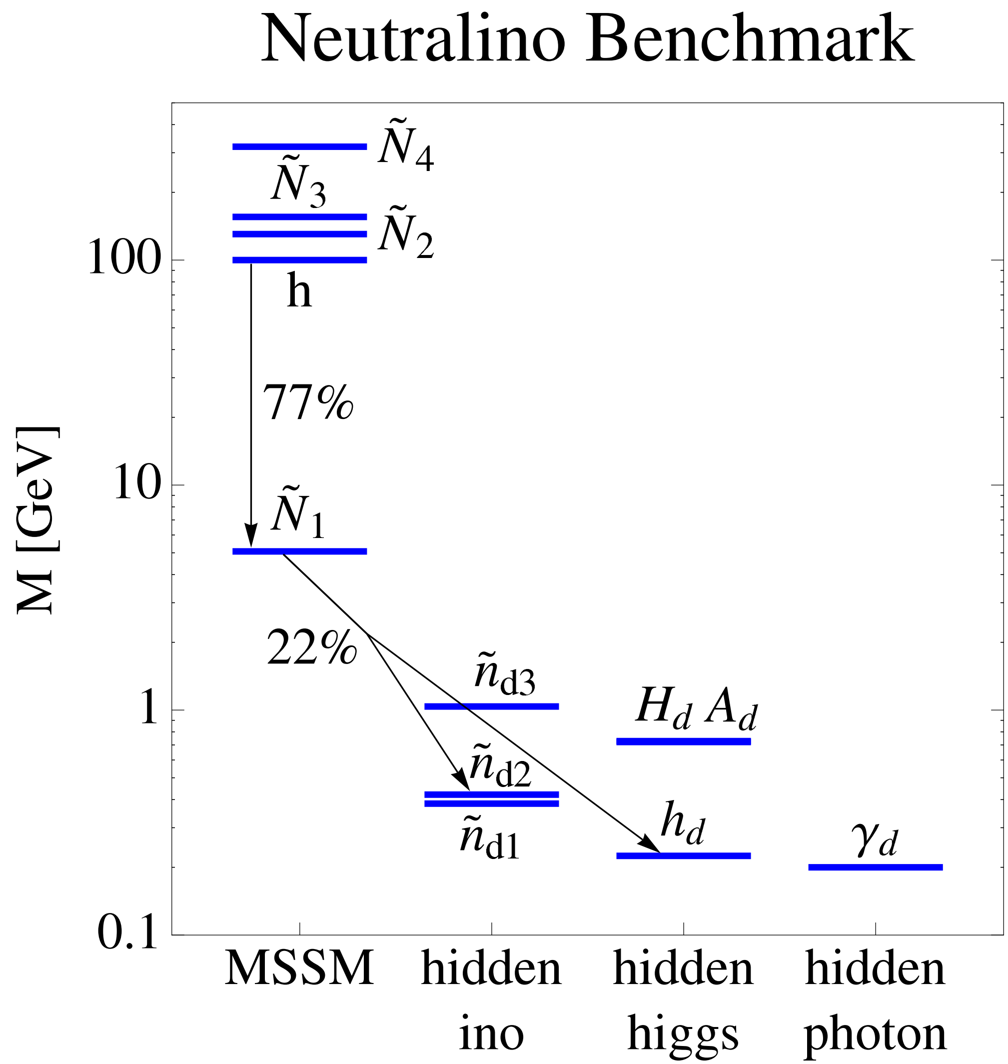
Overview of Signal

- Adaptation of Neutralino Benchmark Model
- Particular parameters from Matt Reece (Princeton) and Lian-Tao Wang (U. Chicago)
- Standard Model production of W or Z + Higgs
- Higgs decays through neutralinos and dark sector
- Model can also explain electron and positron cosmic ray excesses as DM annihilation
- As in many models, leptons are soft: could have evaded previous searches



Dark Sector Hidden Higgs Model

- SUSY Parameters: $\mu = 149$ GeV, $m_{\tilde{N}_1} = 13$ GeV, $m_{\tilde{N}_2} = 286$ GeV, $\tan(\beta) = 3.5$, $\sin(\alpha) = -0.28$
  - SUSY LSP: $m_{\chi_0} = 10$ GeV
- $m_H = 120$ GeV
- Dark Sector:
  - $m_{\chi_d} = 1$ GeV, $m_{\gamma_d} = 300$ MeV
  - $\gamma_d \to e^+e^-$ (52.5%)
  - $\gamma_d \to \mu^+\mu^-$ (46.6%)
  - $\gamma_d \to \pi^+\pi^-$ (0.9%)
- Model the χ_0 decay to dark sector:
  - $\chi_0 \to \chi_d + 2\gamma_d$ (33%)
  - $\chi_0 \to \chi_d + 3\gamma_d$ (33%)
  - $\chi_0 \to \chi_d + 4\gamma_d$ (33%)

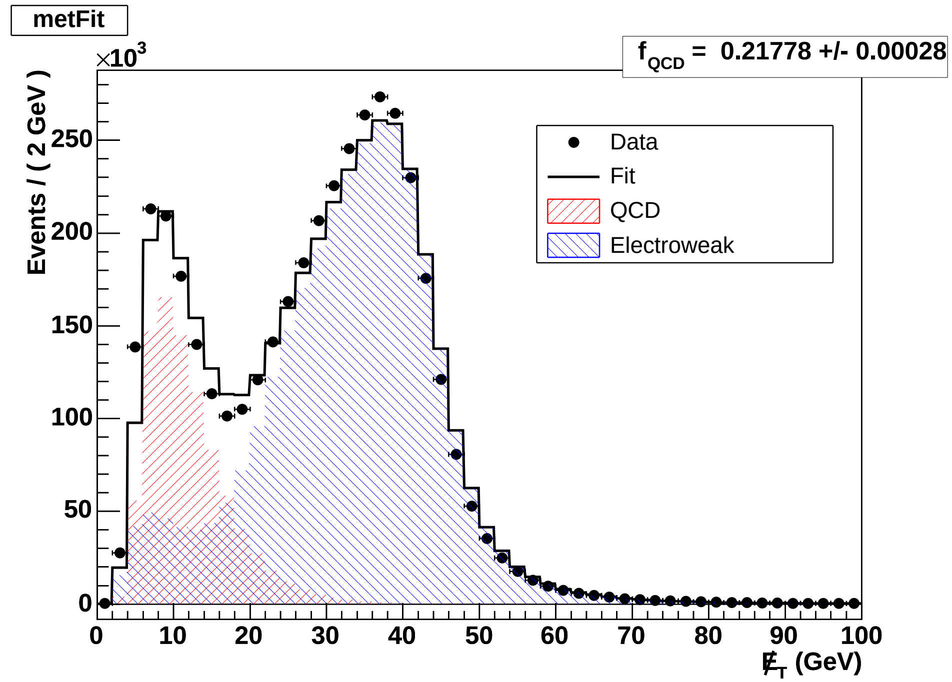


Analysis Strategy

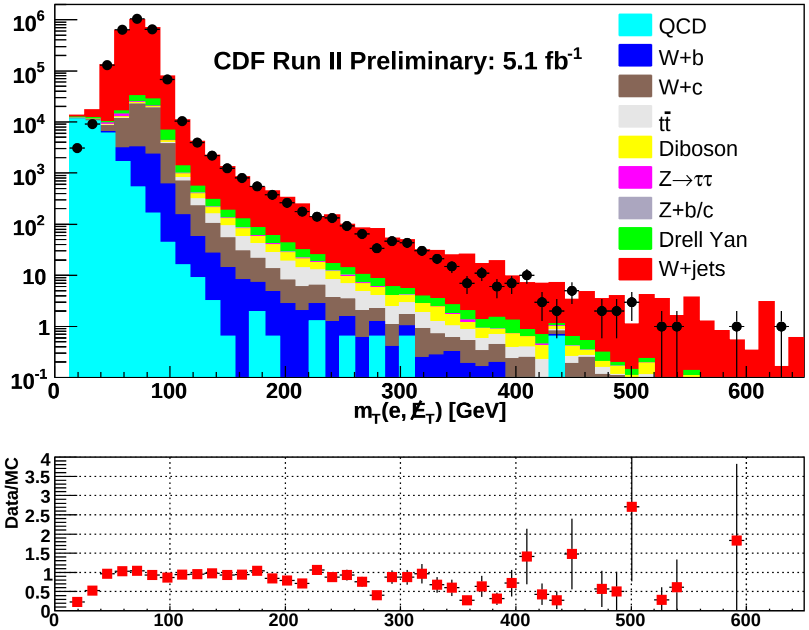
- We use 5.1 fb^{-1} of CDF data, collected from Dec. 2004 to Jan. 2010
- Trigger on leptonic W or Z with standard CDF high-p_T electron and muon cuts, validate W and Z
- Develop soft lepton identification - p_T down to 1 GeV for electrons, 3 GeV for muons
- Parameterize response of soft lepton ID to calculate expected additional leptons in SM
- Normalize predictions to W/Z + exactly one lepton bin
- Count events with multiple additional leptons
- Set limit (or observe excess) based on the number of events with multiple additional electrons and muons

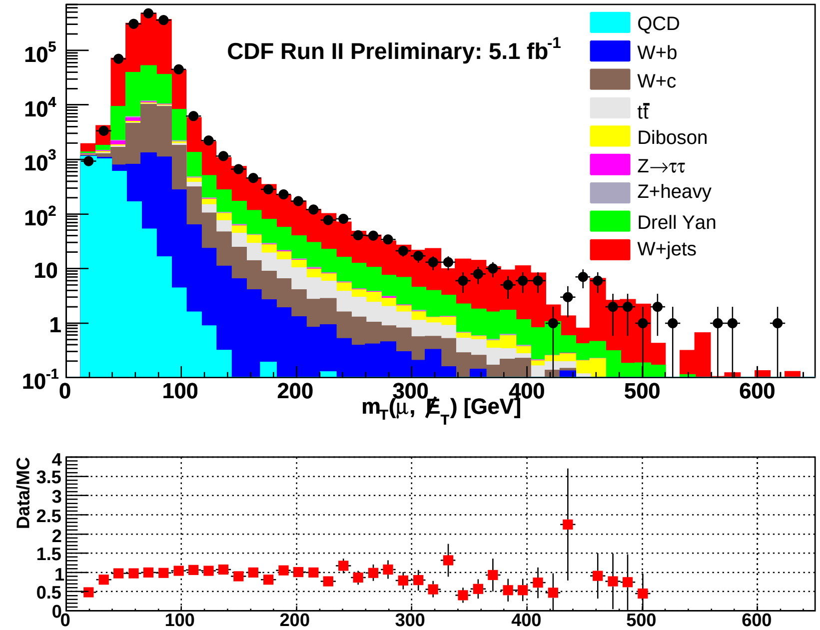
Background Estimation

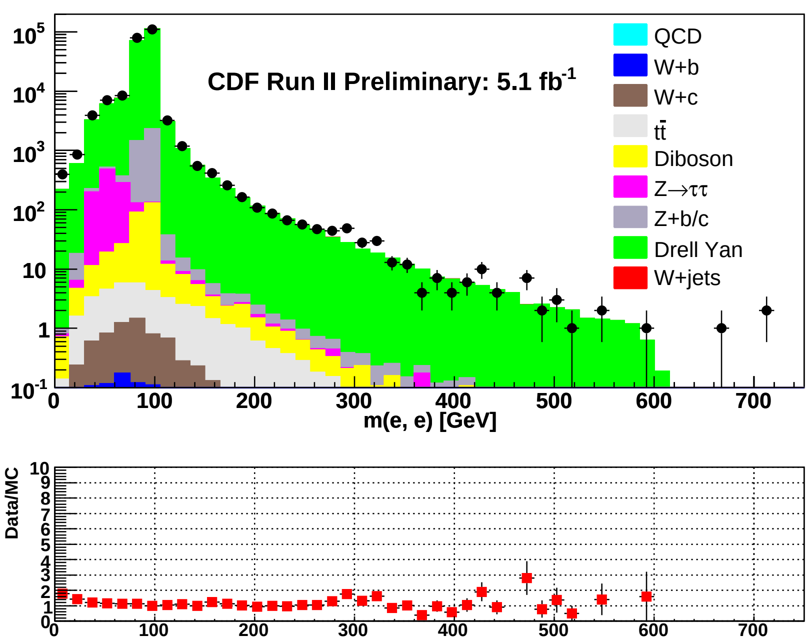
- Use standard CDF MC samples to model EW processes
- Use data-driven technique to model QCD background
  - Electroweak $\not\!\!E_T$ template from MC
  - QCD $\not\!\!E_T$ template from anti-electron selection in data
  - Fit the $\not\!\!E_T$ distribution to find the fraction of events from electroweak and QCD processes

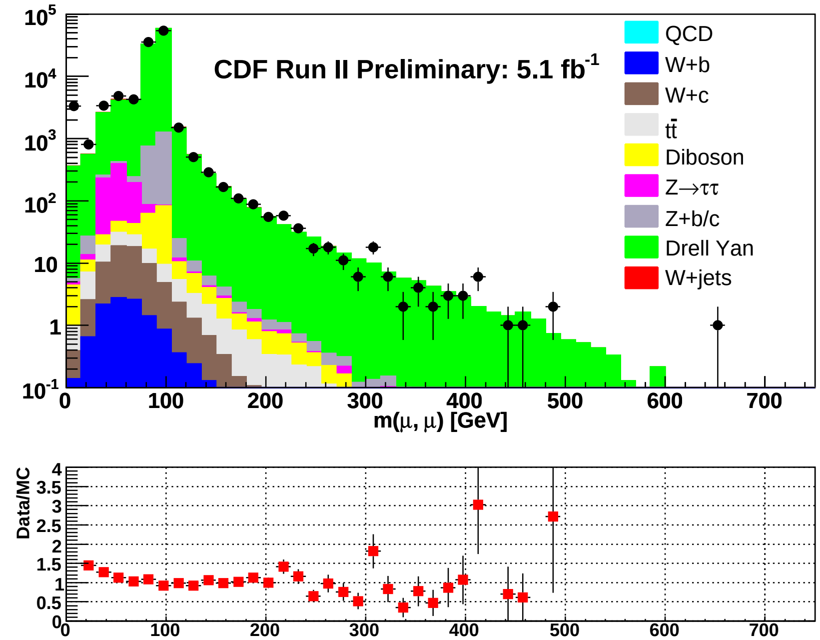


Validation of High-p_T Sample







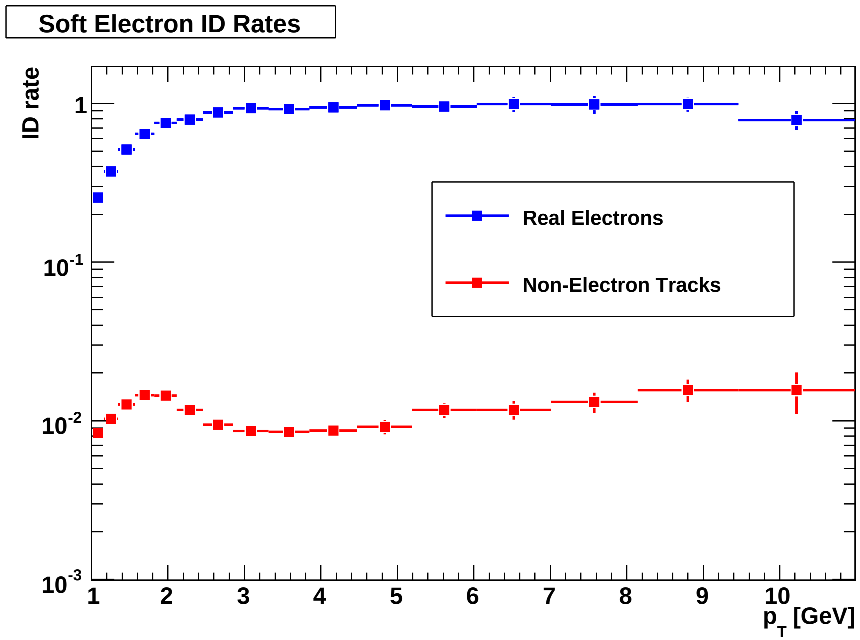


Soft Electrons

- Likelihood-based ID
  - Tracking chamber dE/dx - more useful at low p_T
  - Energy deposited in preradiator, EM and hadronic calorimeters
  - New algorithm for matching tracks to showermax clusters
- Formulated completely with data
  - Pure real sample from conversions
  - Pure fake sample from generic tracks (with conversions, heavy flavor, and hard electrons removed)
- $\mathcal{L} = \frac{\prod Q_i}{1+\prod Q_i}$, where $Q_i = \frac{P(x_i|\text{real})}{P(x_i|\text{fake})}$

Soft Electron Efficiency and Fake Rate

- Pure real sample from conversions
- Pure fake sample from generic tracks (with conversions, heavy flavor, and hard electrons removed)
- Response measured in training samples and parameterized in p_T, η, isolation
- Calculated efficiency and fake rate is applied to the MC to predict SM background
- Systematic uncertainty calculated from difference between muon- and jet- triggered fake samples

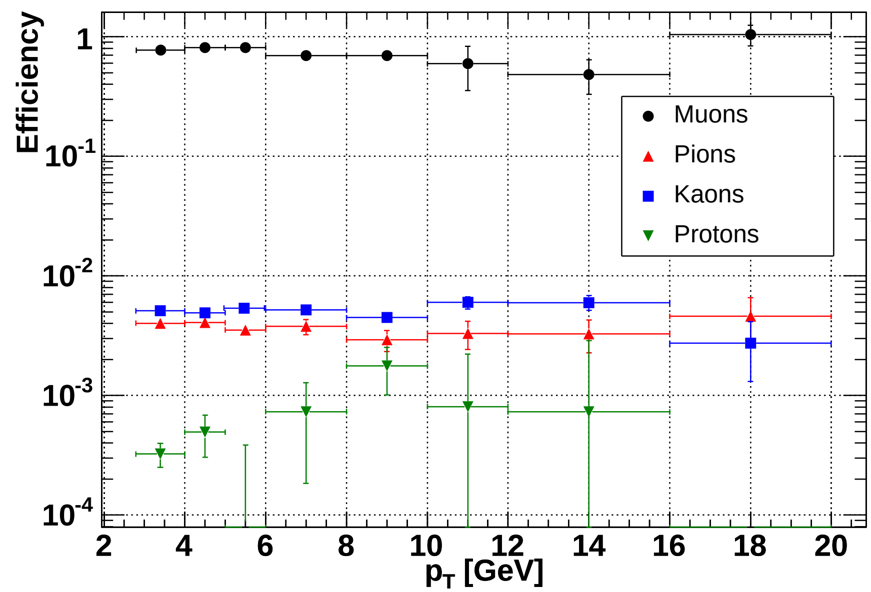


Soft Muons

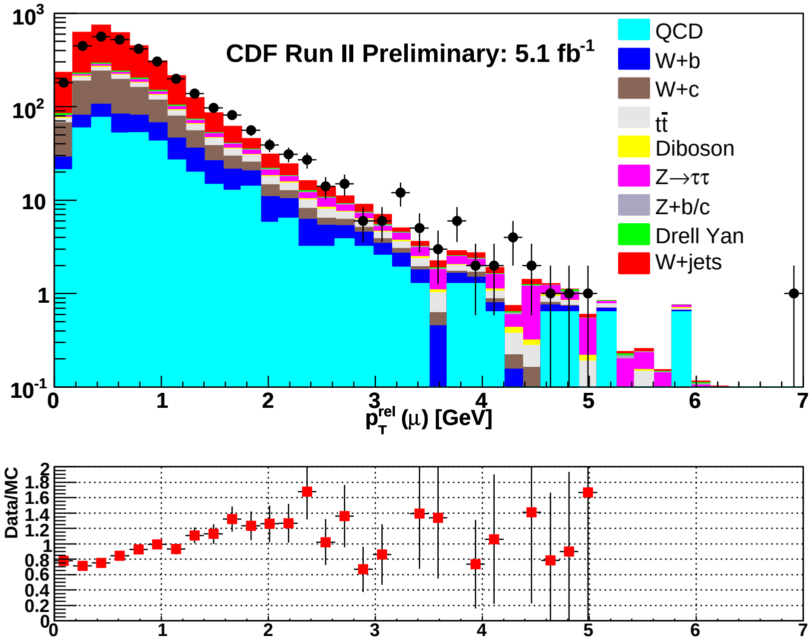
- Use a soft muon tagger originally used for flavor tagging at CDF, ported to our data format
- Uses matching between track and hits in muon detectors, e.g. Δx, Δz, $\Delta\phi$
- $\mathcal{L} = \frac{Q-n}{\sqrt{var(Q)}}$ where Q is a sum of χ^2's of stub-track matching variables
- Tested on μ from J/ψ, π & K from D^*, and p from Λ.

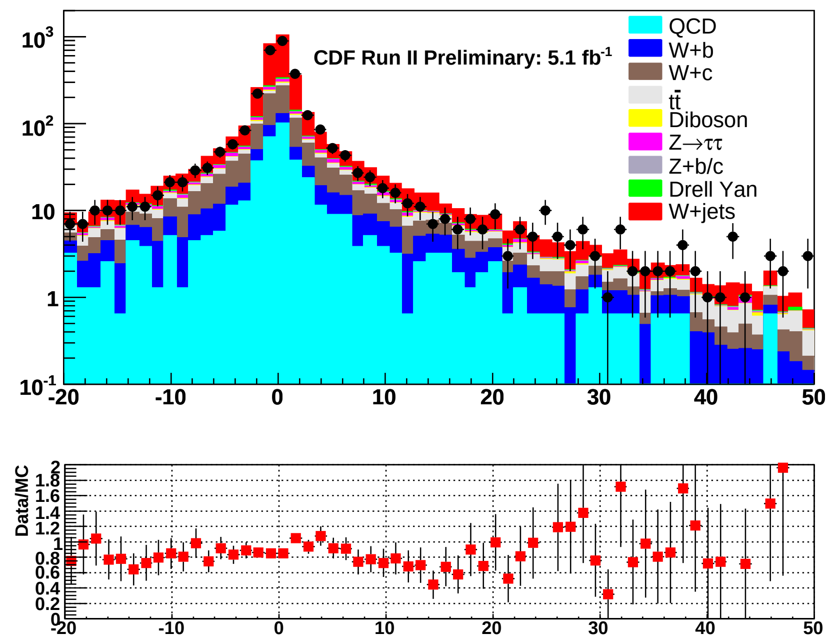
Soft Muon Efficiency and Fake Rate

- Likelihood tested on μ, π, K, p
- Efficiency and fake rate calculated in bins of p_T and η
- Calculated efficiency and fake rate are applied to the MC to predict SM background
- Systematic uncertainty calculated from difference between expected and observed rate in jet-triggered fake samples



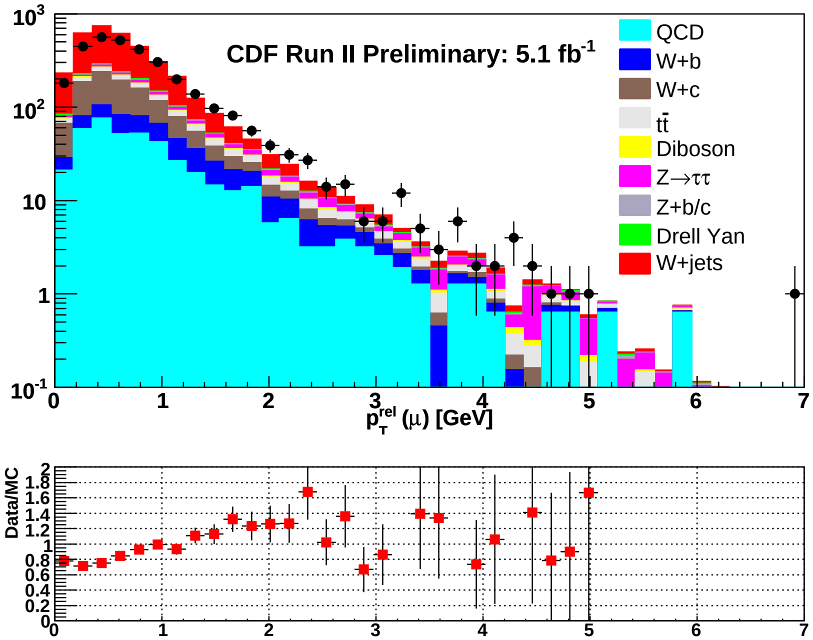
Background Estimation - Heavy Flavor Fraction

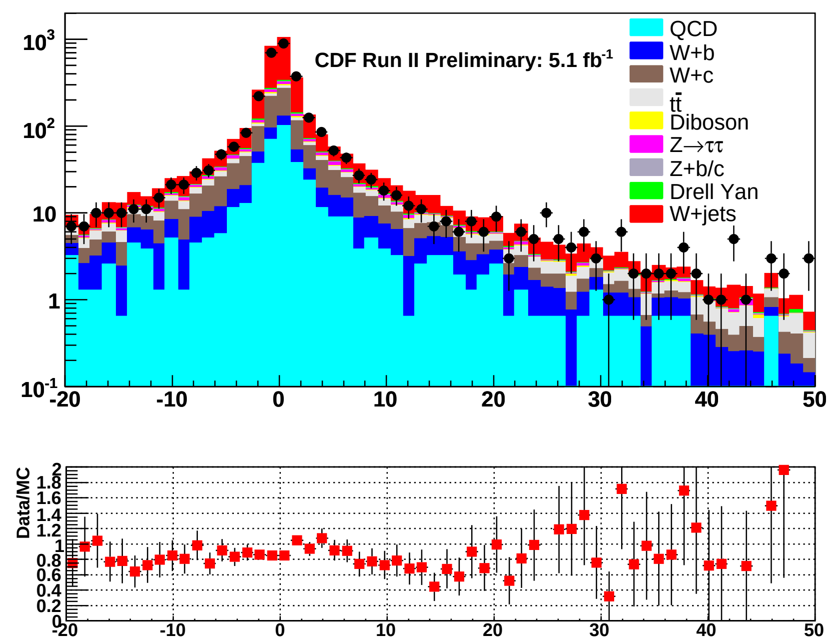




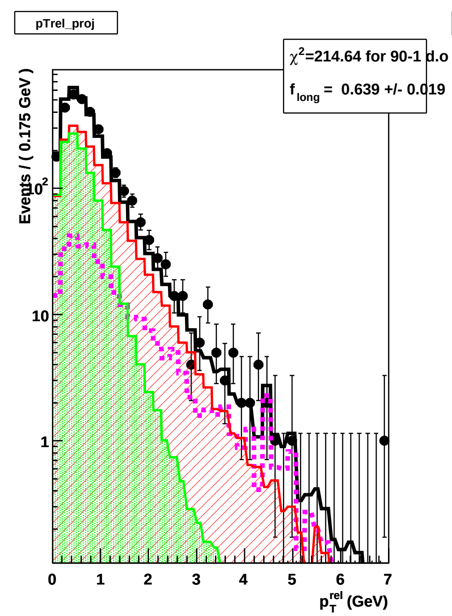
- Semileptonic decays of heavy flavor are the principal background source of real soft leptons
- We find that the amount of heavy flavor is underestimated in our MC after applying the standard scale factors

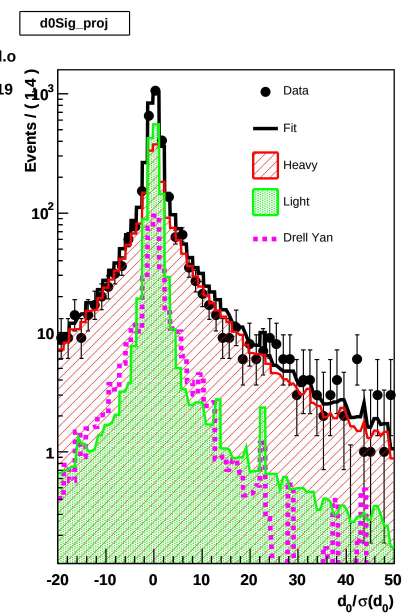
Background Estimation - Heavy Flavor Fraction





- We fit p_T^{rel} and d_0 of soft muons in the "one additional muon" bin
- We fit to templates from light, heavy, and Drell-Yan processes
- We use the result of this fit as a systematic on heavy flavor fraction





Background Estimation - Normalization

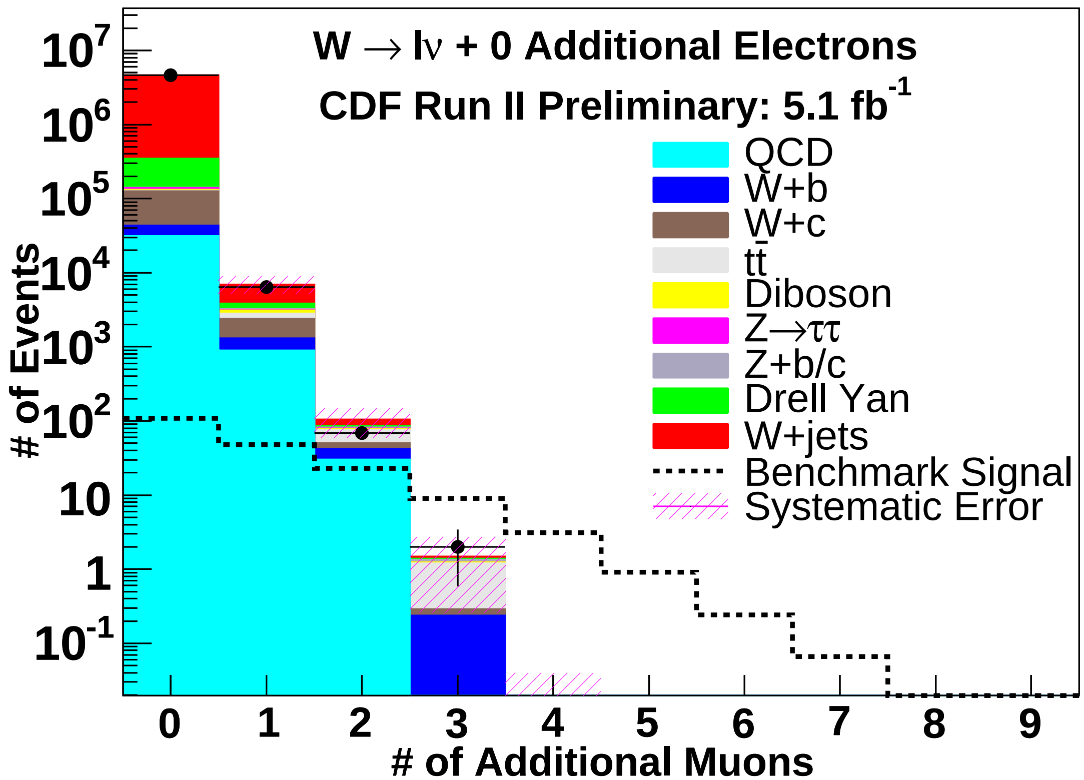
- We scale the background estimate to the one additional lepton bin
  - Expected to be dominated by Standard Model (heavy flavor, Drell-Yan, etc.)
- For events with no additional electrons, we scale to one additional muon
- For events with no additional muons, we scale to one additional electron
- For events with both, we scale to one additional electron (and use the other scale factor as a systematic)

Systematics

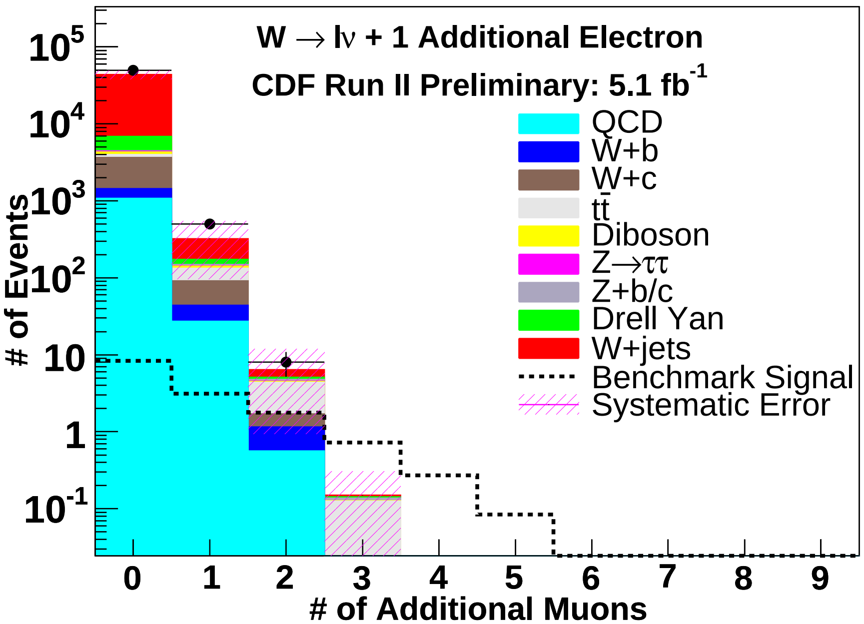
Systematic Source	Uncertainty (Percent)	Effect in Large S/B Region (Events)
Trigger Efficiency	$\pm$(1.6 - 5.9)%	$\pm$0.06
QCD fraction	$\pm$26%	0
Soft e real rate	$\pm$15%	$\pm$0.04
Soft e fake rate	$\pm$15%	$\pm$0.11
Soft μ real rate	$\pm$ stat. err. $\pm$8%	$\pm$0.64
Soft μ fake rate	$\pm$10%	$\pm$0.34
Normalization to e or μ	$\pm$48% (W), $\pm$62% (Z)	$\pm$0.12
Heavy Flavor Fraction	+84% (W), +225% (Z)	+1.51

Results - W

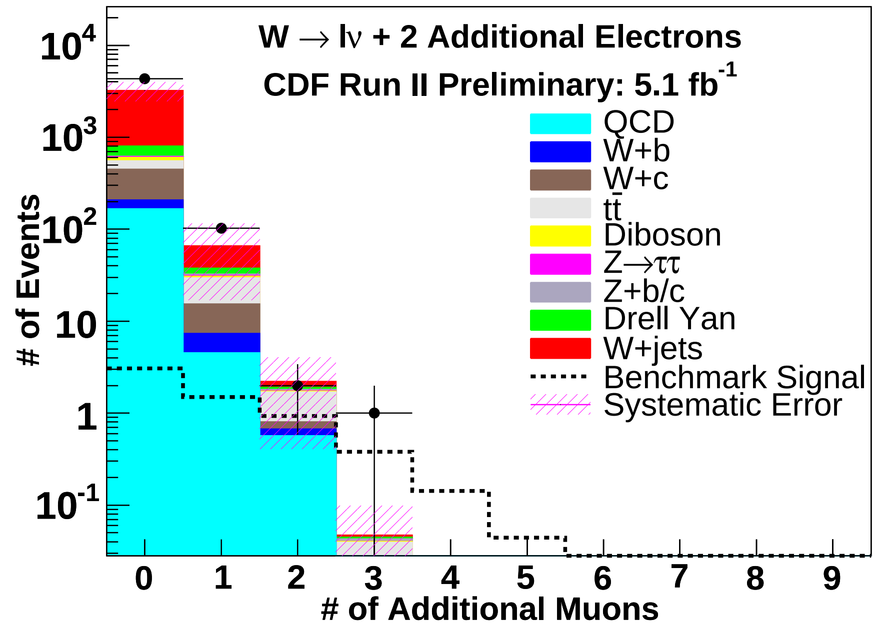
- 2D plot of N_μ vs. N_e, presented in slices of N_e
- Most sensitive in muons, due to photon conversion background



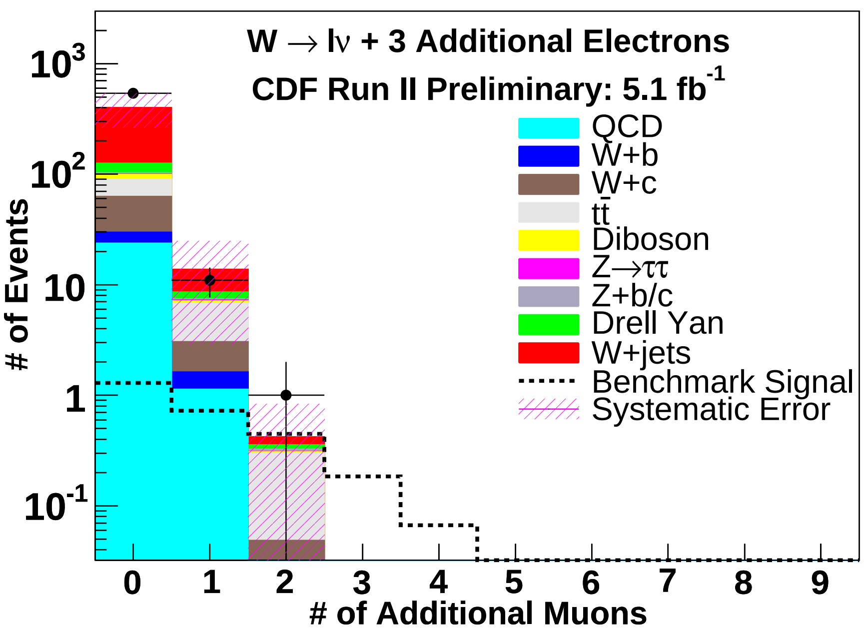
Results - *W*



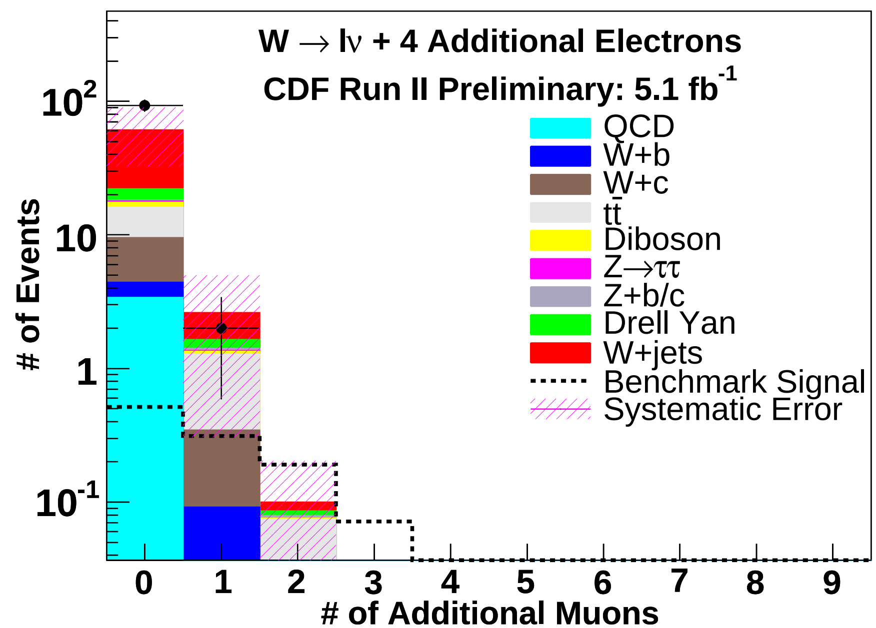
W → lν + 1 Additional Electron
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons



W → lν + 2 Additional Electrons
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons

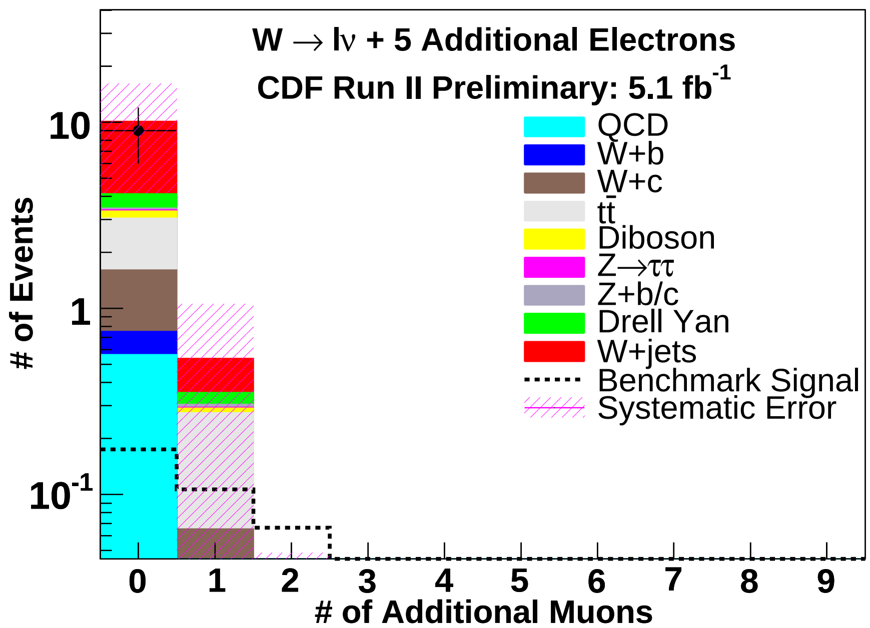


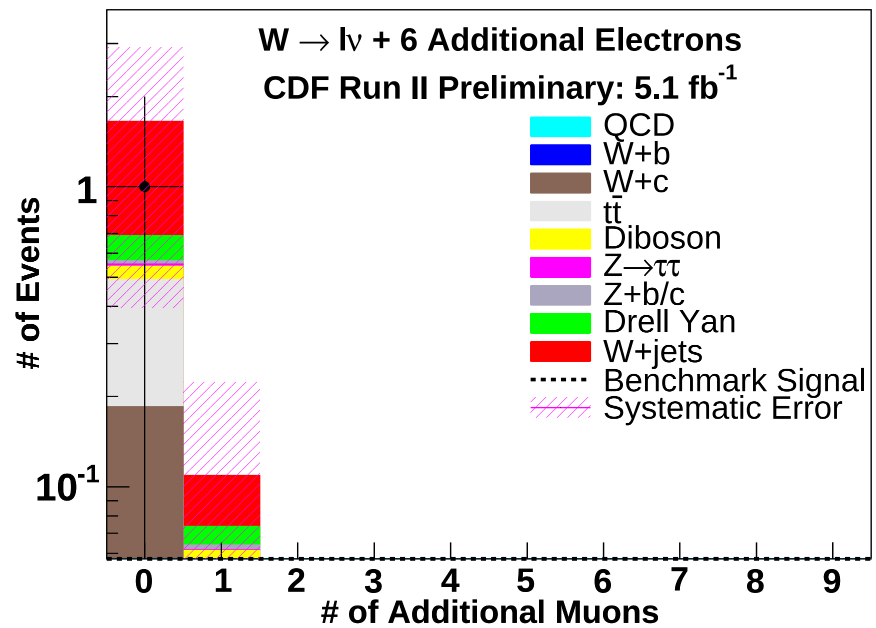
W → lν + 3 Additional Electrons
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons



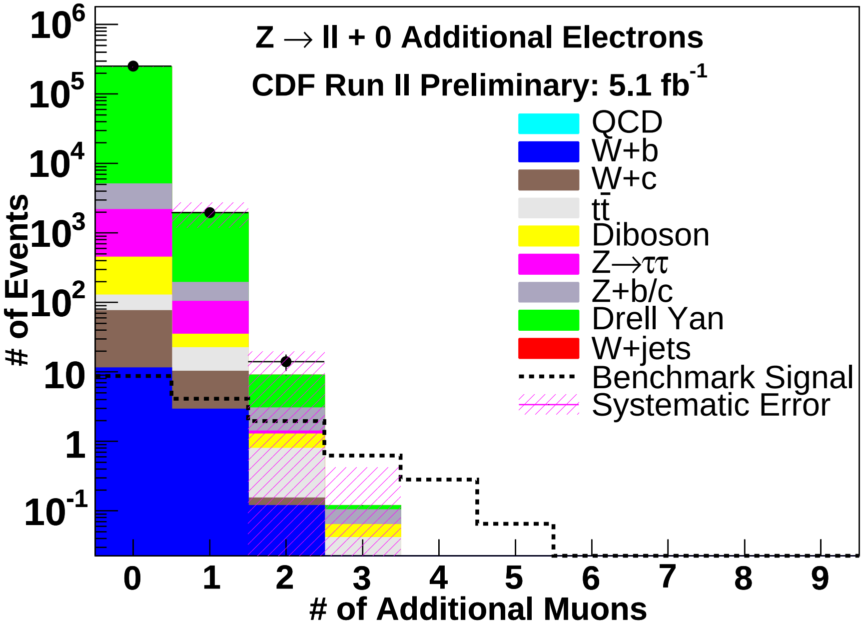
W → lν + 4 Additional Electrons
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons

Results - W


W → lν + 5 Additional Electrons
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons


W → lν + 6 Additional Electrons
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons

Results - Z


Z → ll + 0 Additional Electrons
CDF Run II Preliminary: 5.1 fb-1
QCD
W+b
W+c
tt̄
Diboson
Z→ττ
Z+b/c
Drell Yan
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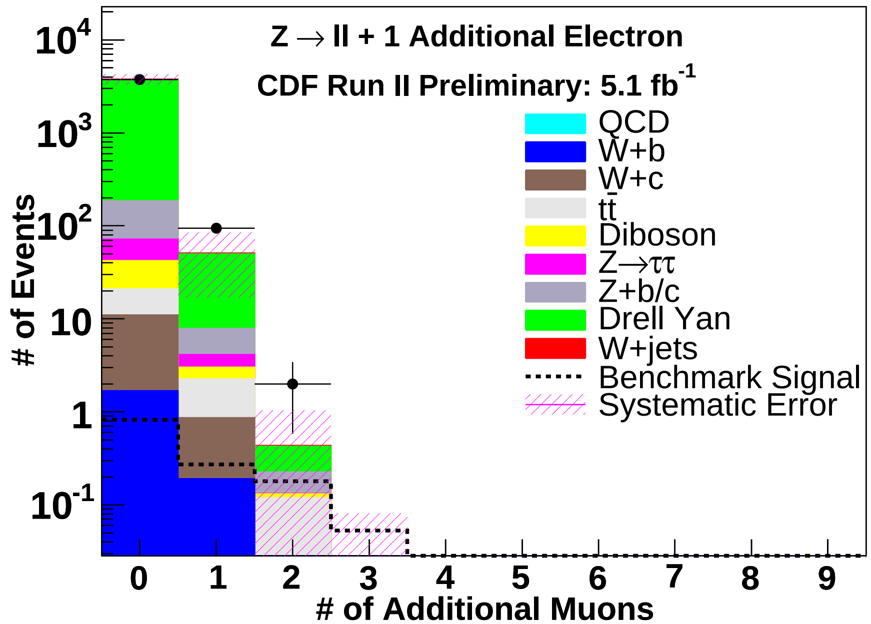
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons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W+c
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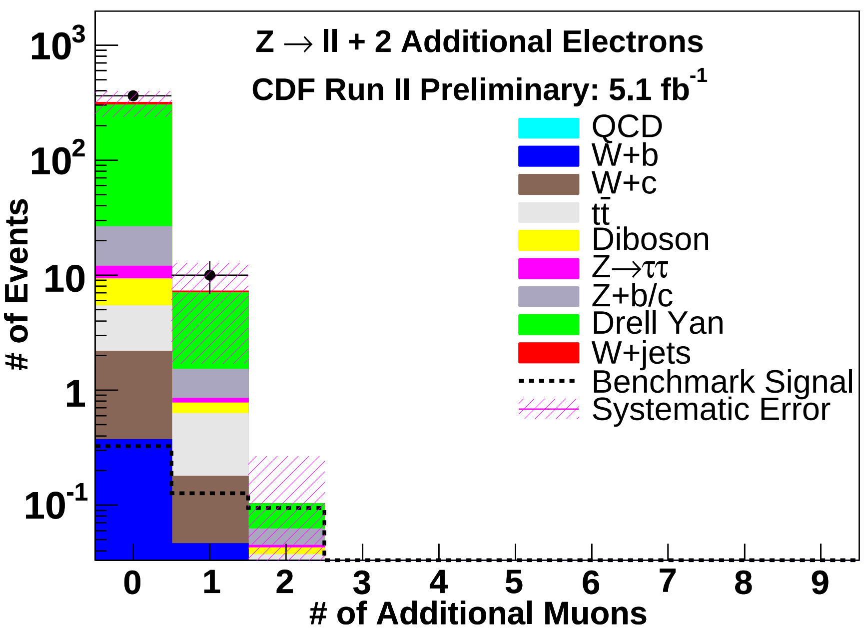
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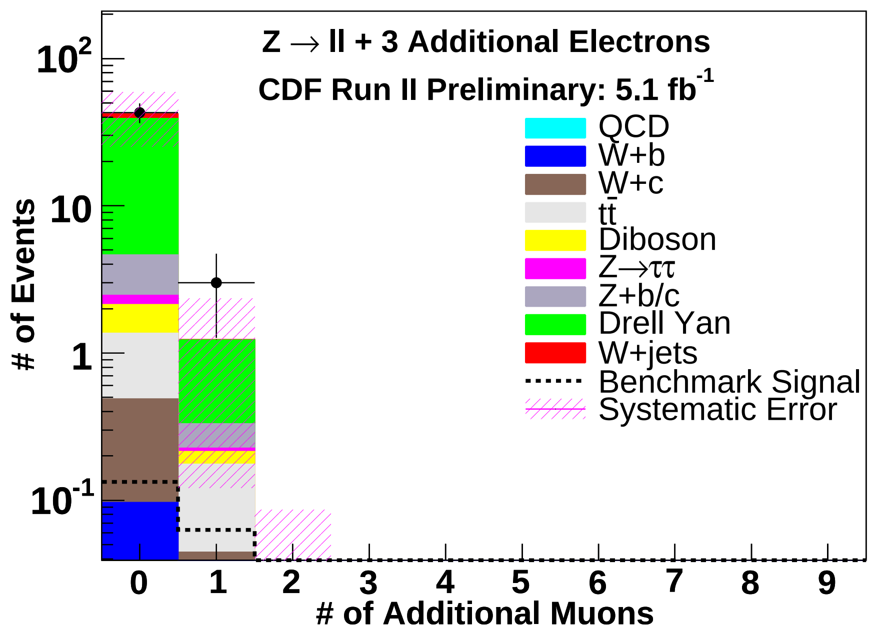
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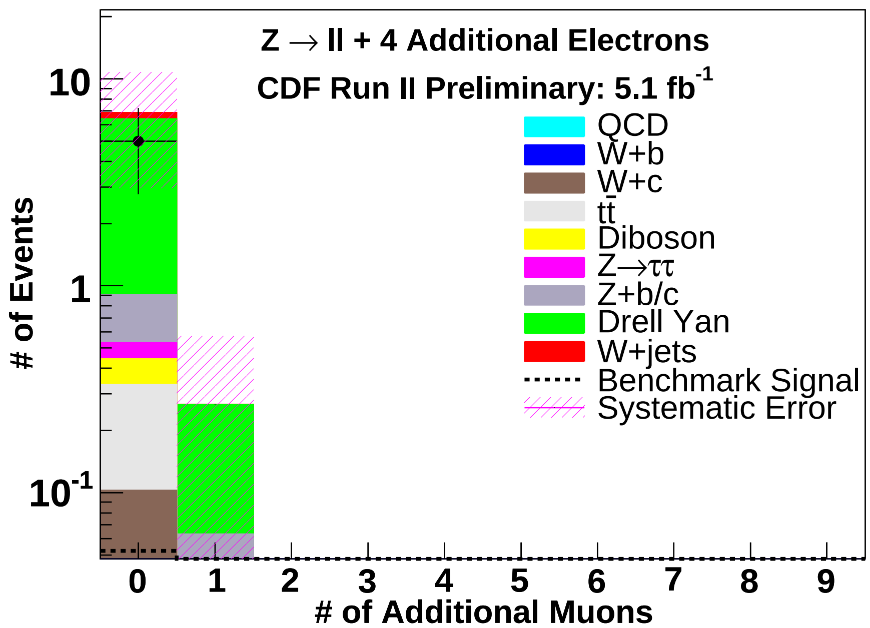
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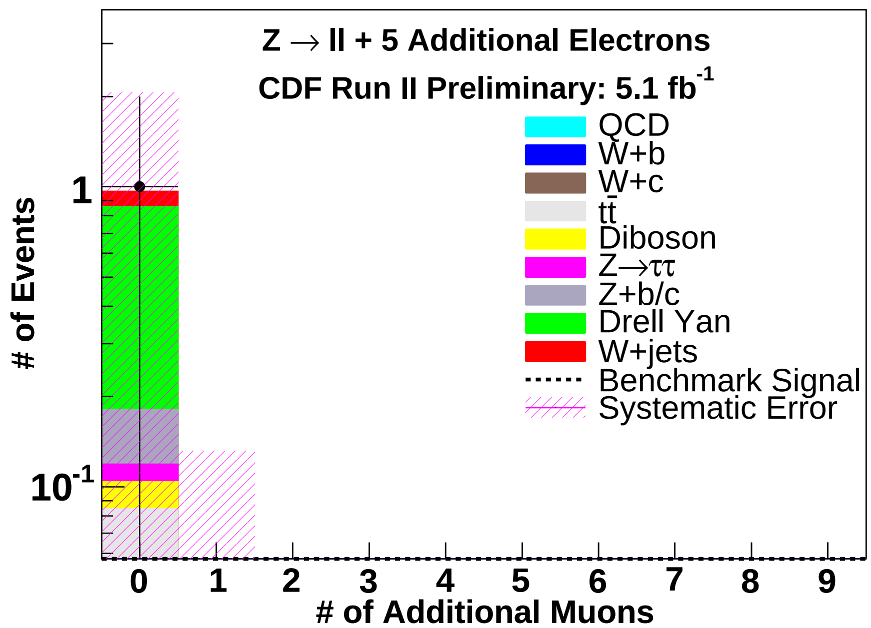
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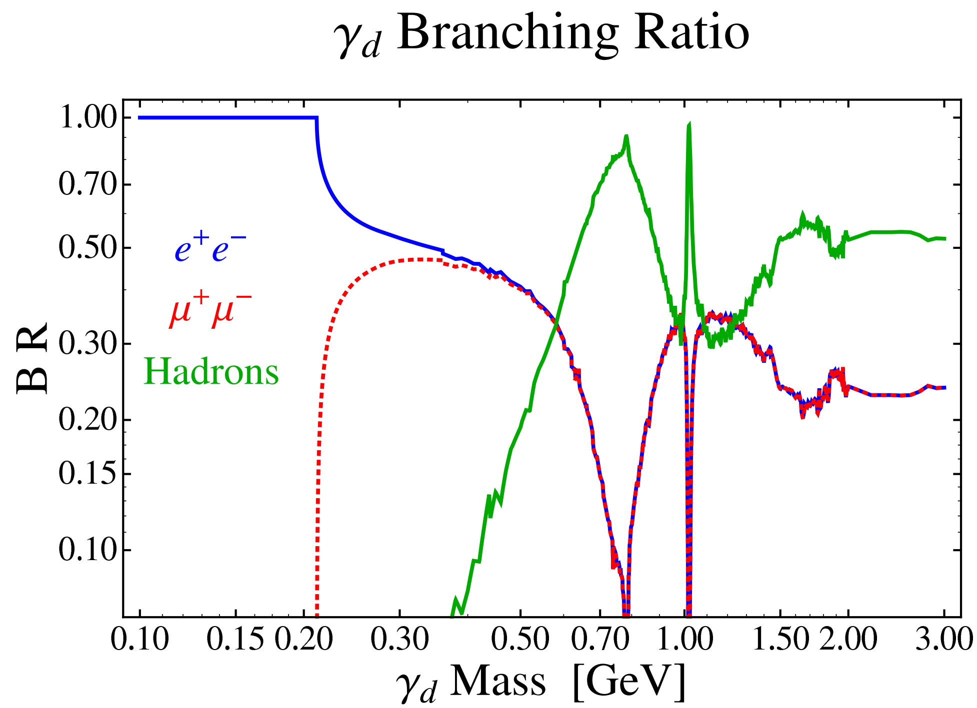
Z→ττ
Z+b/c
Drell Yan
W+jets
Benchmark Signal
Systematic Error
# of Events
# of Additional Muons

Setting a Limit

- We use the `mclimit` code (T. Junk, NIM A434, p. 435-443 (1999)) to set a limit on our benchmark model
- We rule out the benchmark model at 99.7% confidence.
- We set a 95% confidence level limit on this model of 6.9% of the cross section, or 27 fb for a leptonic W or Z plus a Higgs.

Conclusion

- We rule out this model of a hidden Higgs decaying to a dark sector at 99.7% confidence.
- This is one representative point in this class of models
- We will publish the results in terms of efficiencies to find extra leptons, so that any model can be tested.
- In general, good limits on $\gamma_d \to \mu\mu$, weak limits on $\gamma_d \to ee$



Results Summary - W

Bins with < 0.25 events expected in BG and signal, and none observed, are not shown.

N_e	N_μ	Predicted SM Background	Predicted Dark Higgs Signal	Observed
0	0	4632580 ± 21334	108	4660910
0	1	6999 ± 1831	48	6402
0	2	106 ± 45	23	69
0	3	1.5 ± 1.2	9.0	2
0	4	0.019 ± 0.020	3.1	0
0	5	0.00018 ± 0.00021	0.92	0
1	0	43551 ± 5403	8.3	49420
1	1	323 ± 227	3.1	498
1	2	6.4 ± 5.5	1.8	8
1	3	0.15 ± 0.16	0.72	0
1	4	0.0025 ± 0.0031	0.27	0

Results Summary - W (continued)

N_e	N_μ	Predicted SM Background	Predicted Dark Higgs Signal	Observed
2	0	3237 ± 763	3.1	4310
2	1	66 ± 49	1.5	103
2	2	2.2 ± 1.8	0.93	2
2	3	0.047 ± 0.051	0.38	1
3	0	402 ± 139	1.3	538
3	1	14 ± 11	0.72	11
3	2	0.42 ± 0.41	0.45	1
4	0	61 ± 28	0.51	93
4	1	2.6 ± 2.3	0.31	2
5	0	10 ± 6.0	0.17	9
5	1	0.54 ± 0.52	0.11	0

Results Summary - Z

N_e	N_μ	Predicted SM Background	Predicted Dark Higgs Signal	Observed
0	0	244858 ± 3263	8.8	252132
0	1	1964 ± 783	4.1	1976
0	2	9.0 ± 11	2.0	14
0	3	0.12 ± 0.30	0.63	0
0	4	0 ± 0.00094	0.28	0
1	0	3797 ± 495	0.82	3747
1	1	51 ± 34	0.27	94
1	2	0.43 ± 0.61	0.18	2
2	0	318 ± 79	0.33	363
2	1	7.2 ± 5.5	0.13	10
3	0	42 ± 17	0.13	43
3	1	1.2 ± 1.1	0.063	3
4	0	6.9 ± 3.9	0.052	5
4	1	0.27 ± 0.30	0.019	0
5	0	0.97 ± 1.1	0.017	1