Searches for New Physics in Photon Final States

Andrei Loginov
ITEP Moscow
for the CDF Collaboration

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Why Photon Final States?

$\surd$ Well Motivated Theories

$\rightarrow$ Most importantly Supersymmetry

$\surd$ History

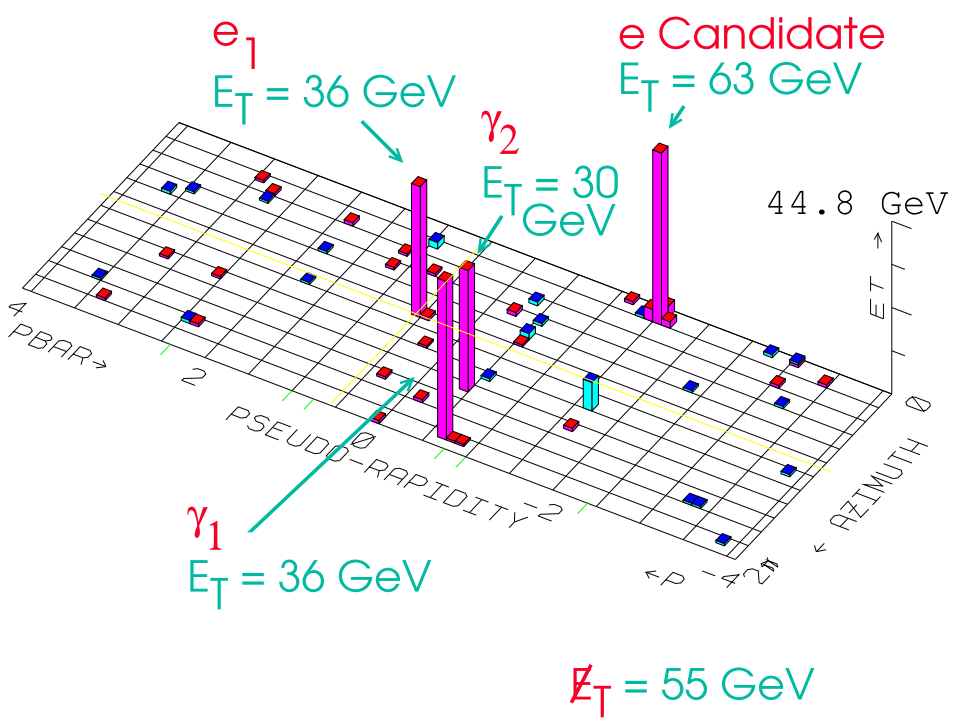
$\rightarrow$ Follow up on some of the anomalies from CDF in Run I

$\surd$ Just because...

$\rightarrow$ The photon is coupled to electric charge
$\rightarrow$ The photon is massless
$\rightarrow$ The photon is stable
$\rightarrow$ The photon is a boson
$\rightarrow$ And then...

- **Additional Lepton(s)** $\Rightarrow$ Rare in SM, Backgrounds are low for searches!
- **Additional Photon(s)** $\Rightarrow$ The photons have moderate signal-to-noise but good efficiency and mass peak resolution

Run I Results: $ee\gamma\gamma\not{E}_T$ Event



Rare in the Standard Model?

Dominant SM Source:

$WW\gamma\gamma \to (e\nu)(e\nu)\gamma\gamma \to ee\gamma\gamma\not{E}_T$

$\Rightarrow$ **8×10^{-7} Events**

All other sources

$\Rightarrow$ **5×10^{-7} Events**

Total:

$\Rightarrow$ **10^{-6} Events**

Prediction of Supersymmetry?

(Ambrosanio, Kane, Kribs, Martin, Mrenna, hep/ph 9607414):

$$p\bar{p} \to \tilde{e}^+\tilde{e}^-(+X)$$

$$\tilde{e} \to \tilde{\chi}_2^0 + e$$

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\gamma$$

Run I: No other $\ell\ell\gamma\gamma\not{E}_T$ candidates

$ee\gamma\gamma\not{E}_T \Rightarrow$ **Signature-Based Searches**

From $\gamma\gamma$ to $\ell\gamma$: $\ell\gamma X$ Search

$\surd$Run I Searches for $\gamma\gamma$+X

Results consistent with the SM

(CDF PRL 81, 1791 (1998), PRD 59, 092002 (1999))

$\Rightarrow$ Search for $\ell\gamma$+X instead of $\gamma\gamma$+X

Run I Photon-Lepton Results (86 pb^{-1})

Category	μ_{SM}	N_0	$\mathbf{P}(N \geq N_0 \mid \mu_{SM})$, %
All $\ell\gamma X$	–	**77**	–
Z-like $e\gamma$	–	**17**	–
Two-Body $\ell\gamma X$	**24.9±2.4**	**33**	**9.3**
Multi-Body $\ell\gamma X$	**20.2±1.7**	**27**	**10.0**
Multi-Body $\ell\ell\gamma X$	**5.8 ± 0.6**	**5**	**68.0**
Multi-Body $\ell\gamma\gamma X$	**0.02±0.02**	**1**	**1.5**
Multi-Body $\ell\gamma\not{E}_{\rm T}X$	**7.6 ± 0.7**	**16**	**0.7**

CDF PRL 89, 041802 (2002), PRD 66, 012004 (2002)

$\surd$ $\ell\gamma\not{E}_{\rm T}$ Category:

16 $\ell\gamma\not{E}_{\rm T}$ Events vs 7.6±0.7 Expected

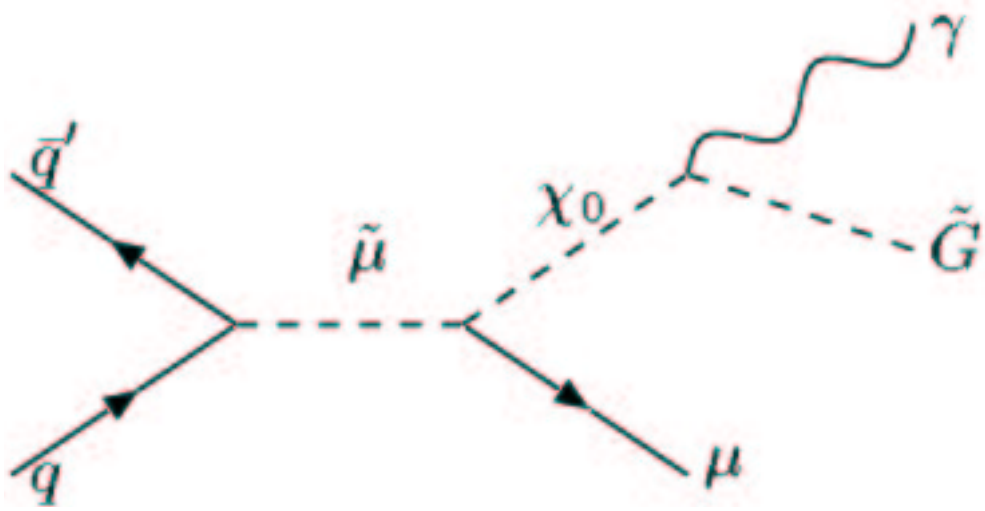
11 $\mu\gamma\not{E}_{\rm T}$ Events vs 4.2±0.5 Expected

5 $e\gamma\not{E}_{\rm T}$ Events vs 3.4±0.3 Expected

$\surd$ Observed rate of $\ell\gamma\not{E}_{\rm T}$:

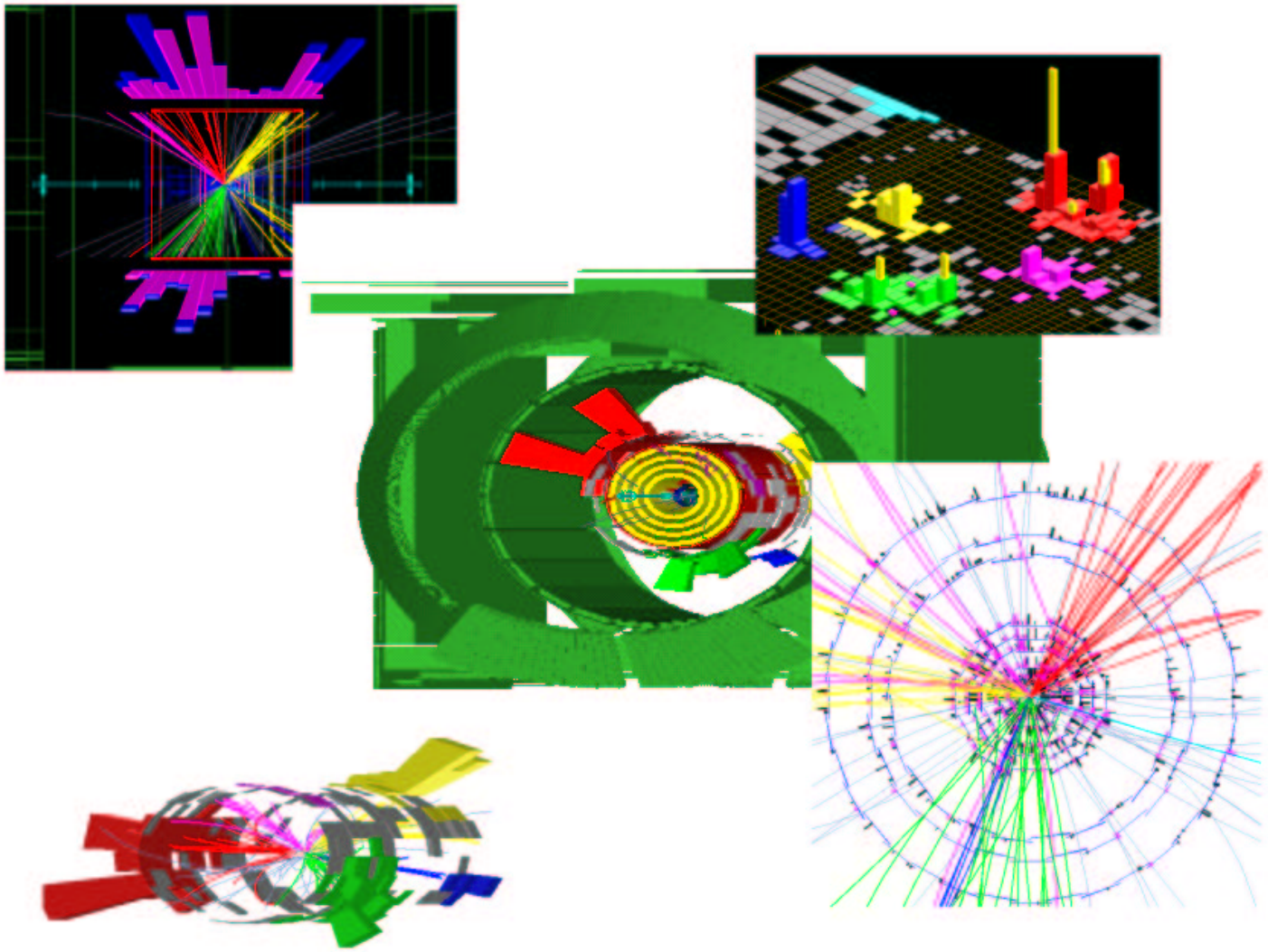
0.7% probability (**2.7** standard deviations).

$\Rightarrow$ Resonant Smuon Production?



(hep/ph 0111014, B.C.Allanach, S.Lola, K.Sridhar)

Run II: Take More Data!



- √ Increase the Collision Energy
- √ Increase the rate at which we take data
- √ Upgrade the Detectors

Run II: Searches for New Physics in Photon Final States

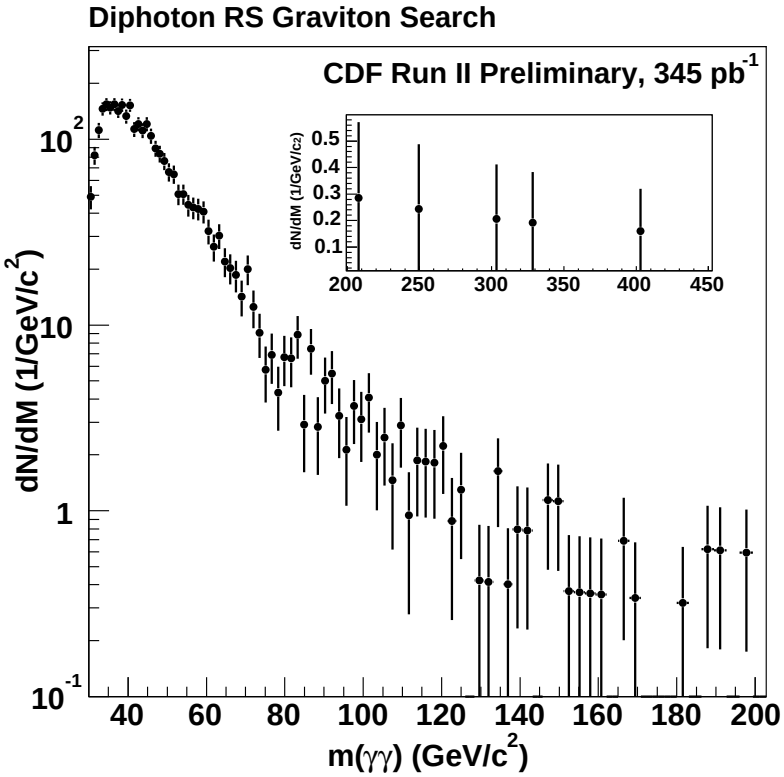
Will cover three of them:

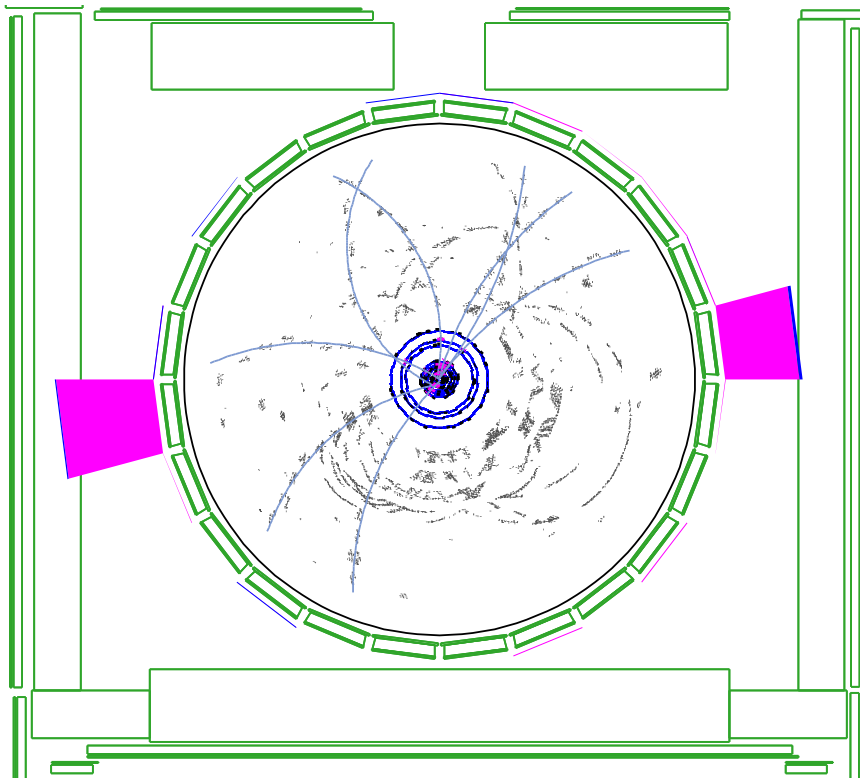
- √ **Search for High-Mass Diphoton State and Limits for Randall-Sundrum Graviton**
- √ **Search for Anomalous Production of Diphoton Events with $\not\!\!E_T$ and Limits on GMSB Models**
- √ **Search for Lepton-Photon-X Events**

  New! first time presented outside of CDF!

Search for High-Mass Diphoton State and Limits for Randall-Sundrum Graviton

- **Photons in Central Calorimeter,** $\eta^{\gamma} < 1.05$
- $E_T^{\gamma} >$ **15 GeV**
- **M** $(\gamma, \gamma) >$ **30 GeV**

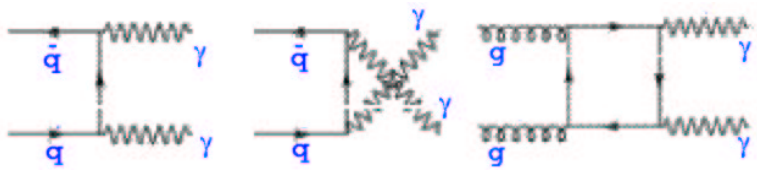


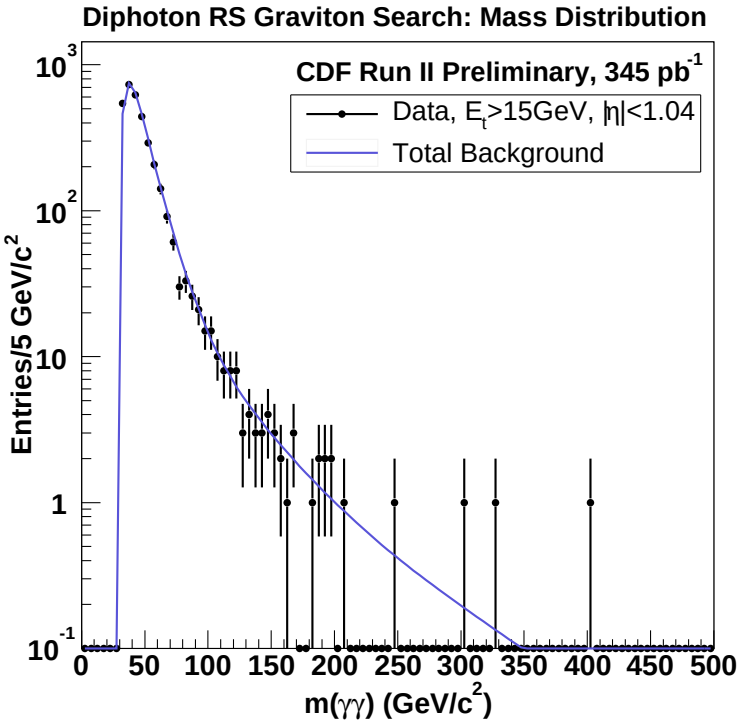


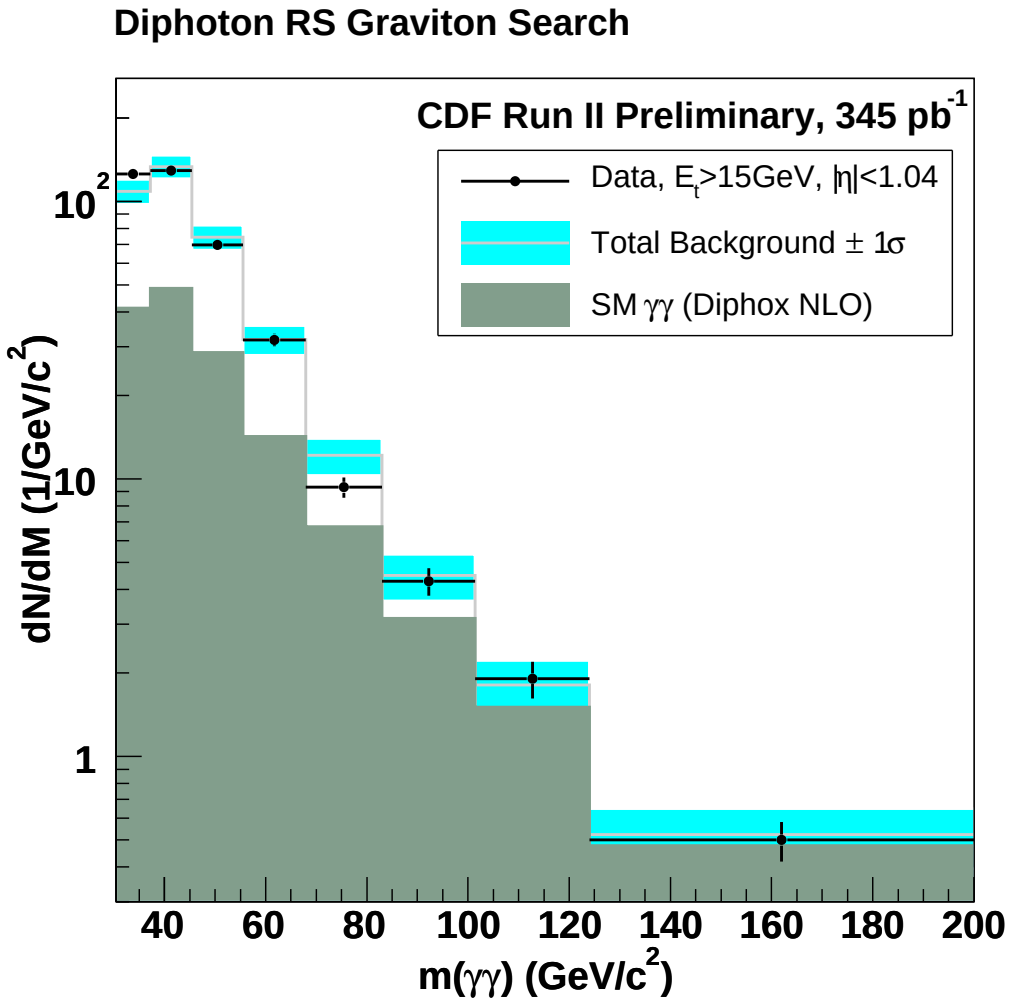
$\gamma\gamma$ **Highest Mass Event**
M $(\gamma\gamma) =$ **405 GeV**
$E_T^{\gamma 1} =$ **172 GeV**
$E_T^{\gamma 2} =$ **175 GeV**

Search for High-Mass Diphoton State...

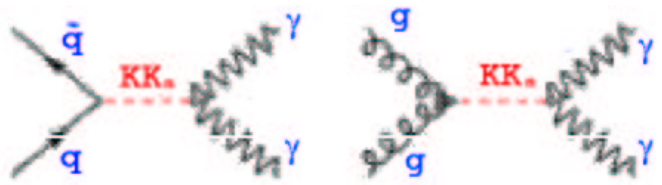
- SM Background
  - NLO Diphox calculation
  - normalized to $\mathcal{L}$
- Jets Faking Photon
  - Usually a high-E_T π^0
  - normalize to low mass



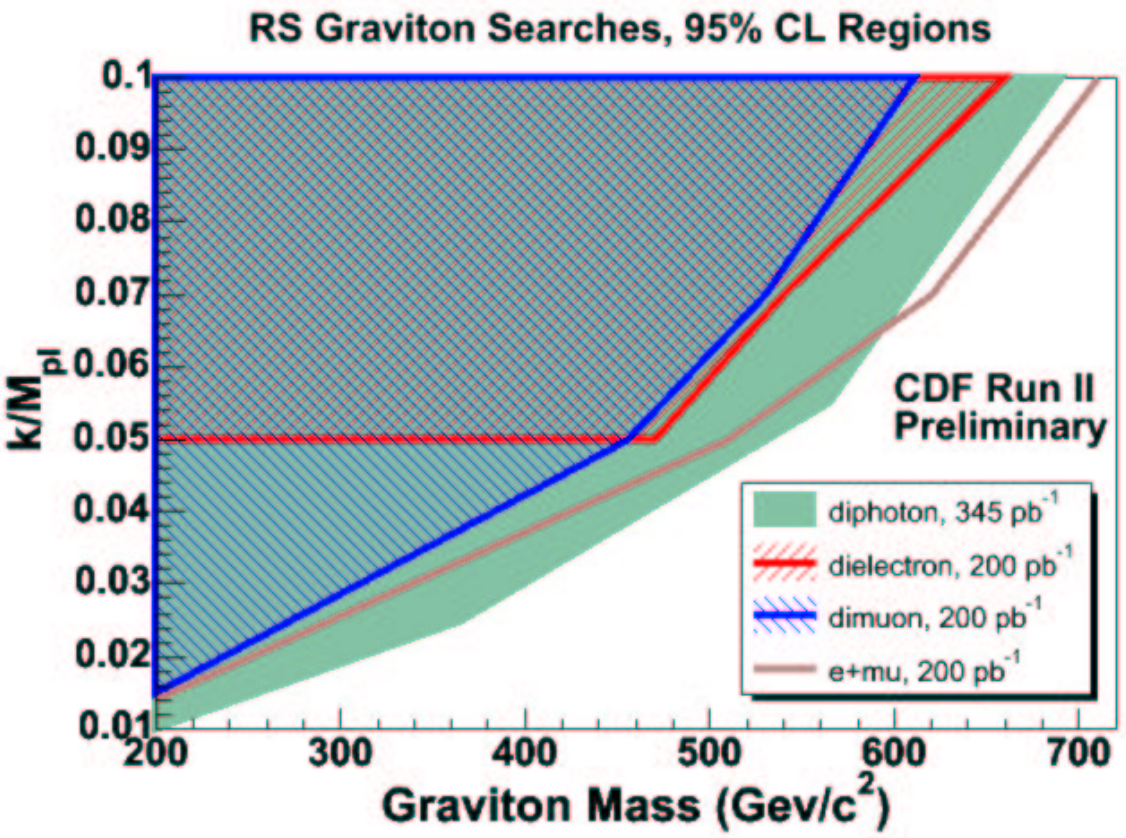




...and Limits on Randall-Sundrum Graviton



- **Model**
  - **S-channel Graviton**
  - **Warp factor: curvature in extra dimension⇒** M_{KK}
  - **small warp values predict narrow peaks**
- **Limits:** ee, $\mu\mu$ **and** $\gamma\gamma$
  - $\gamma\gamma$: **345** pb^{-1}
  - ee, $\mu\mu$: **200** pb^{-1}
  - $\gamma\gamma$ **has larger BR**
  - $\gamma\gamma$ **spin factors improve acceptence**



Search for Anomalous Production of Diphoton Events with $\not\!\!E_{\rm T}$ at CDF and Limits on GMSB Models

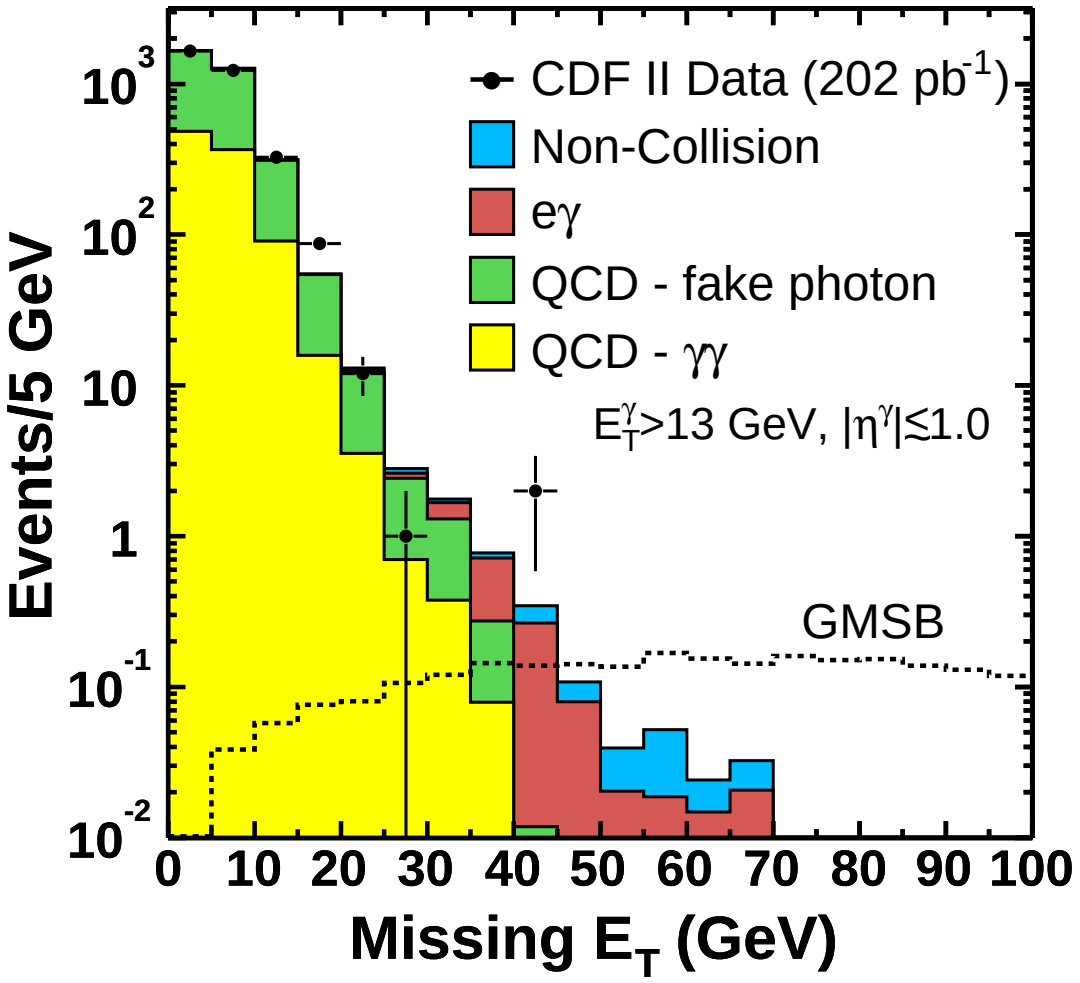
- **Search for $\gamma\gamma + \not\!\!E_{\rm T} + $ X**
- **Photons in Central Calorimeter, $\eta^{\gamma} < 1.05$**
- **$E_T^{\gamma} >$ 13 GeV**

Backgrounds:

- **QCD background: fake photon (jj, jγ)**
- **QCD background: $\gamma\gamma$**
- **$e\gamma$**
- **Non-Collision: beam-related, cosmic rays**

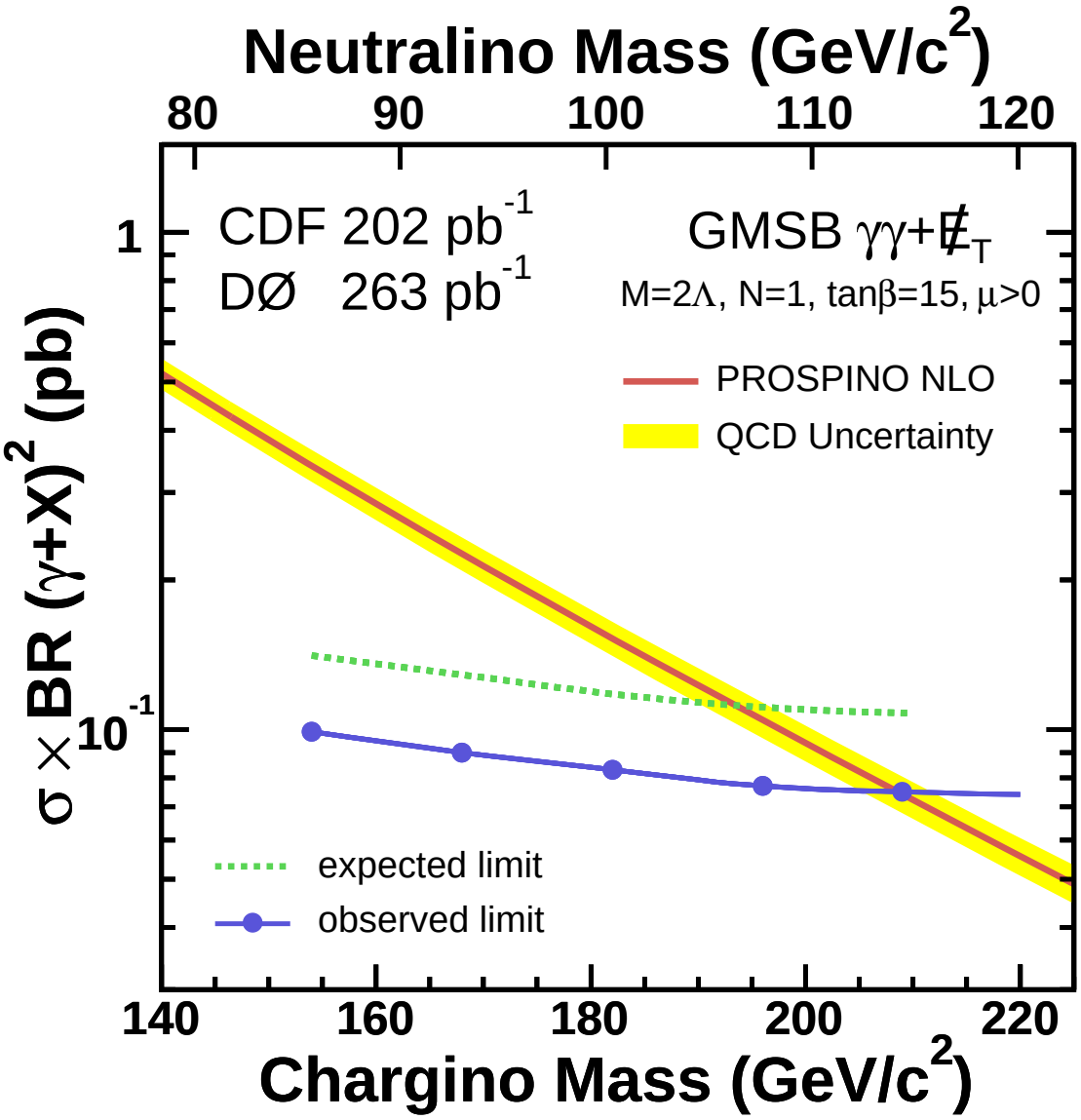
Are there any $ee\gamma\gamma\not\!\!E_{\rm T}$ Events like in Run I?..

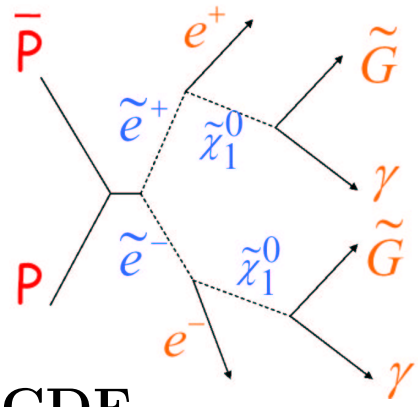
$\not\!\!E_T$ cut	Expected	Observed
25 GeV	$5.95 \pm 3.25(\text{stat}) \pm 3.81(\text{sys})$	3
35 GeV	$1.39 \pm 0.40(\text{stat}) \pm 0.40(\text{sys})$	2
45 GeV	$0.27 \pm 0.07(\text{stat}) \pm 0.10(\text{sys})$	0
55 GeV	$0.12 \pm 0.04(\text{stat}) \pm 0.05(\text{sys})$	0



No excess in two photons + energy imbalance

...and Limits on GMSB Models





CDF

$M_{\tilde{\chi}_1^\pm} > 167\ \mathrm{GeV}/c^2$

$M_{\tilde{\chi}_1^0} > 93\ \mathrm{GeV}/c^2$

$\Lambda > 69\ \mathrm{GeV}/c^2$

Combined CDF+D0

$M_{\tilde{\chi}_1^\pm} > 209\ \mathrm{GeV}/c^2$

$M_{\tilde{\chi}_1^0} > 114\ \mathrm{GeV}/c^2$

$\Lambda > 84.6\ \mathrm{GeV}/c^2$

at 95% C.L. in GMSB Model

(Buescher, Culbertson et al., *hep/ex 0504004)*

Search for Lepton-Photon-X Events

New! first time presented outside of CDF

√ **Datasets**

- Logical 'OR' of
  Inclusive High-E_T Lepton and Inclusive High-E_T Photon Samples

√ **Objects:** *a priori* **selection - same as in Run I**

- **Tight** Muons: P_T >**25** GeV
- **Tight** Central Electrons, Photons: E_T >**25** GeV
- **Loose** Muons: P_T >**20** GeV
- **Loose** Central Electrons: E_T >**20** GeV
- **Loose** Plug Electrons: E_T >**15** GeV
- $\not\!\!E_T$ >**25** GeV

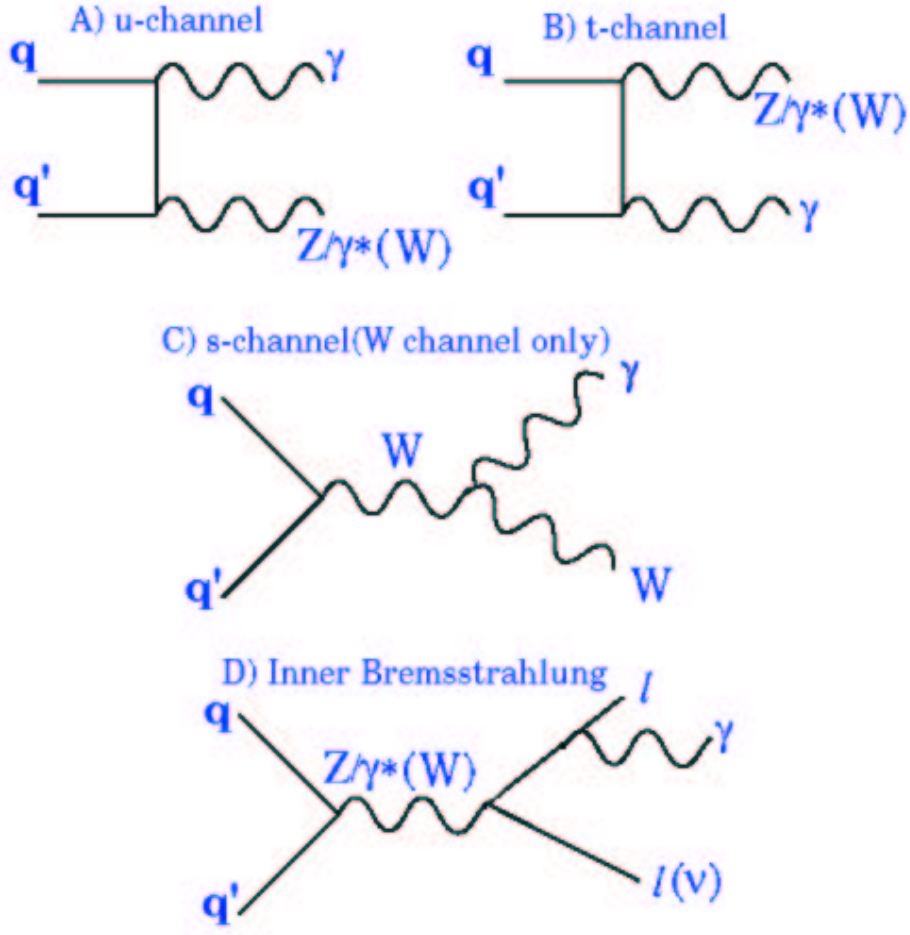
√ **Take Runs with Detector Fully Operational**
$\mathcal{L} = 307 pb^{-1}$

Search for Lepton-Photon-X Events

New! first time presented outside of CDF

√ Standard Model Contribution

- MadGraph, CompHep and Baur SM MC
- $W\gamma$, $Z\gamma$, $W\gamma\gamma$, $Z\gamma\gamma$ Samples



√ Fakes

- Jet faking photon
- $e \rightarrow \gamma$ Fakes
- QCD (Jets faking lepton and $\not\!\!E_T$)

√ Lepton-Photon-X

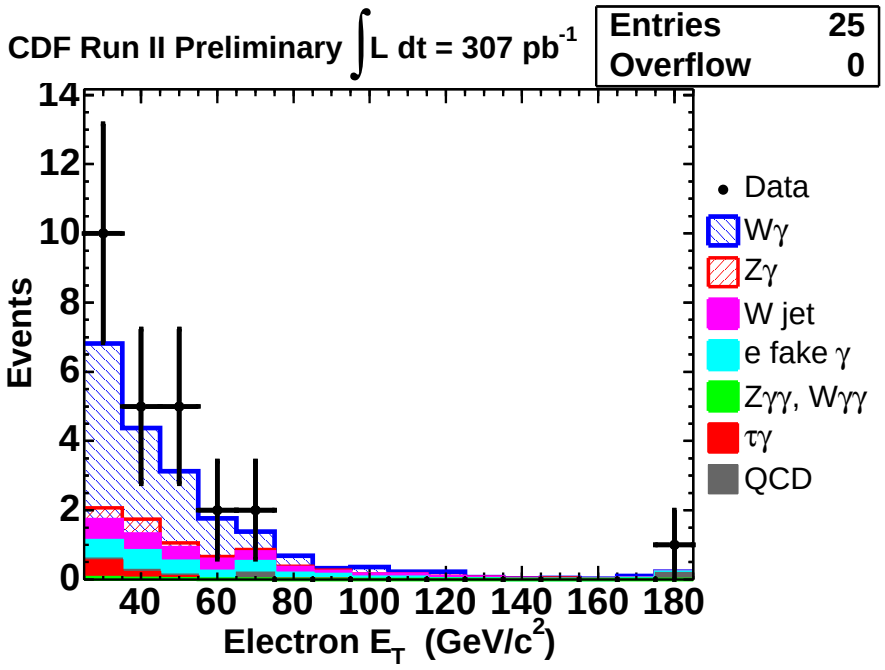
- $\mathbf{X} \equiv \not\!\!E_T \Rightarrow \ell\gamma\not\!\!E_T$
- $\mathbf{X} \equiv \ell \quad \Rightarrow \ell\ell\gamma$

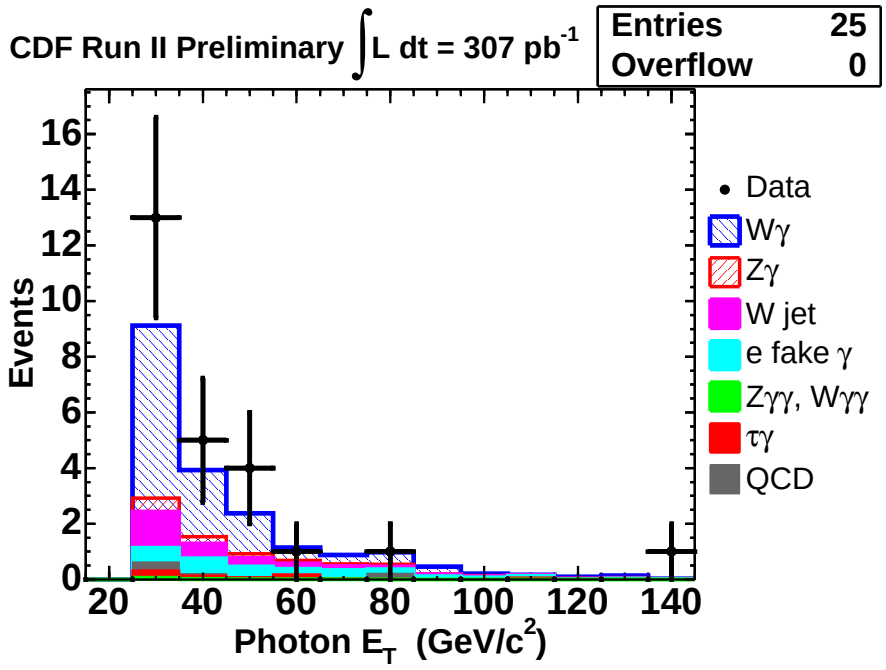
$\ell\gamma\not{E}_{\rm T}$: Predicted and Observed Events

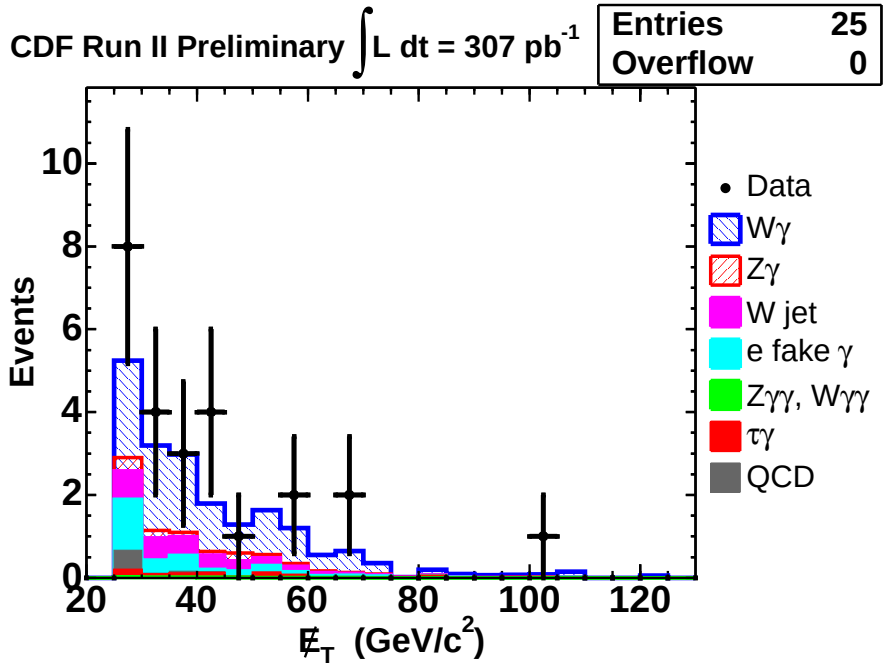
Lepton+Photon+$\not{E}_{\rm T}$ Predicted Events: $\int \mathcal{L}dt = 307pb^{-1}$

Standard Model Source	$e\gamma\not{E}_{\rm T}$	$\mu\gamma\not{E}_{\rm T}$	$(e+\mu)\gamma\not{E}_{\rm T}$
$W^{\pm}\gamma$	11.9 ± 2.0	9.0 ± 1.4	20.9 ± 2.8
$Z^0/\gamma + \gamma$	1.2 ± 0.3	4.2 ± 0.7	5.4 ± 1.0
$W^{\pm}\gamma\gamma, Z^0/\gamma + \gamma\gamma$	0.14 ± 0.02	0.18 ± 0.02	0.32 ± 0.04
$Z^0/\gamma \to e^+e^-, e \to \gamma$	2.5 ± 0.2	-	2.5 ± 0.2
Jet faking γ	2.8 ± 2.8	1.6 ± 1.6	4.4 ± 4.4
$\tau\gamma$ contribution	0.7 ± 0.2	0.3 ± 0.1	1.0 ± 0.2
QCD (Jets faking lepton and $\not{E}_{\rm T}$)	0.6 ± 0.1	< 0.1	0.6 ± 0.1
Total SM Prediction	**19.8 ± 3.2**	**15.3 ± 2.2**	**35.1 ± 5.3**
Observed in Data	**25**	**18**	**43**

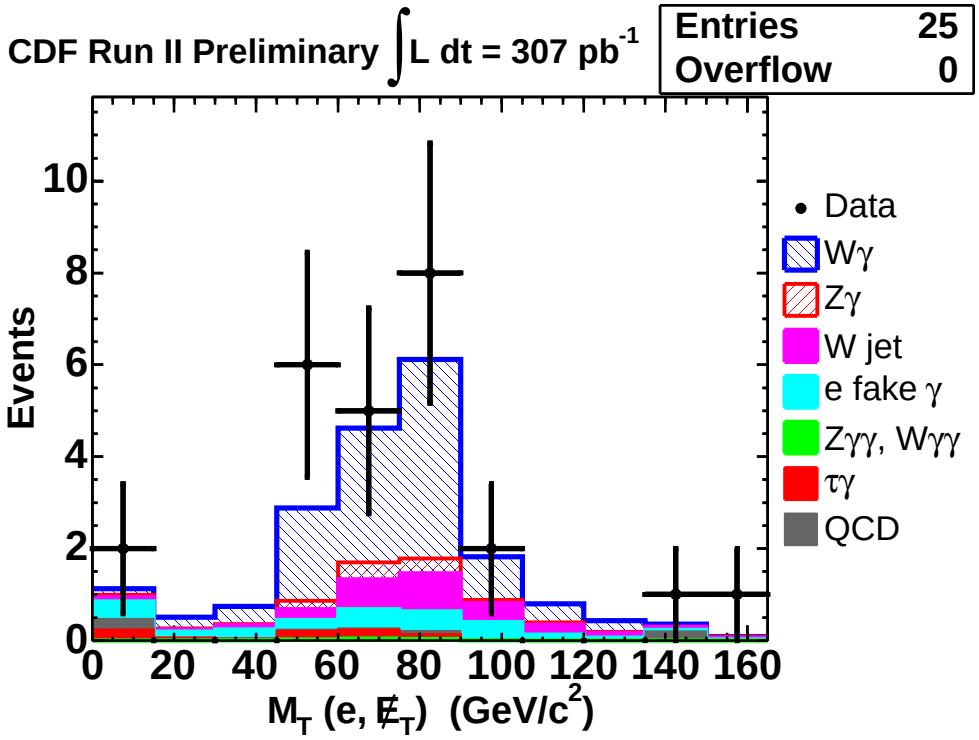
$\ell\gamma \not\!\!E_T$ Distributions: Electron Channel

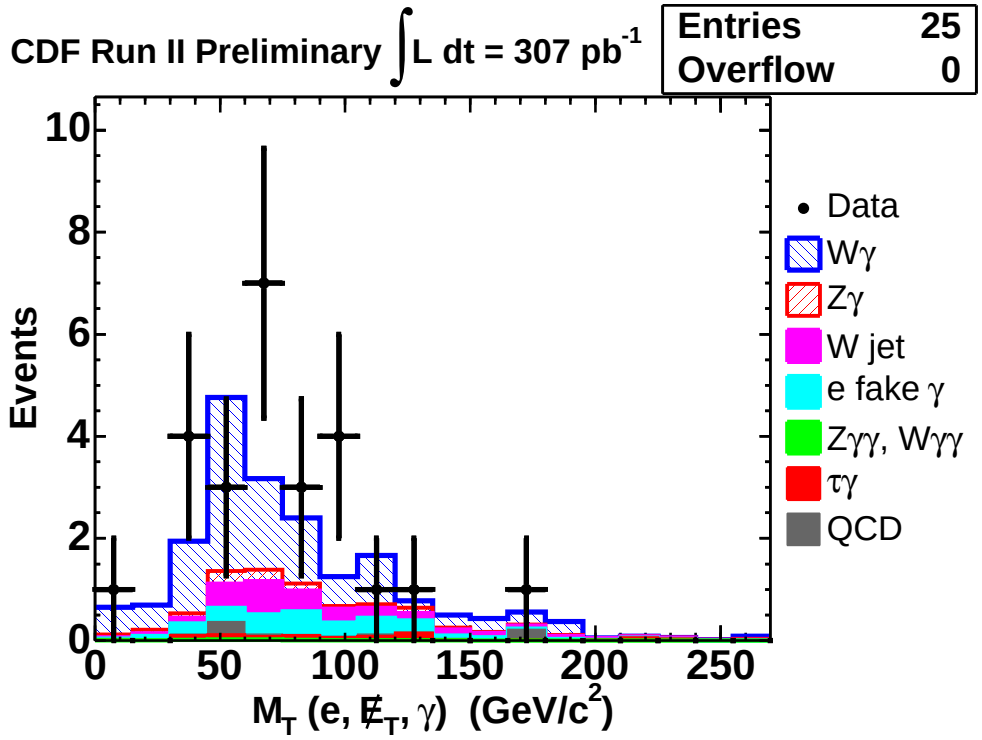




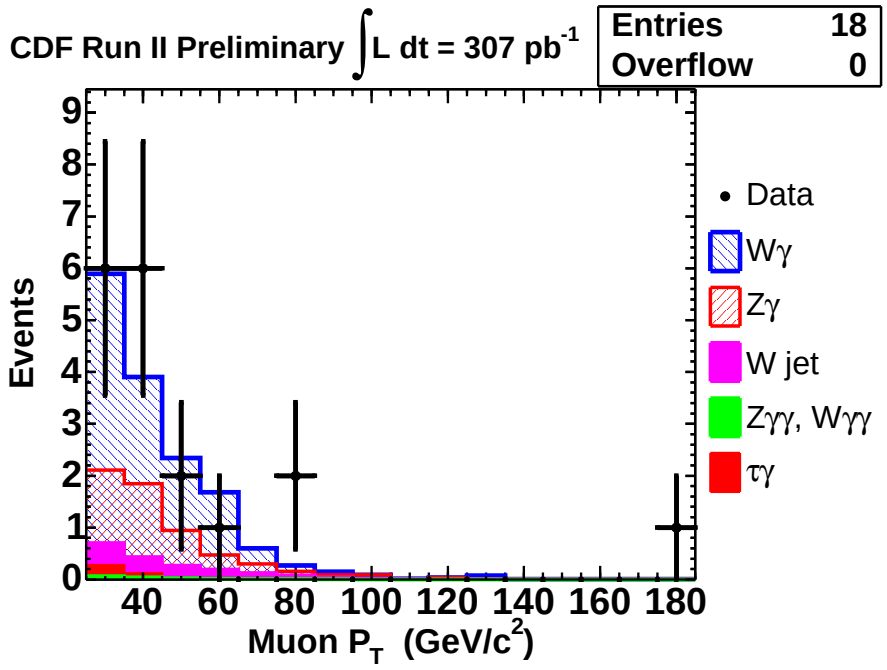


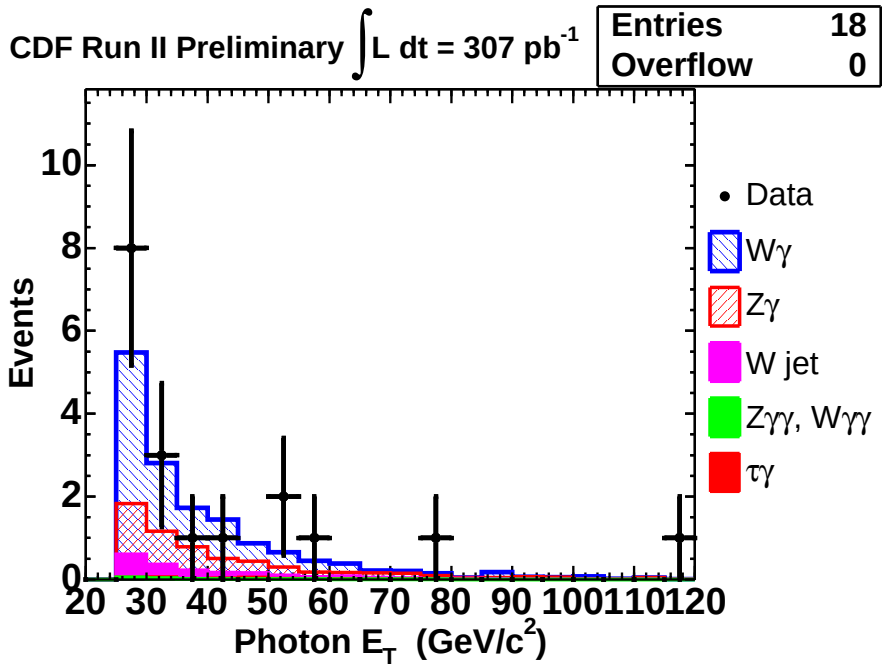
$\ell\gamma \not\!\!E_T$ Distributions: Electron Channel

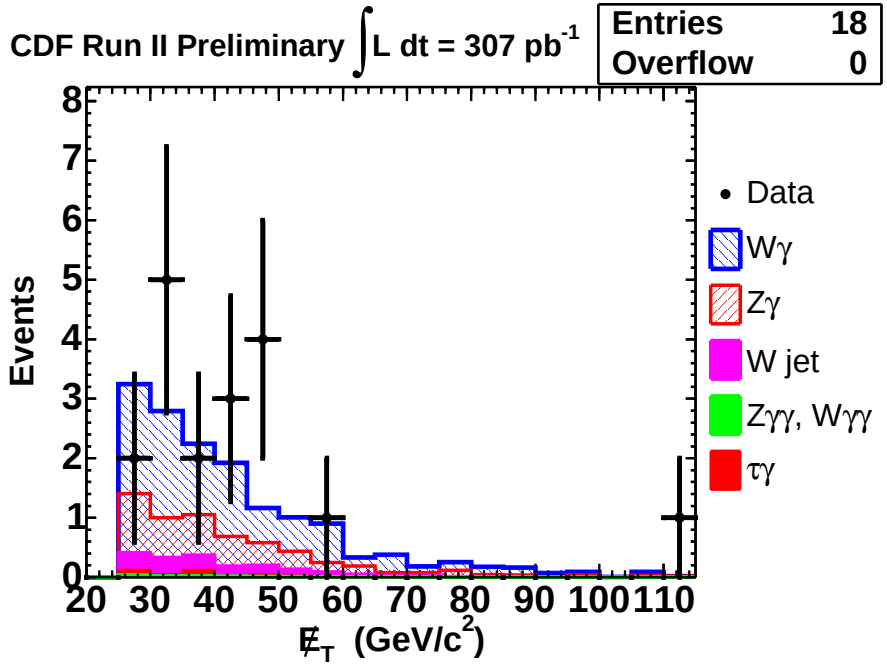




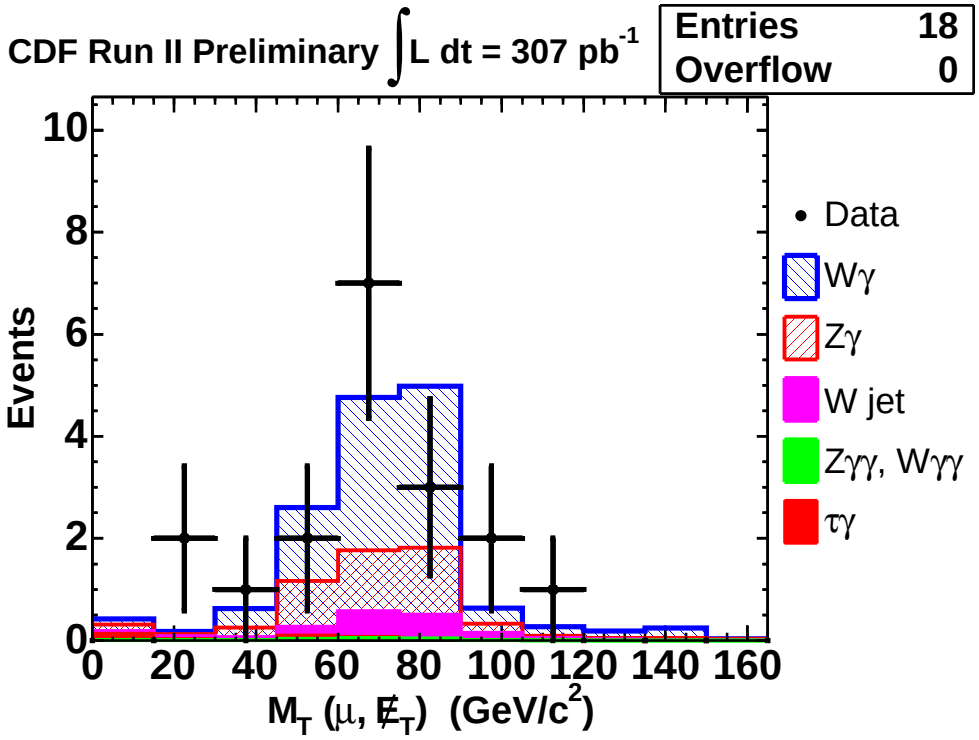
$\ell\gamma \not\!\!E_T$ Distributions: Muon Channel

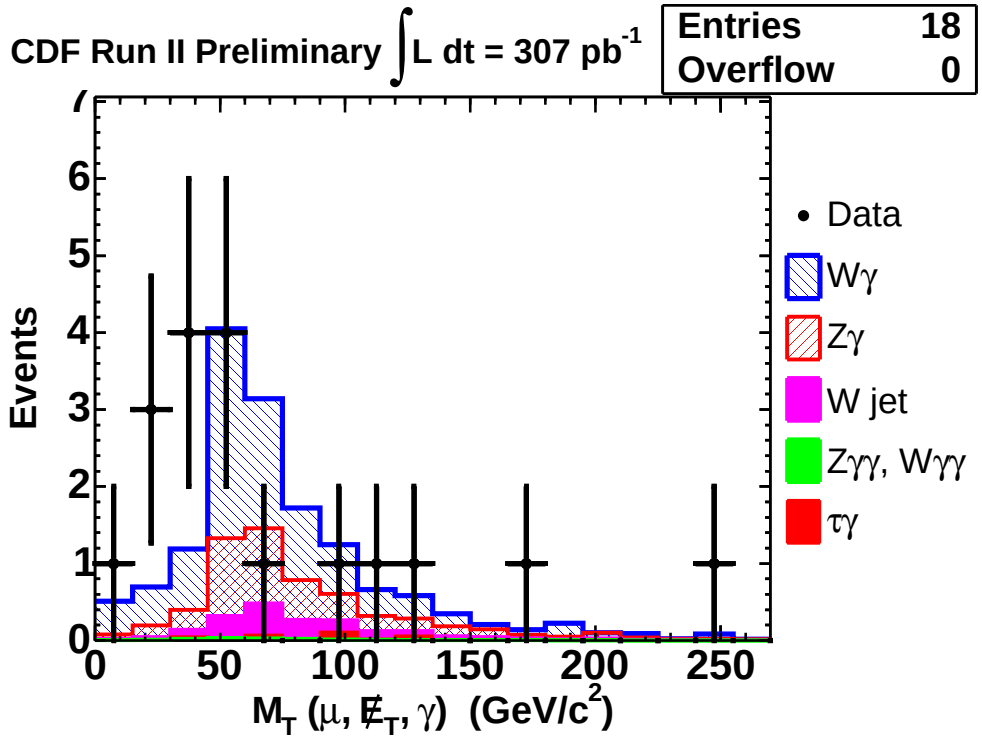






$\ell\gamma \not\!\!E_T$ Distributions: Muon Channel

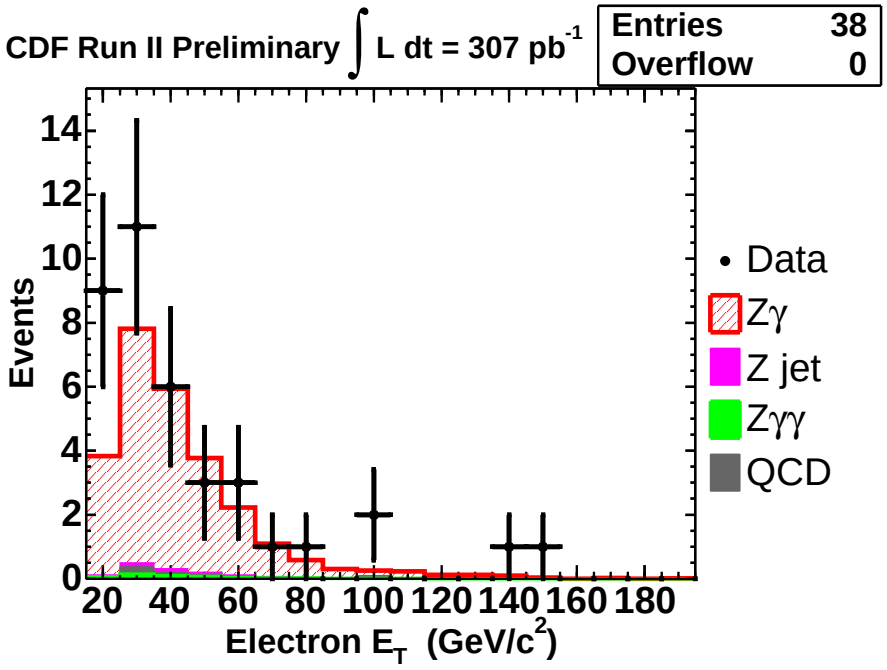


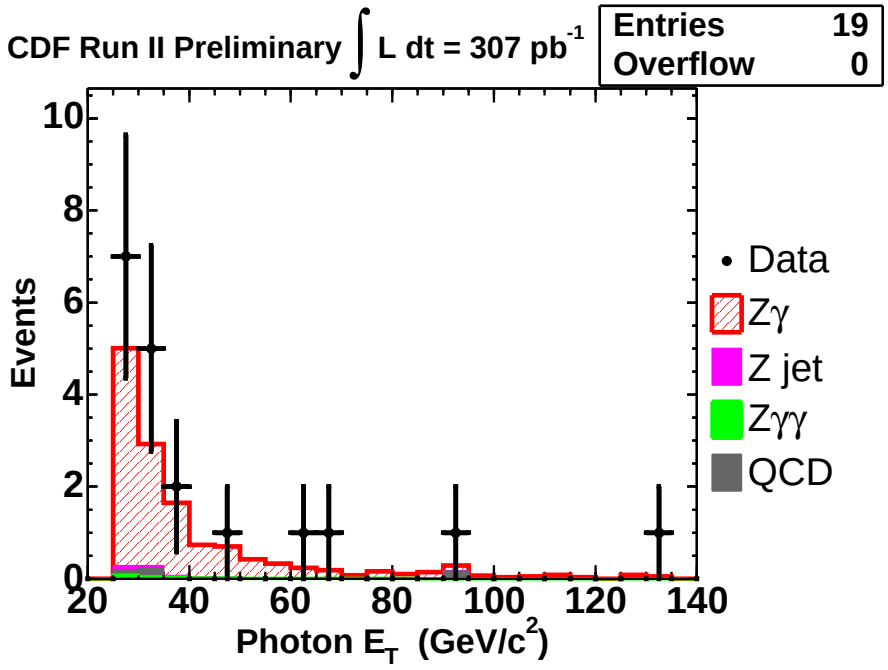


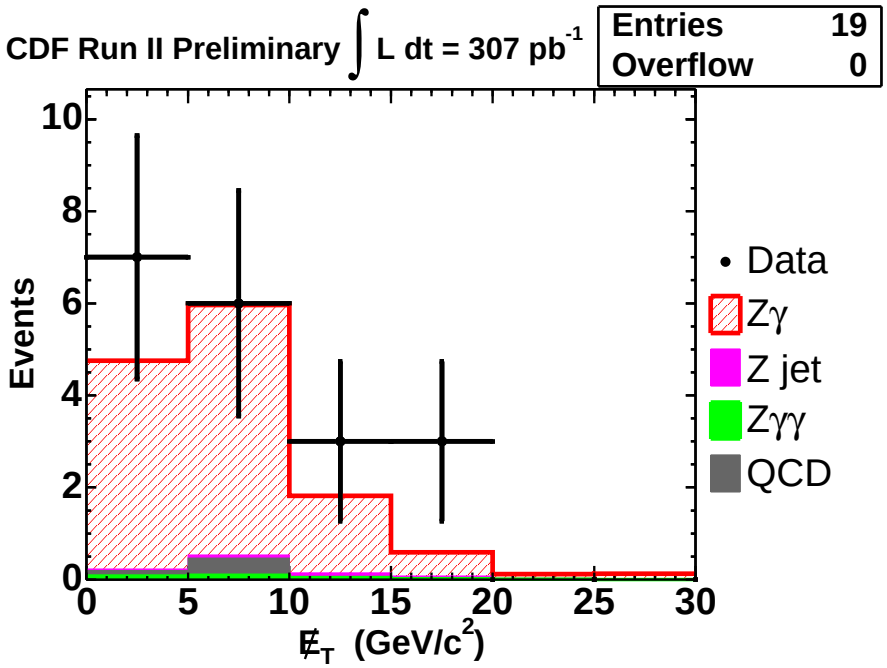
$ll\gamma$: Predicted and Observed Events

Multi-Lepton+Photon Predicted Events: $\int \mathcal{L}dt = 307pb^{-1}$			
Standard Model Source	$ee\gamma$	$\mu\mu\gamma$	$ll\gamma$
$Z^0/\gamma + \gamma$	12.5 ± 2.3	7.3 ± 1.7	19.8 ± 4.0
$Z^0/\gamma + \gamma\gamma$	0.24 ± 0.03	0.12 ± 0.02	0.36 ± 0.04
Z^0/γ + Jet, Jet faking γ	0.3 ± 0.3	0.2 ± 0.2	0.5 ± 0.5
QCD (Jets faking lepton and $\not\!\!E_T$)	0.5 ± 0.1	< 0.1	0.5 ± 0.1
Total SM Prediction	**13.6 ± 2.3**	**7.6 ± 1.7**	**21.2 ± 4.0**
Observed in Data	**19**	**12**	**31**

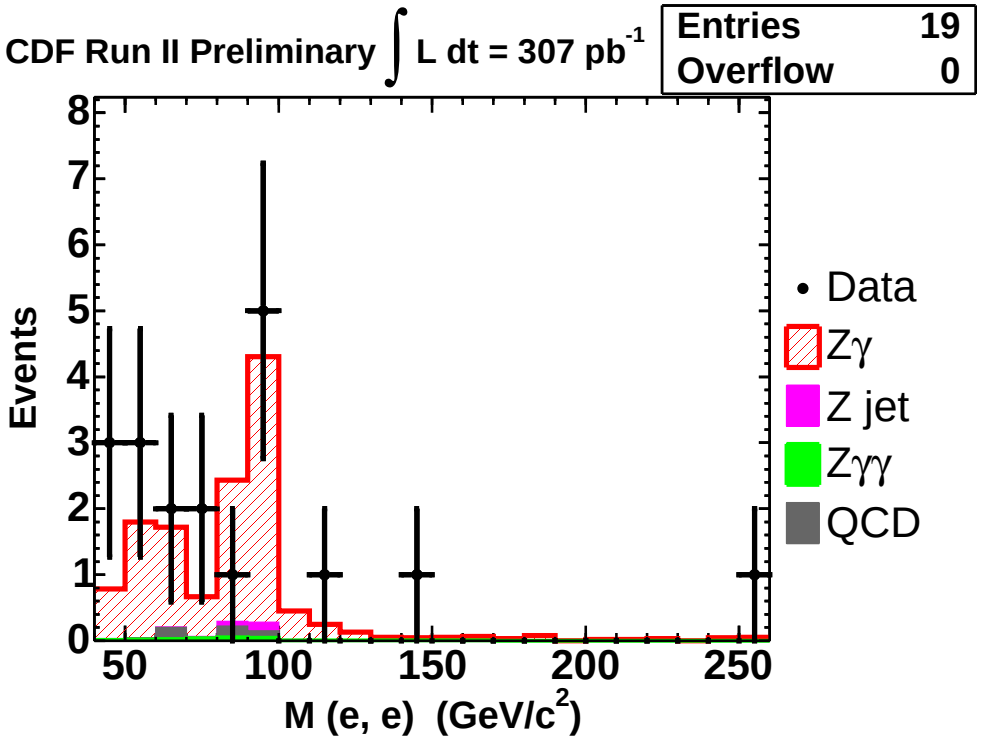
$\ell\ell\gamma$ Distributions: Electron Channel

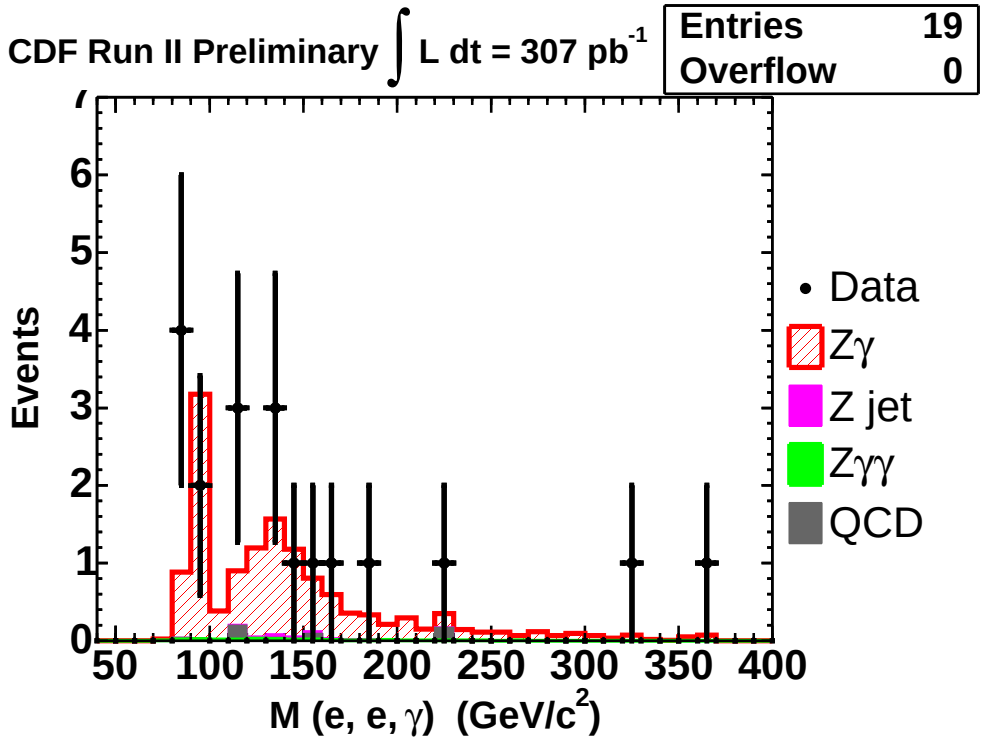




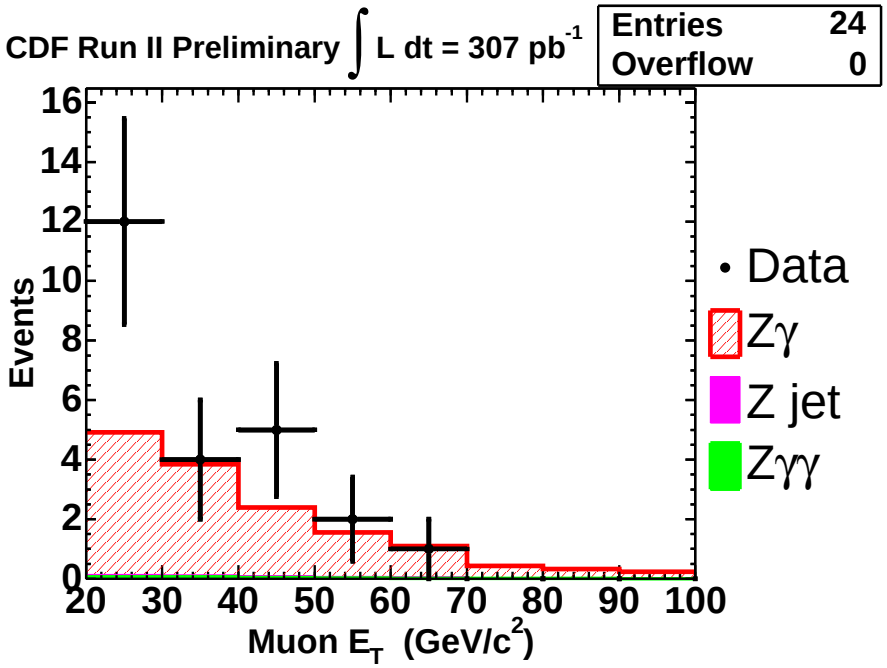


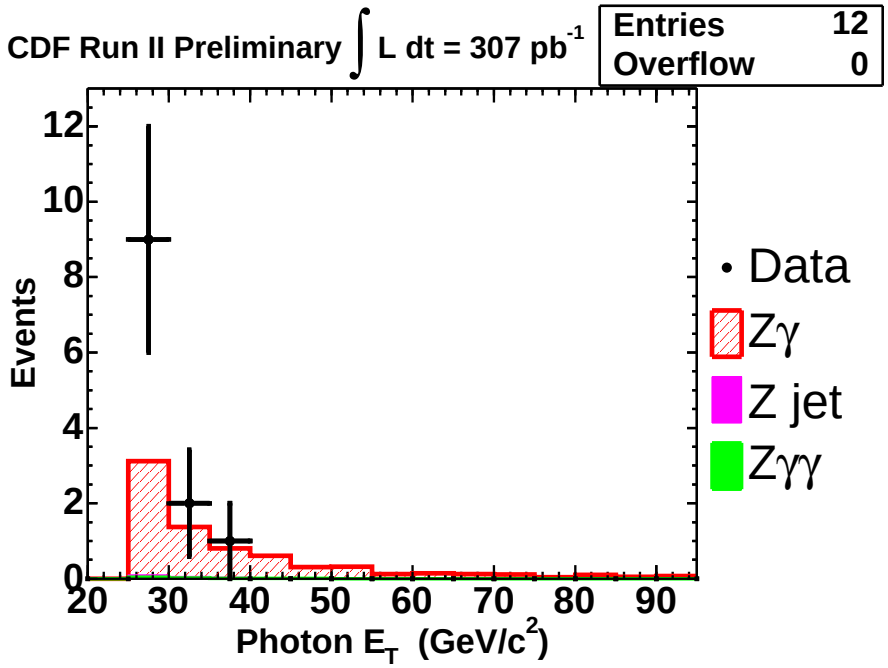
$\ell\ell\gamma$ Distributions: Electron Channel

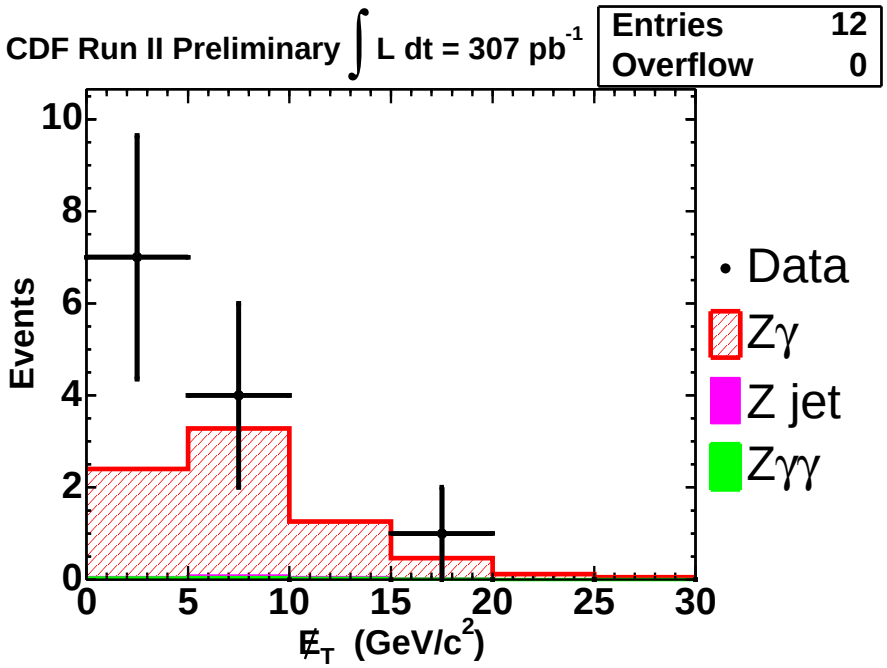




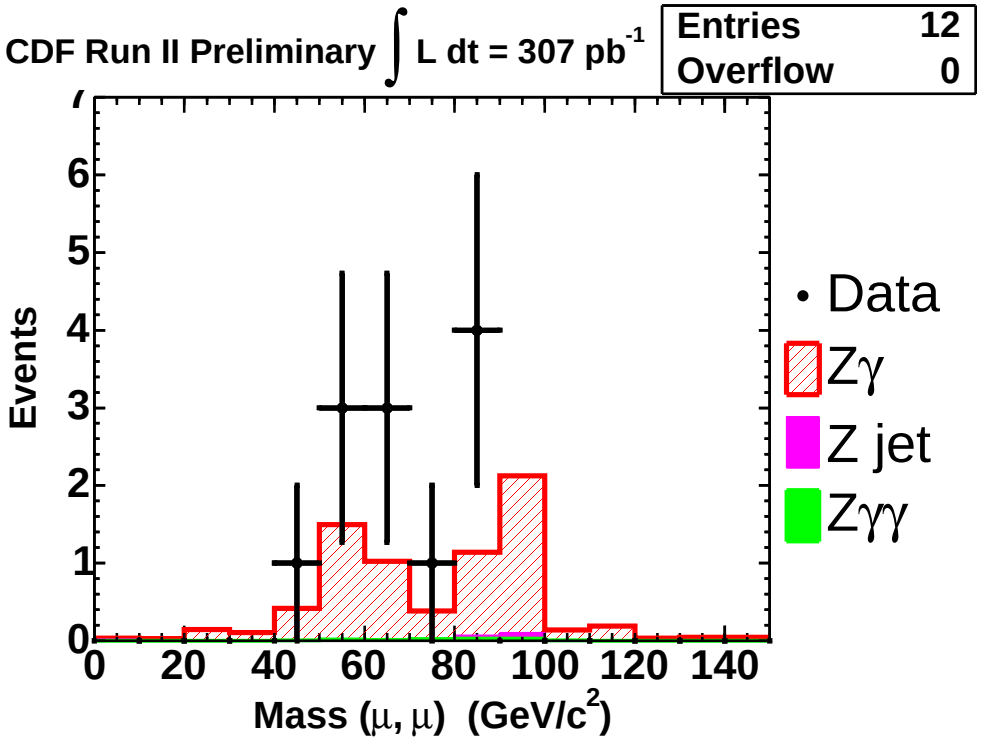
$\ell\ell\gamma$ Distributions: Muon Channel

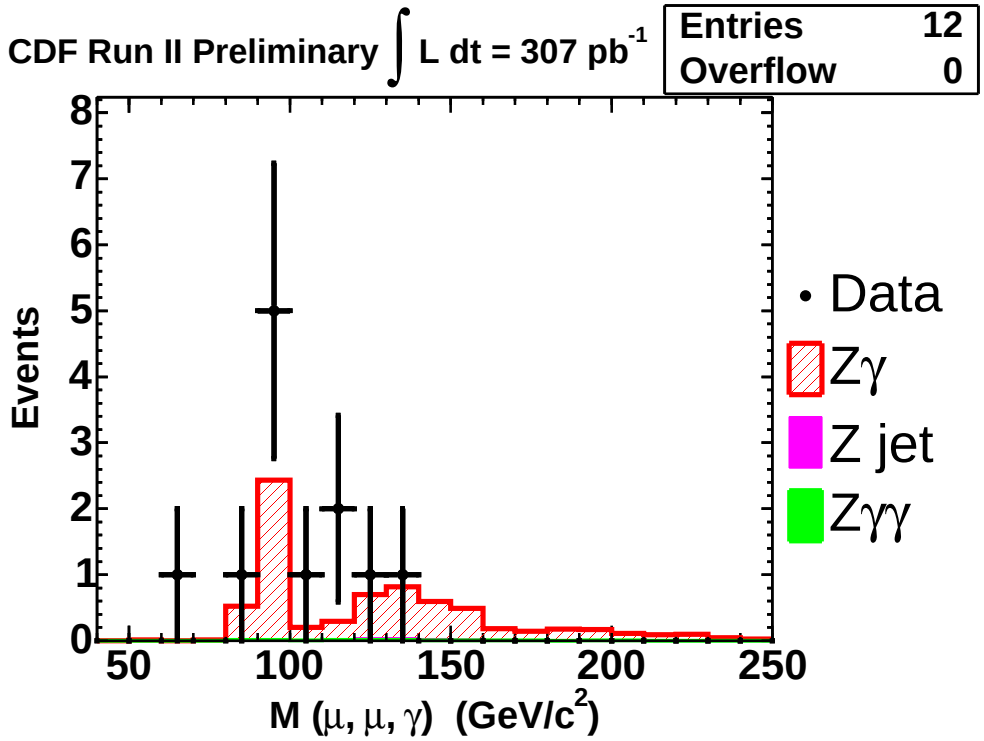






$\ell\ell\gamma$ Distributions: Muon Channel





Search for Lepton-Photon-X Events: Summary

Predicted and Observed Events: $\int \mathcal{L}dt = 307 pb^{-1}$			
Channel	e	μ	$(e+\mu)$
$\ell\gamma \not\!\!E_{\rm T}$			
Predicted	**19.8 ± 0.8(stat) ± 3.1(sys)**	**15.3 ± 0.6(stat) ± 2.1(sys)**	**35.1 ± 1.0(stat) ± 5.2(sys)**
Observed in Data	**25**	**18**	**43**
$\ell\ell\gamma$			
Predicted	**13.6 ± 0.3(stat) ± 2.3(sys)**	**7.6 ± 0.2(stat) ± 1.7(sys)**	**21.2 ± 0.3(stat) ± 4.0(sys)**
Observed in Data	**19**	**12**	**31**

Photon Searches at CDF: Summary...

√ **[New Physics Result] Run 1 2.7 sigma excess in $\ell\gamma\not\!\!E_{\rm T}$ not confirmed**

√ **Search for $\gamma\gamma\not\!\!E_{\rm T} + X$: No excess in two photons + energy imbalance. Combined CDF and D0: most stringent limits on GMSB SUSY**

√ **Search for high-mass diphotons**: DATA agrees with predictions. **Photon signature is promising** (fermiphobic parent?)

...and Future!

√ **The next big discovery in particle physics may well come from looking at samples with final state photons**

→ **Model Independent Search Techniques**

→ **Recent upgrade: brand new EM Timing system**

∗ **Confirm or Deny: photon from the primary collision**

√ **Photon Searches at CDF are underway: hunting for New Phenomena. Hope to get physics results with 1 fb^{-1} by Moriond**