Six Femtobarn Photon Searches from CDF

$\gamma\gamma$MEt • $\gamma\gamma\, l$ • $\gamma\gamma\gamma$ • $\gamma\gamma$ mass • $l\gamma$X • $l\gamma$bMEt

All CDF Photon Results

Cross sections

$\gamma\gamma$	$200pb^{-1}$	PRL 95, 022003 (2005)
γ+b	$340pb/230pb^{-1}$	*see Mario Campanelli's talk*
$W/Z\rightarrow l\nu/ll+\gamma$	$200pb^{-1}$	PRL 94, 041803 (2004)
$W/Z\rightarrow jets+\gamma$	$180pb^{-1}$	available

Searches

γ MEt	$70pb^{-1}$	available
e* in eeγ	$200pb^{-1}$	PRL 94, 101802 (2005)
μ* in $\mu\mu\gamma$	$370pb^{-1}$	submitted to PRL
$\gamma\gamma$ mass peaks	$1.1fb^{-1}$	this talk
$\gamma\gamma$MEt, $\gamma\gamma$l, $\gamma\gamma\gamma$	$1.1fb^{-1}$	this talk
lγ+X	$300pb^{-1}/930pb^{-1}$	PRL 97, 031801 (2006)/this talk
lγbMEt	$0.9fb^{-1}$	this talk
delayed photons	$500pb^{-1}$	*see Max Goncharov's talk*

Photon Triggers and Selections

DiPhoton triggers

$2 \times Et > 12$, w/cal iso

$2 \times Et > 18$, wo/cal iso

Photon triggers

$Et > 25$, w/cal iso

$Et > 50$, wo/cal iso

plus ... photon+muon, photon+b, photon+2jet, triphoton

Central Cuts ($\eta<1.0$)

- Had/EM <0.055
- Calorimeter Iso, cone 0.4 < 2 GeV
- cluster in shower max, good χ^2
- small leading track Pt < 1 GeV
- track isolation, cone 0.4 < 2 GeV
- second Sh.Max. cluster Et < 2 to 3 GeV

Forward Cuts ($1.2<\eta<2.8$)

Had/EM <0.05

Calorimeter Iso, cone 0.4 < 2 GeV

cluster in shower max, good shape

small leading track Pt < 1 GeV

track isolation, cone 0.4 < 2 GeV

tower shower shape, good χ^2

MEt search adds anti-cosmic cuts:

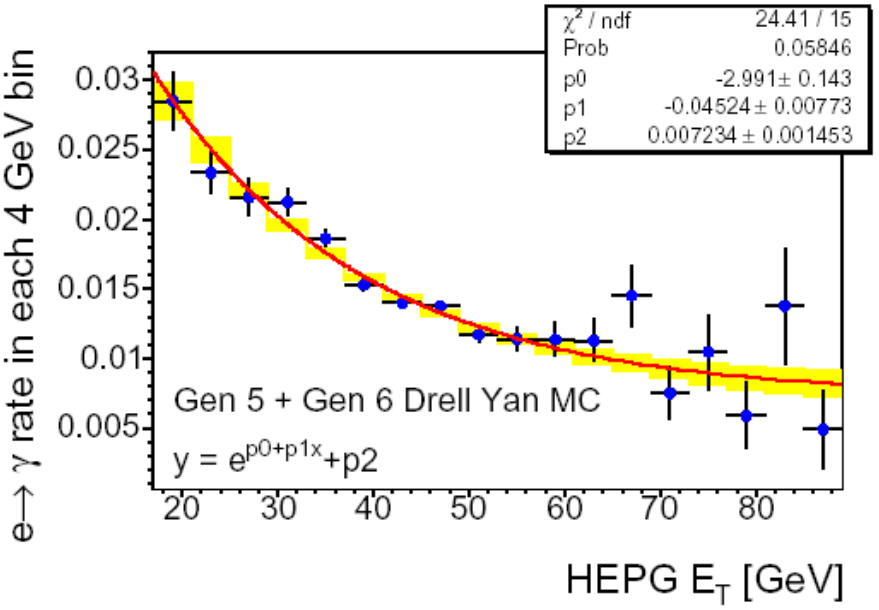
EM TDC times (when available), jet topology, unattached muon stubs

All analyses use $Z \rightarrow ee$ and minbias to study/correct ID efficiencies

Two Techniques

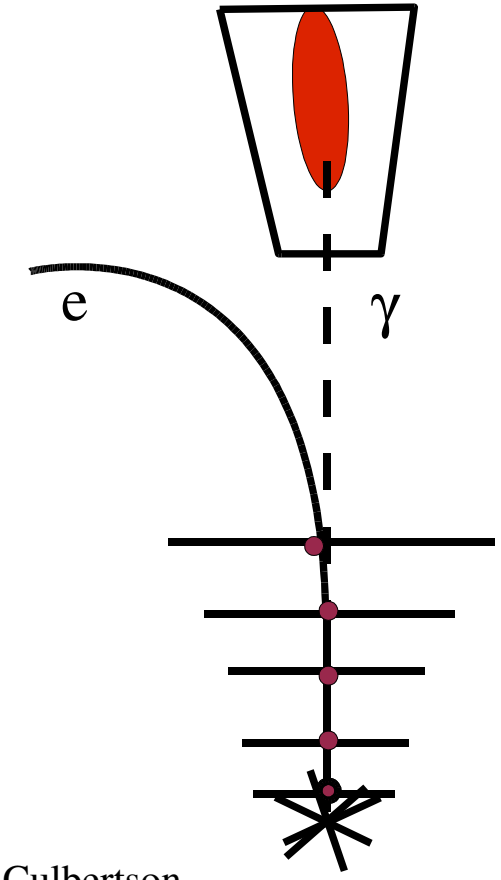
e → γ fake rate

- almost all due to brem in detector
- Compare:
  - Z peak in ee
  - Z peak in eγ
- take Et dependence from Monte Carlo



Phoenix Tracking

- seed a track from cal cluster and event vertex
- find forward electrons
- or reject electrons with evidence of an e brem in the Si tracking



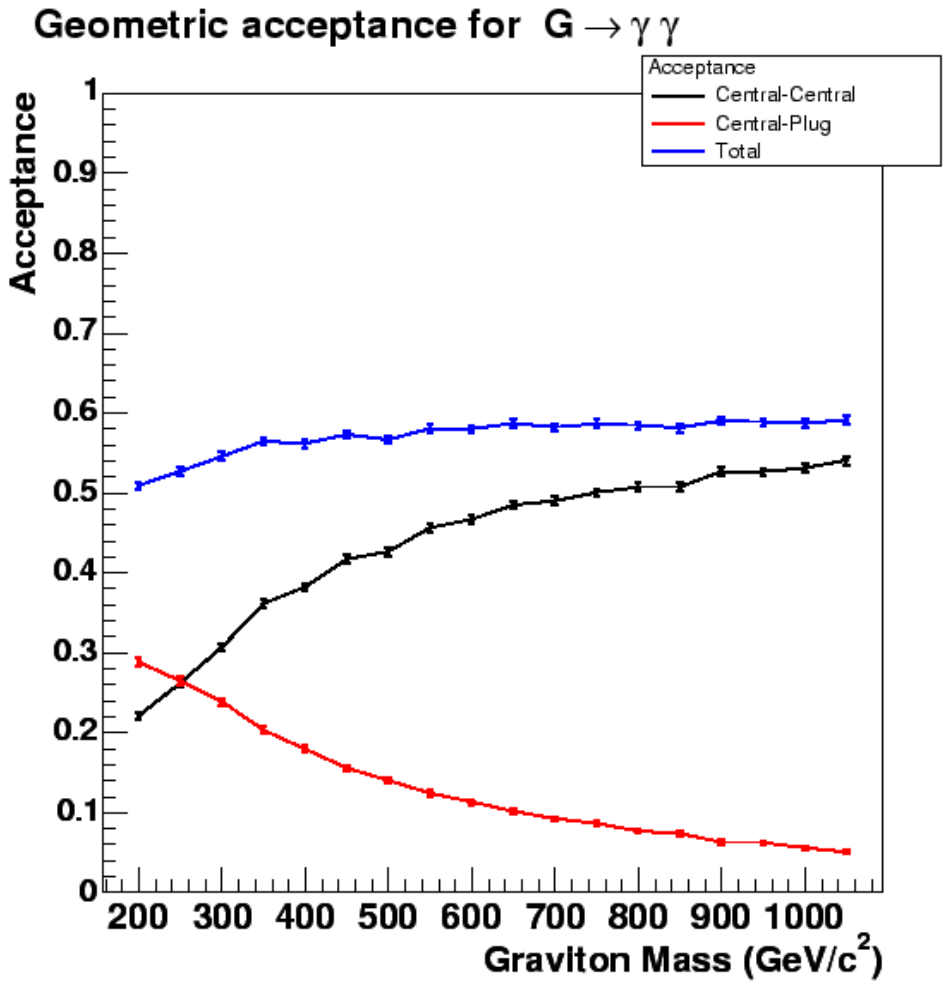
Search for Diphoton Peaks

Model

- Randall-Sundrum Gravitons
- Extra dimension is "warped", with parameter k
- S-channel Graviton yields e^+e^-,$\mu^+\mu^-$,$\gamma\gamma$,... peaks at high-mass
- this search sensitive to any narrow diphoton peak

Analysis

- 2 central-central or central-forward photons
- Et>15 GeV
- Mass > 30 GeV



central-central and central-forward have complimentary acceptence

Search for Diphoton Peaks

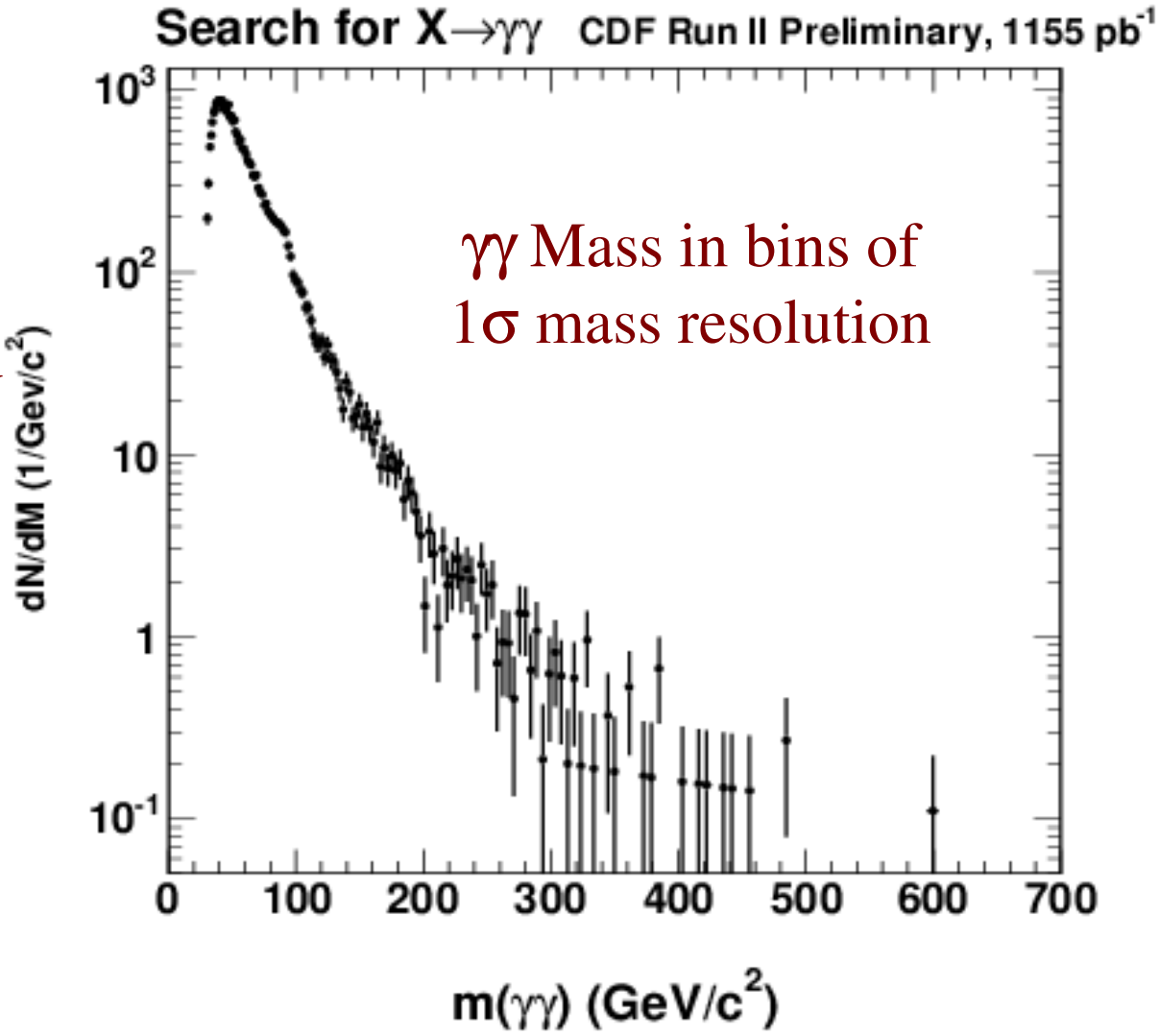
Data sample

- 1.2 fb^{-1}

- Highest mass events:
  central-central: 602 GeV
  central-forward: 454 GeV

- no significant MEt observed in high-mass events

- No sign of cosmics which brem in calorimeters

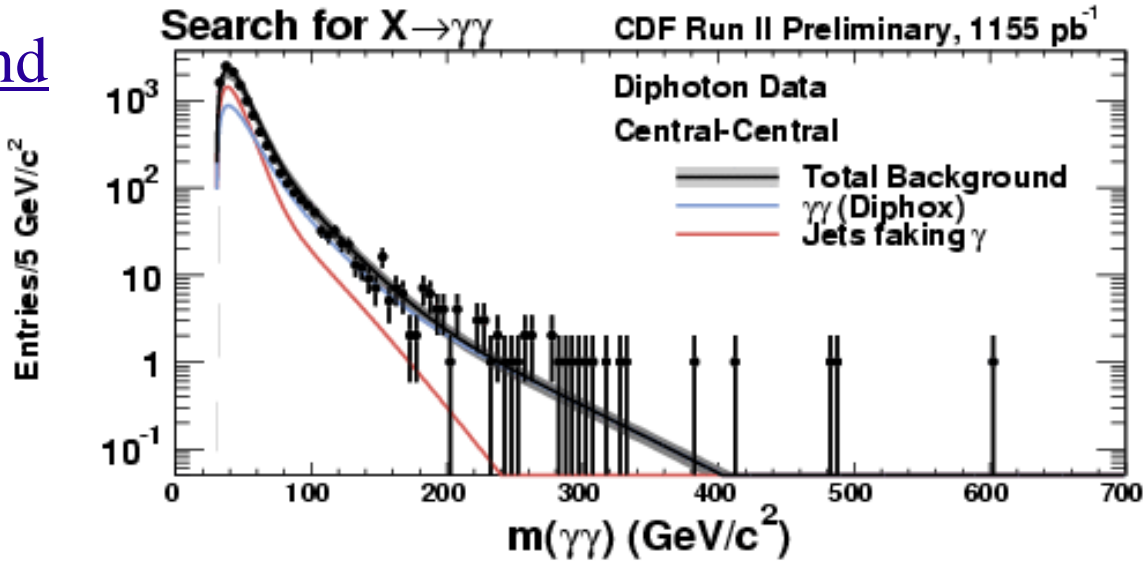


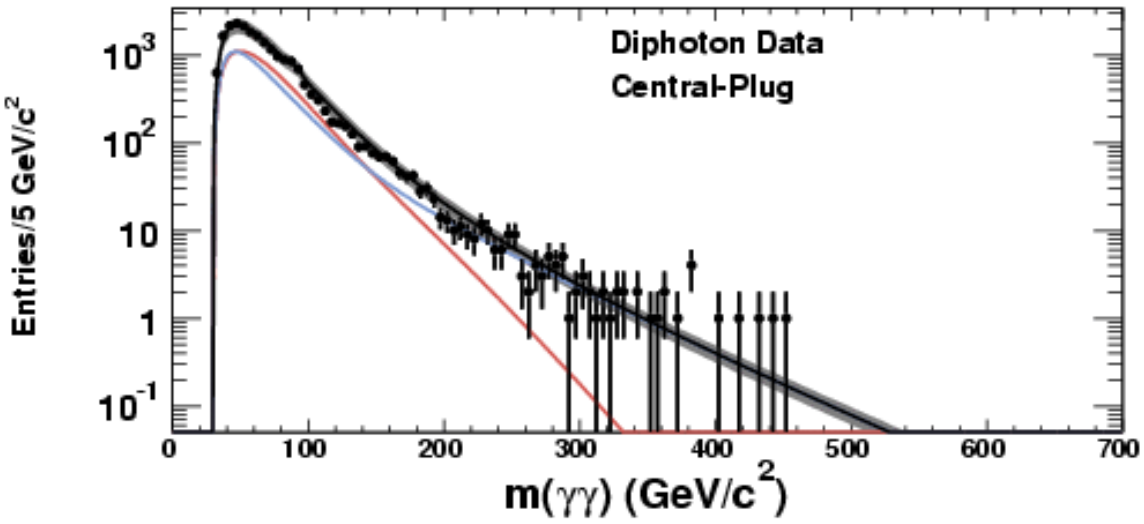
Search for Diphoton Peaks

SM Diphoton Background
- NLO Diphox calculation
- normalized by luminosity

Jets Faking Photons
- mostly hard π^0's
- Mass shape from a sample of loose diphoton candidates
- normalized to low mass - DiPhox

this background is not used in setting limits

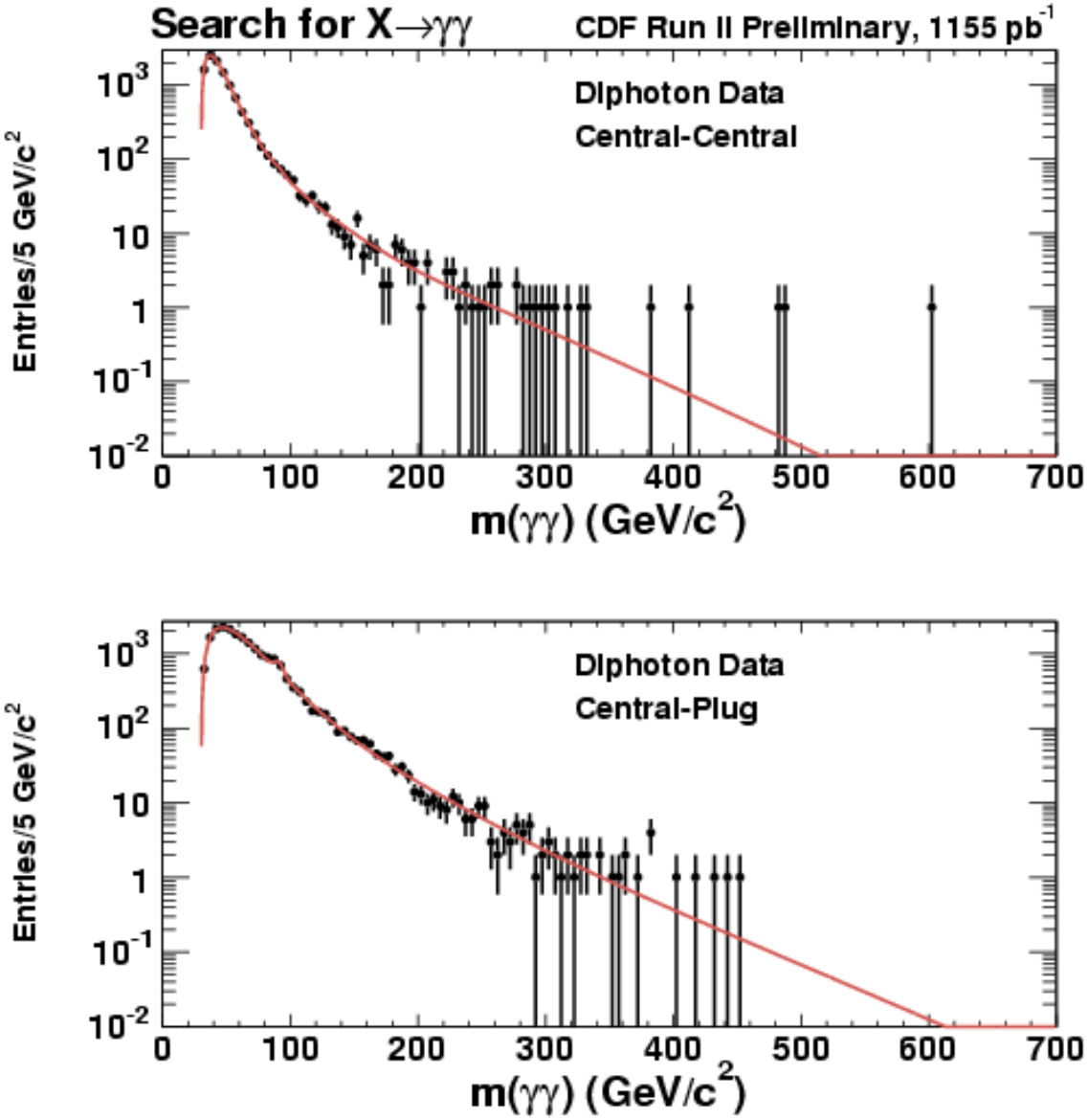




Search for Diphoton Peaks

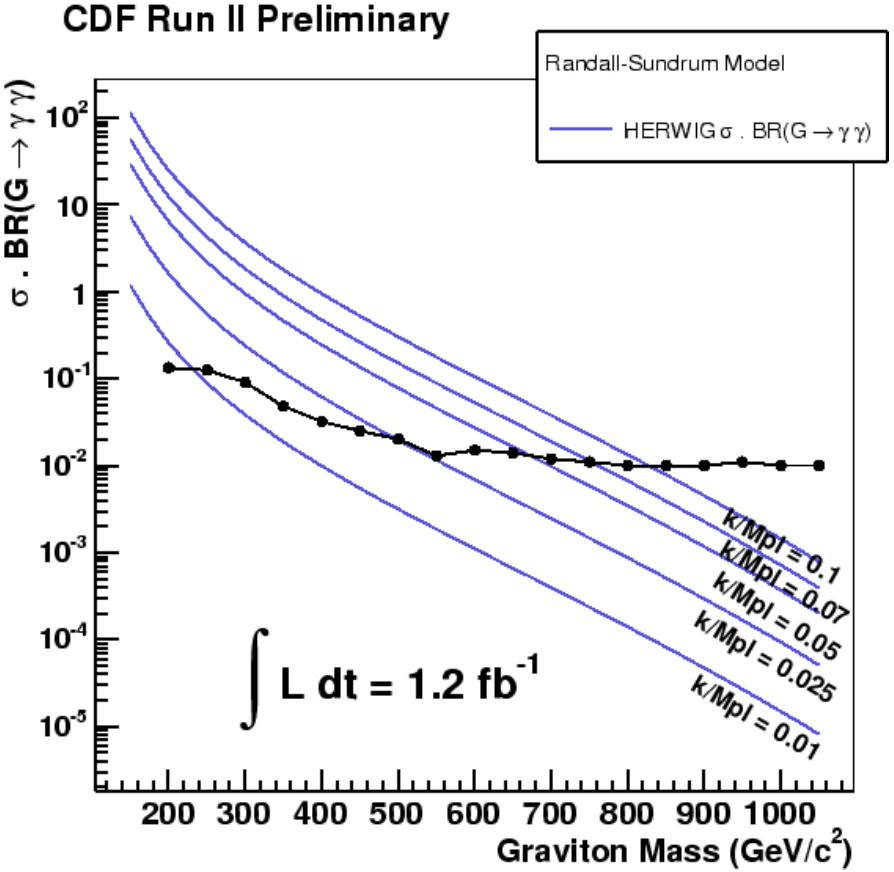
Limits

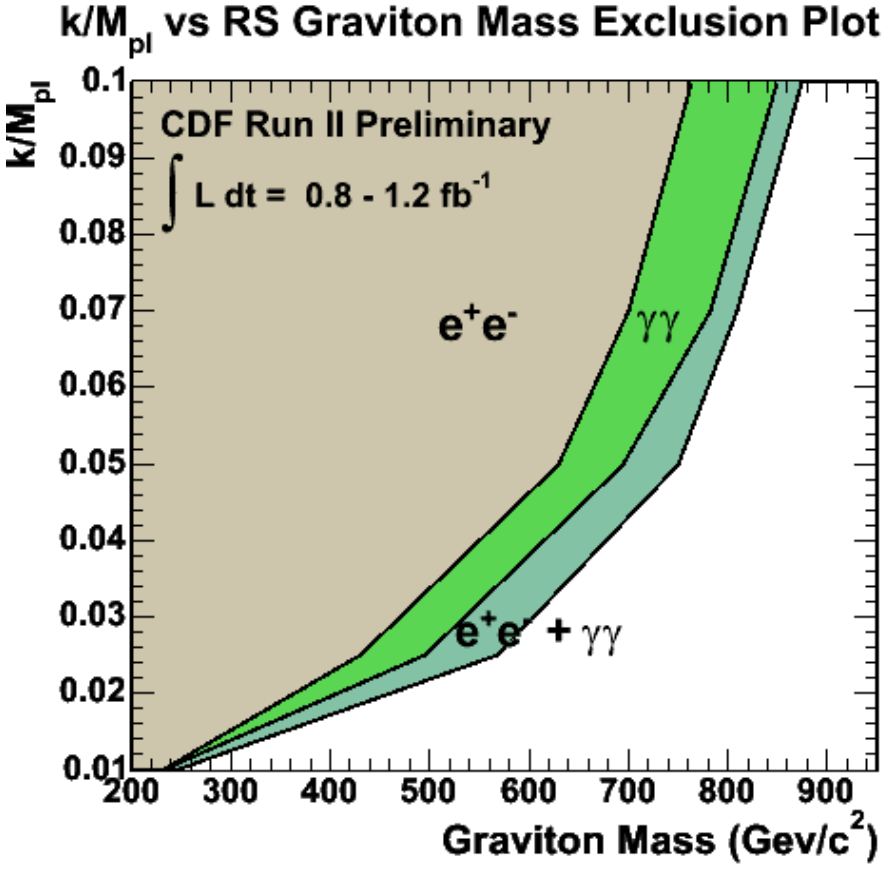
- Fit spectrum to Diphox + exponentials
- fit central-central and central-forward separately
- no normalization constraints
- limits from binned maximum likelihood with Monte Carlo signal shape times efficiency



Randall-Sundrum Graviton Limits

- for k/M_{pl}=0.1, M(G)>850 GeV
- combined with e^+e^- RS search result: M(G)>875 GeV
- $\gamma\gamma$ has larger BR, better acceptance due to spin effects





Search in Diphoton and Met

Sample

- 1.2 fb^{-1}
- Two central photons
  with Et>13
- Signature-based

Remove fake MEt

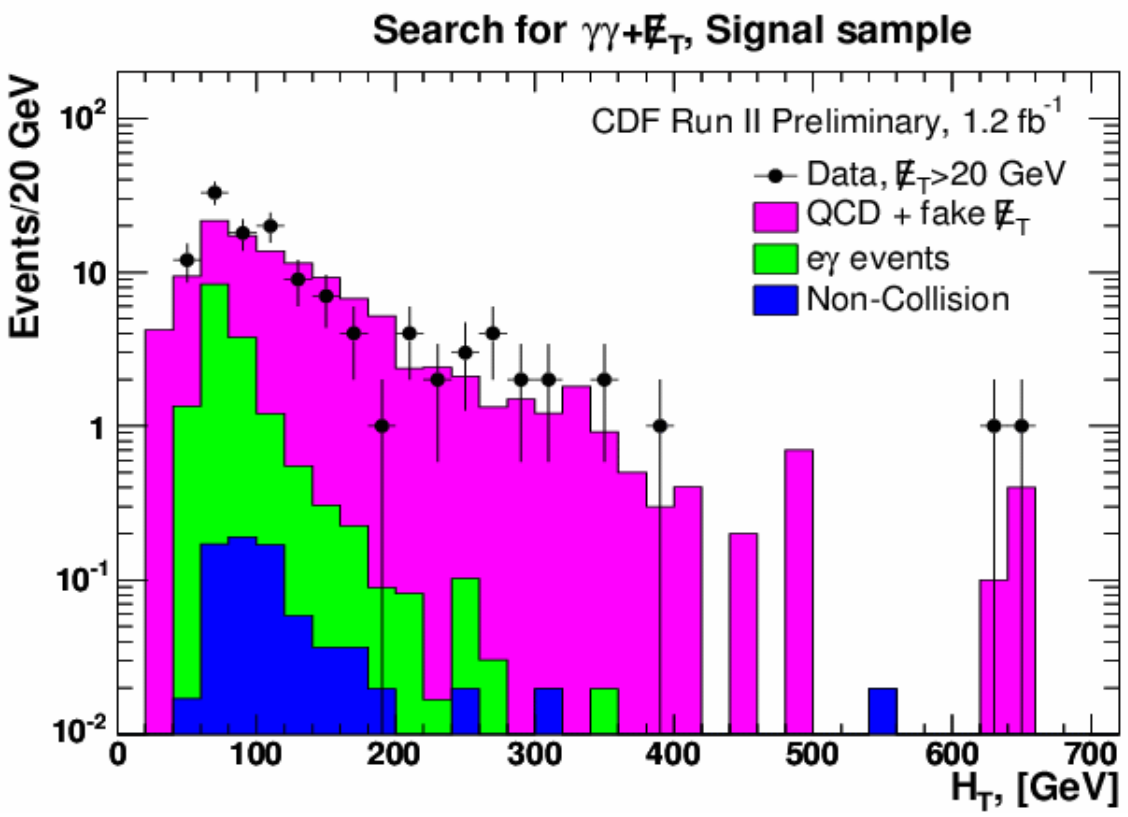
- remove jets along MEt
- use lowest MEt vertex

Remove Ewk

- W→e→γ by brem
  rejected by Phoenix

Remove non-collision

- EM timing
- extra muon stubs



Ht = scalar sum of Et from photons, leptons, jets, and MEt

Search in Diphoton and Met

QCD background

- MEt Model from control samples
- predict MEt from energy and expected resolution

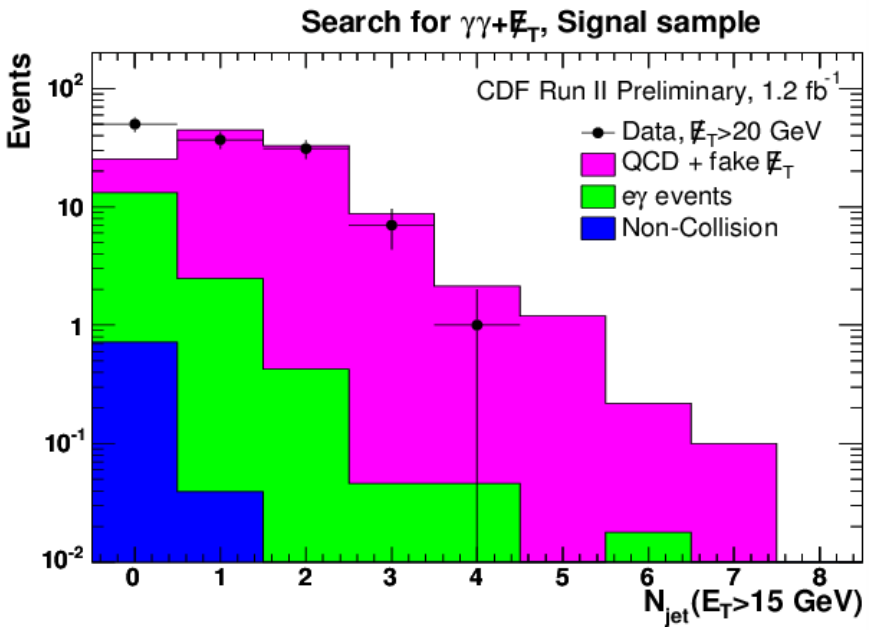
Ewk background

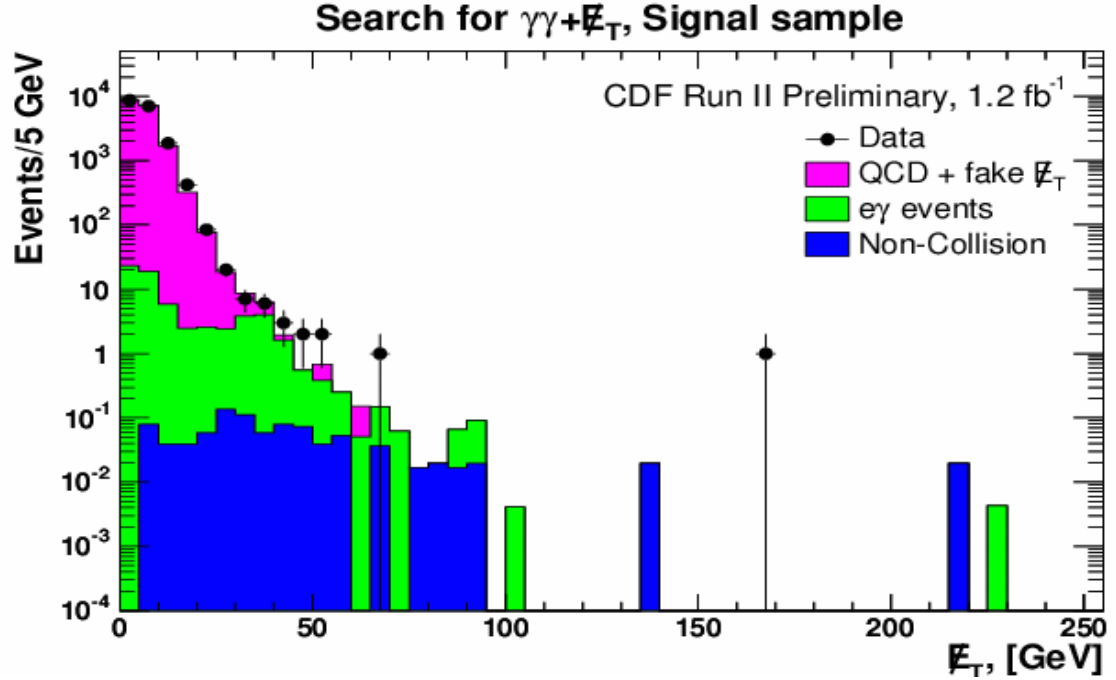
- e+γ sample times e→γ fake rate

Non-Collision background

-no-vertex and out-of-time control samples

Total background, MEt>50GeV: 1.6 ± 0.3, 4 observed





Search for Diphotons and Leptons

Sample

- Same diphotons
- 1.0 to 1.1fb^{-1}
- top-like leptons:

Electrons

- Central e Et>20 GeV
- Forward e Et>20 GeV, including Phoenix tracks

Muons

- Central μ Pt>20 GeV
- Forward (CMX) μ Pt>20 GeV

Backgrounds:

- Ewk $l\gamma\gamma$ (MadGraph)

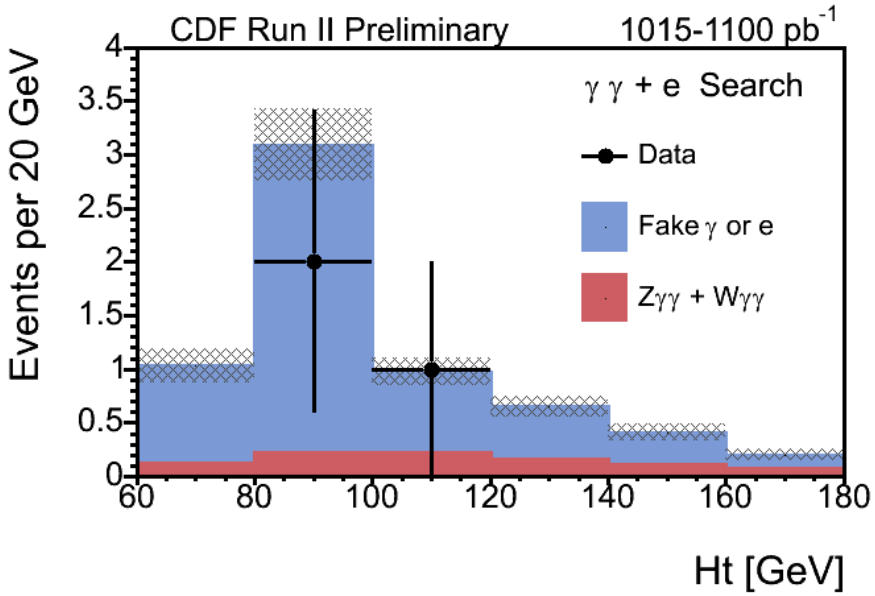
Denominator times fake rate for:

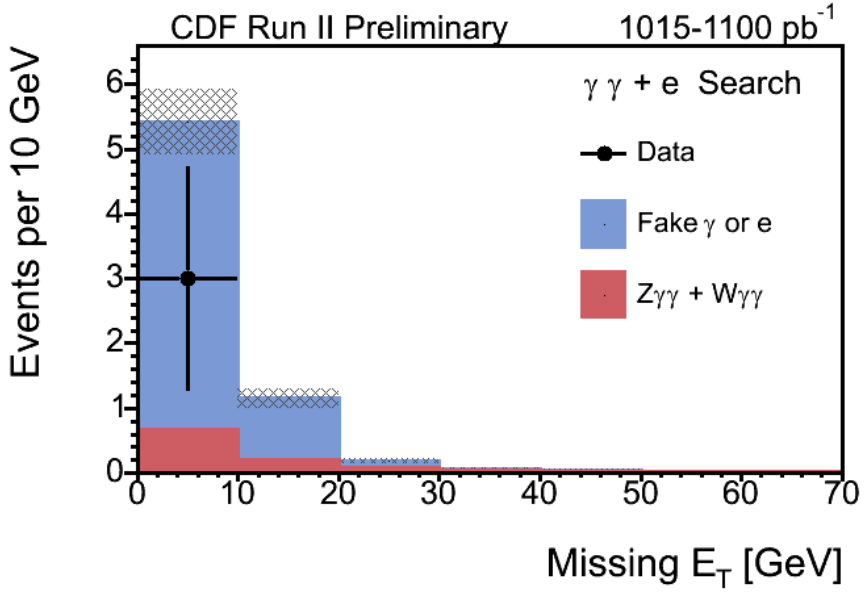
- jets faking leptons
- jets faking photons
- electrons faking photons

Before applying Phoenix rejection		
Source	electron	muon
$Z\gamma\gamma$	$0.904 \pm 0.023 \pm 0.085$	$0.552 \pm 0.017 \pm 0.050$
$W\gamma\gamma$	$0.170 \pm 0.012 \pm 0.016$	$0.086 \pm 0.008 \pm 0.008$
Fake $l+\gamma\gamma$	$0.131 \pm 0.004 \pm 0.053$	$0.004 \pm 0.003 \pm 0.002$
$l\gamma + \text{jet} \to \gamma$	$0.475 \pm 0.025 \pm 0.312$	$0.133 \pm 0.013 \pm 0.090$
$l\gamma + e \to \gamma$	$5.140 \pm 0.340 \pm 0.584$	$0.017 \pm 0.017 \pm 0.002$
Total	6.82 ± 0.75	0.79 ± 0.11
Data	3	0

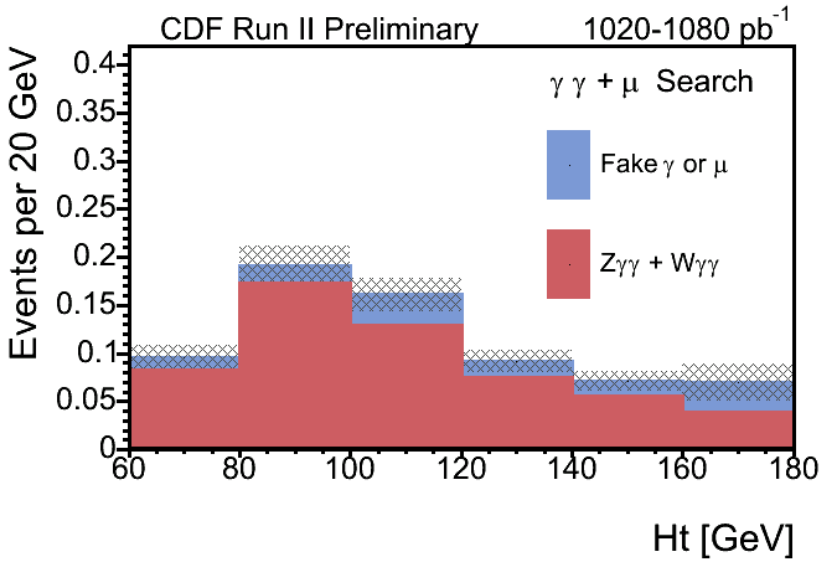
Search for Diphotons and Leptons

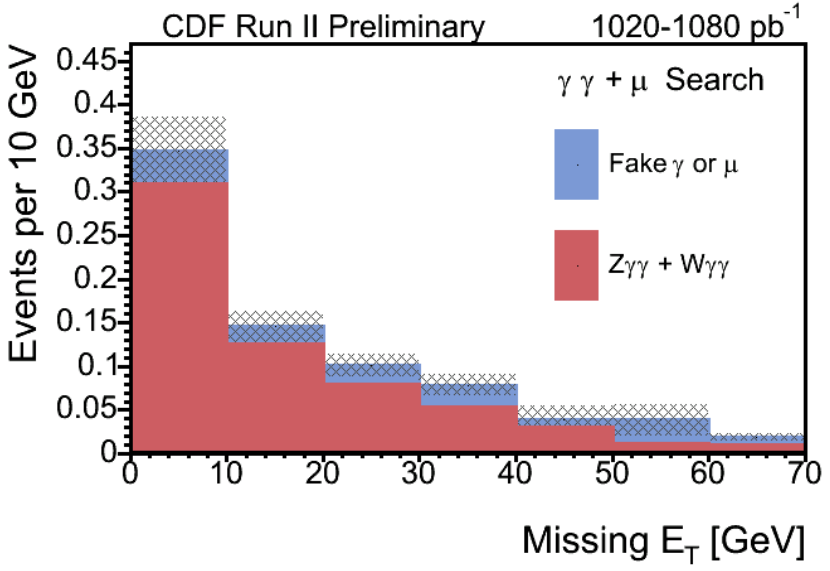
$\gamma\gamma e$





$\gamma\gamma\mu$





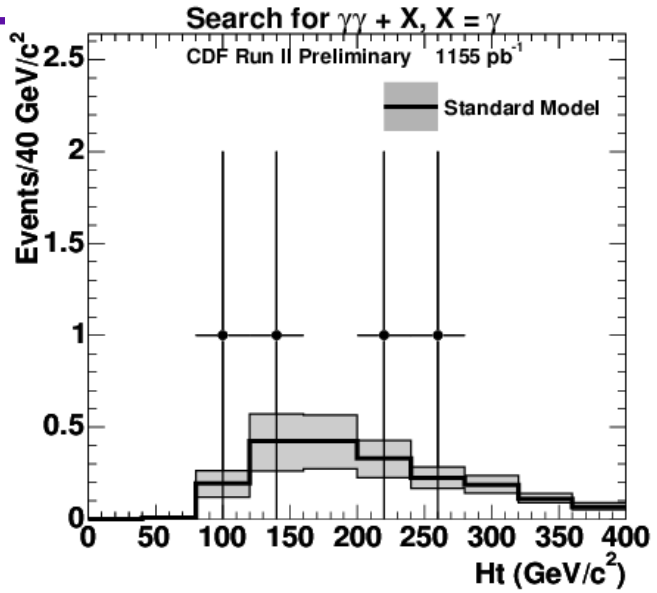
Search for Triphotons

Sample

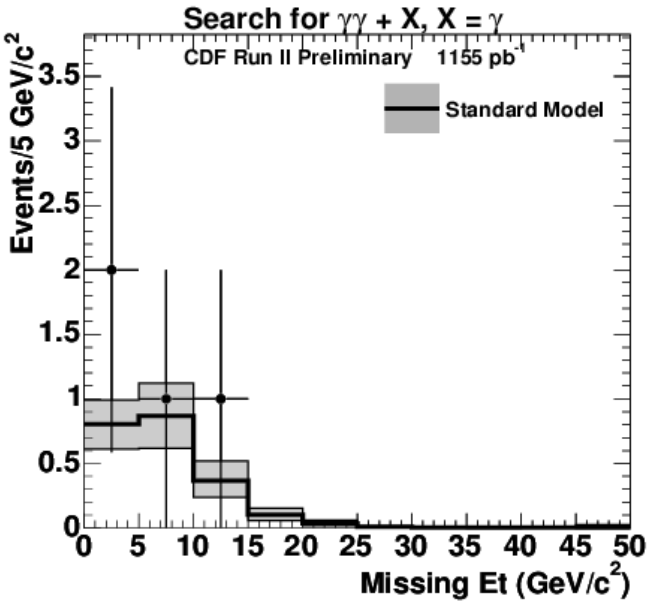
- 1155 pb^{-1}
- Start with same diphotons
- add a third central photon
  with Et>13 GeV

Backgrounds

S.M. Triphotons	
from MadGraph:	0.8 ± 0.15
At least one fake:	1.4 ± 0.6
Total:	2.2 ± 0.6
Observed:	4



Ht



MEt

Search for Lepton+Photon+X

- In Run I, in μγMEt, expected 4 and observed 11
- Repeat the Run I analysis, so kinematics are completely *a priori*

Sample

- 930 pb^{-1}
- Require:
  - ♦ tight central electron or muon, Et (Pt)>25 GeV
  - ♦ central photon, Et>25 GeV
- Look for
  - ♦More Photons
  - ♦Loose central or plug electron
  - ♦Loose central muons
  - ♦MEt > 25 GeV

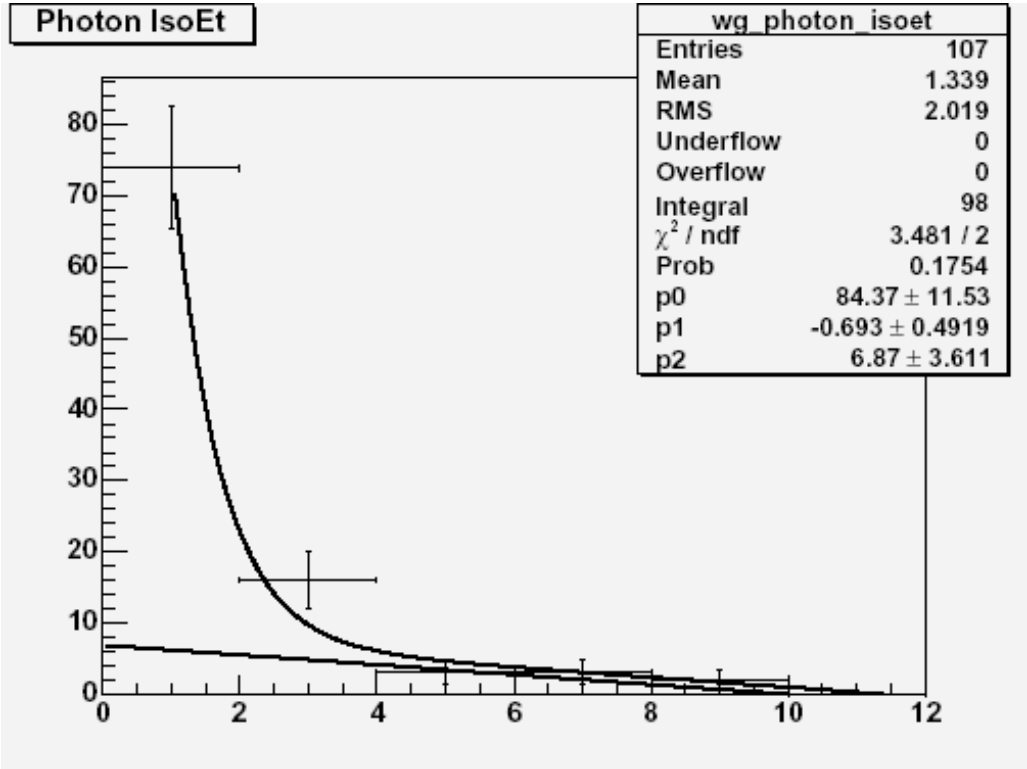
Backgrounds

- W/Zγ, W/Zγγ Baur and MadGraph Monte Carlo
- e→γ fake rate
- jet →γ iso method (see next)
- jet →*l* fake rate

Search for Lepton+Photon+X

Iso technique

- Find isolated shower isolation distribution from $Z \rightarrow e^- e^+$
- From non-isolated shape from jets
- Fit candidates calorimeter isolation distribution to the two shapes



Search for Lepton+Photon+X

eγMEt

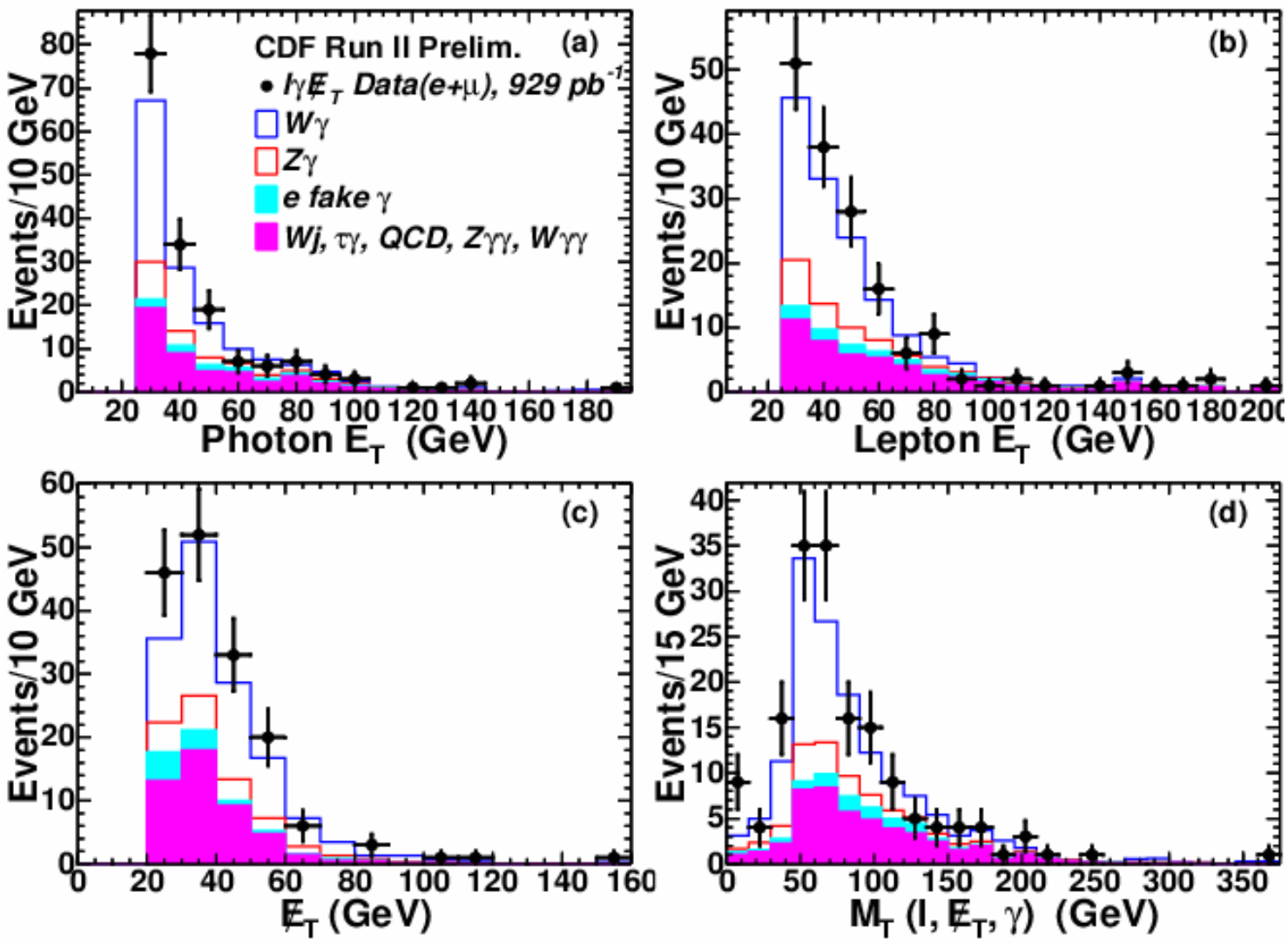
Expect 94.2± 8.1

Observe 96

μγMEt

Expect 53.9± 7.1

Observe 67



Search for Lepton+Photon+X

eeγ

Expect 39.0±4.8

Observe 53

μμγ

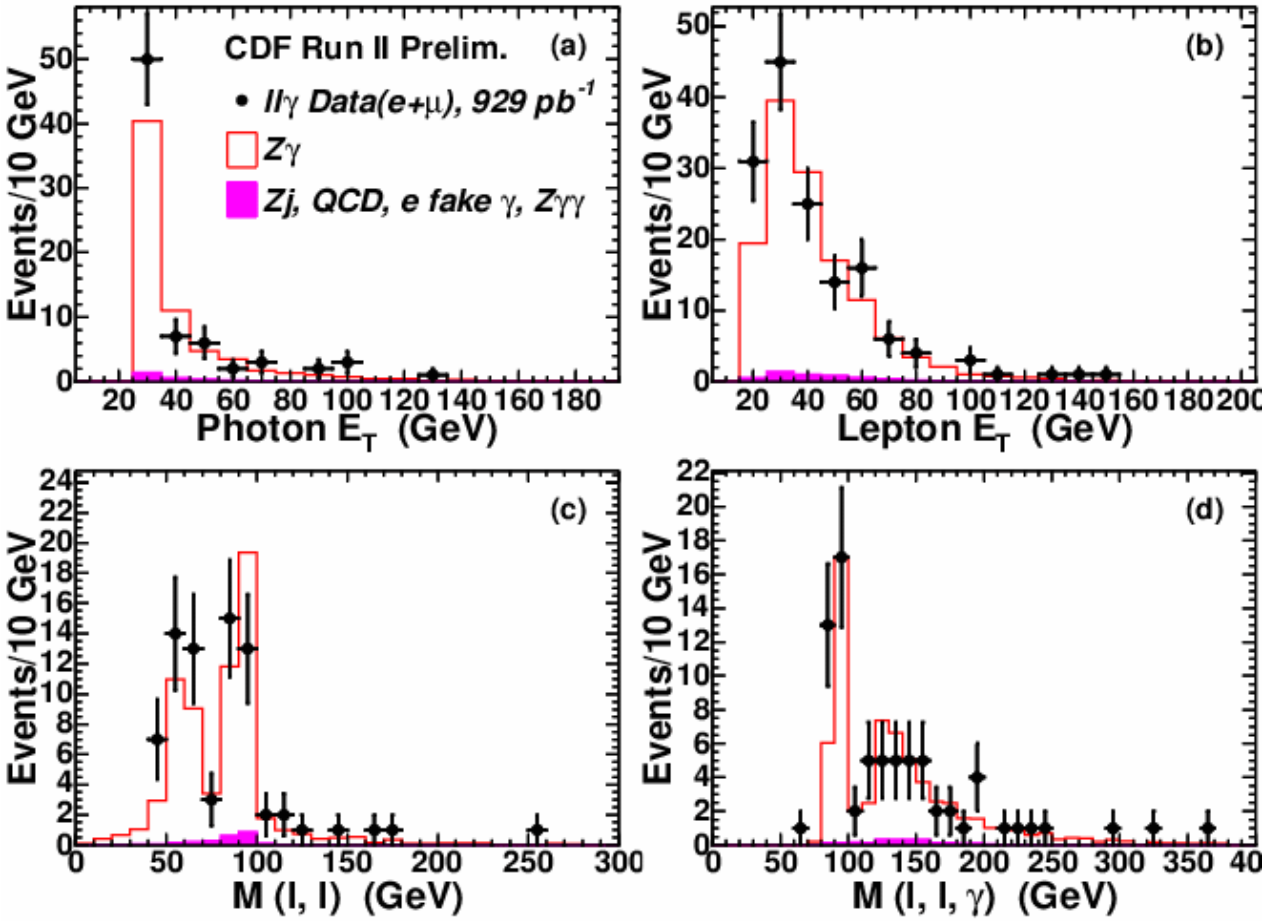
Expect 26.0±3.1

Observe 21

eμγ

0 observed,

1.0±0.3 expected



***llγ* MEt>25 GeV**

3 observed,

0.6±0.1 expected

lγγ

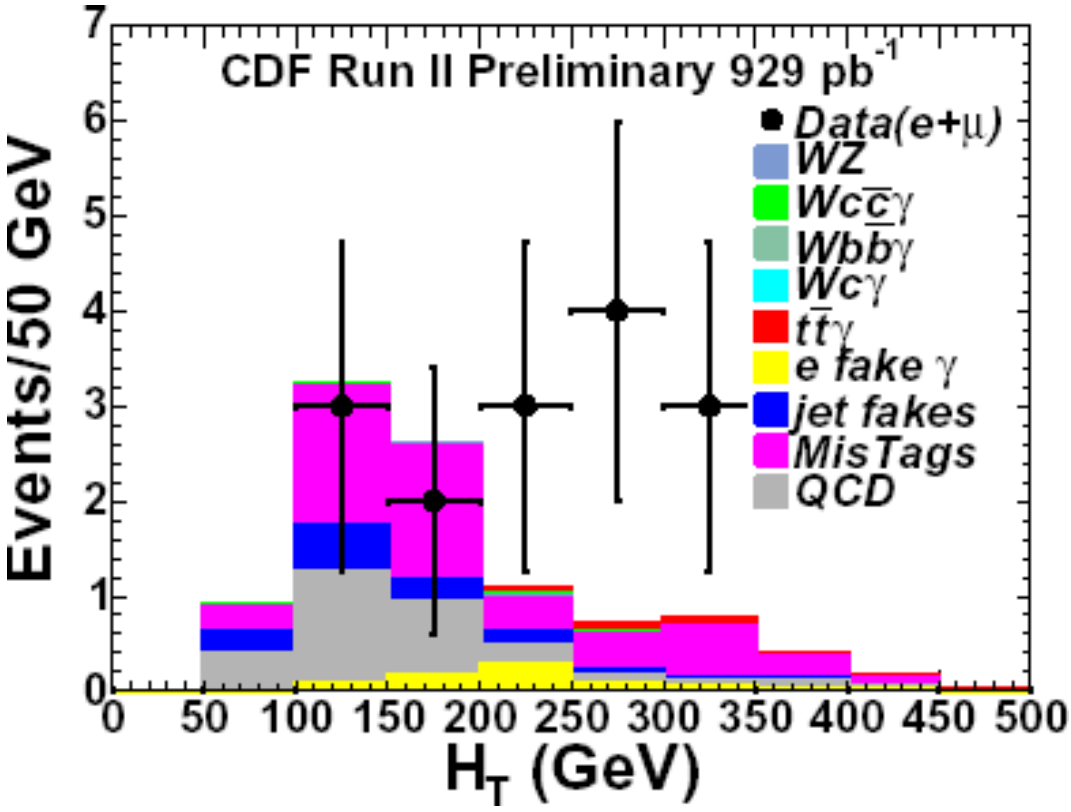
0 observed

0.5±0.1 expected

Search for $l\gamma\not{E}_T b$

Sample

- 929 pb^{-1}
- Lepton: central,
  Et>20 GeV
- Photon: central,
  Et>10 GeV
- Standard secondary
  vertex tag, Et>15 GeV, $|\eta|<2$
- MEt > 20 GeV



Ht = scalar sum of Et from photons, leptons, jets, and MEt

Search for $l\gamma\not{E}_T$b

Backgrounds

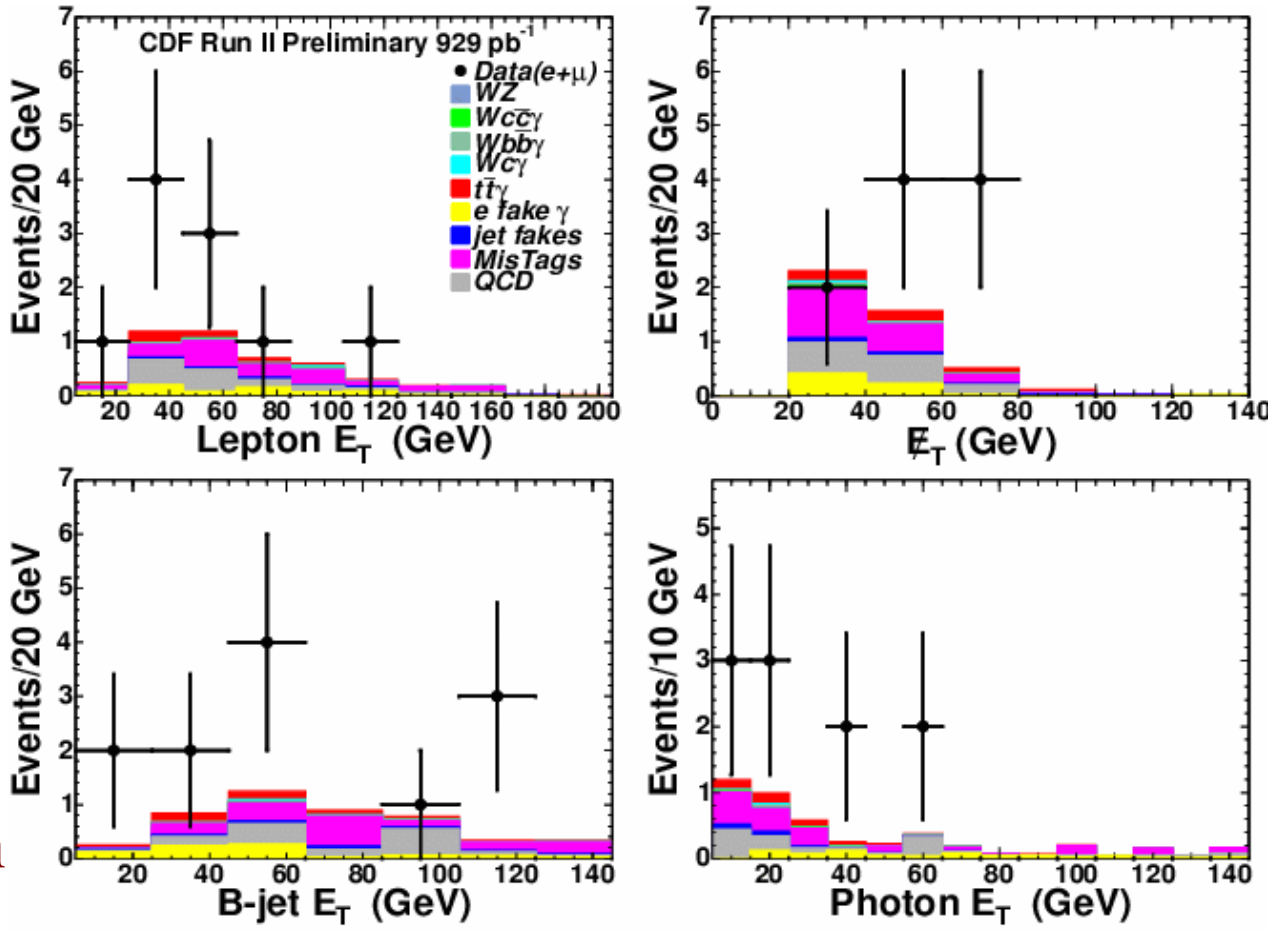
- Mostly fakes
  Especially tags
- 15 observed,
  11.37 ±1.52
  expected

CDF Run II Preliminary, $929pb^{-1}$			
Lepton + Photon + $\not{E}_T$ + b Events, Isolated Leptons			
Standard Model Source	$e\gamma b\not{E}_T$	$\mu\gamma b\not{E}_T$	$(e+\mu)\gamma b\not{E}_T$
$t\bar{t}\gamma$	0.32 ± 0.036	0.21 ± 0.025	0.53 ± 0.058
$W^{\pm}c\gamma$	0.14 ± 0.031	0.14 ± 0.029	0.28 ± 0.048
$W^{\pm}cc\gamma$	0.023 ± 0.010	0.048 ± 0.014	0.071 ± 0.018
$W^{\pm}bb\gamma$	0.14 ± 0.024	0.099 ± 0.018	0.24 ± 0.035
WZ	0.029 ± 0.014	0.0 ± 0.0075	0.029 ± 0.016
$Z(\tau\tau)\gamma$	0.041 ± 0.041	0.11 ± 0.063	0.15 ± 0.076
$ee\not{E}_Tb$, $e\rightarrow\gamma$	1.04961 ± 0.21	–	1.04961 ± 0.21
$\mu e\not{E}_Tb$, $e\rightarrow\gamma$	–	0.24 ± 0.08	0.24 ± 0.08
Jet faking γ ($ej\not{E}_Tb$, $j\rightarrow\gamma$)	0.73 ± 0.34	0.46 ± 0.20	1.19 ± 0.028
MisTags	2.85 ± 0.35	1.89 ± 0.26	4.74 ± 0.51
QCD(Jets faking ℓ and $\not{E}_T$)	2.85 ± 1.32	0.0 ± 0.50	2.85 ± 1.41
Total SM Prediction	$8.17 \pm 1.43(tot)$	$3.20 \pm 0.60(tot)$	$11.37 \pm 1.52(tot)$
Observed in Data	7	8	15

Search for $l\gamma\not{E}_T b$

ttbar Selection

- create a subsample
- related to $t\bar{t}\,h^0$
- sensitive to t charge
- require Ht>200GeV
  (*a priori* top-like cut)



Results

- 10 observed,
  4.7 ±1.0 expected
- ttγ is still out of reach

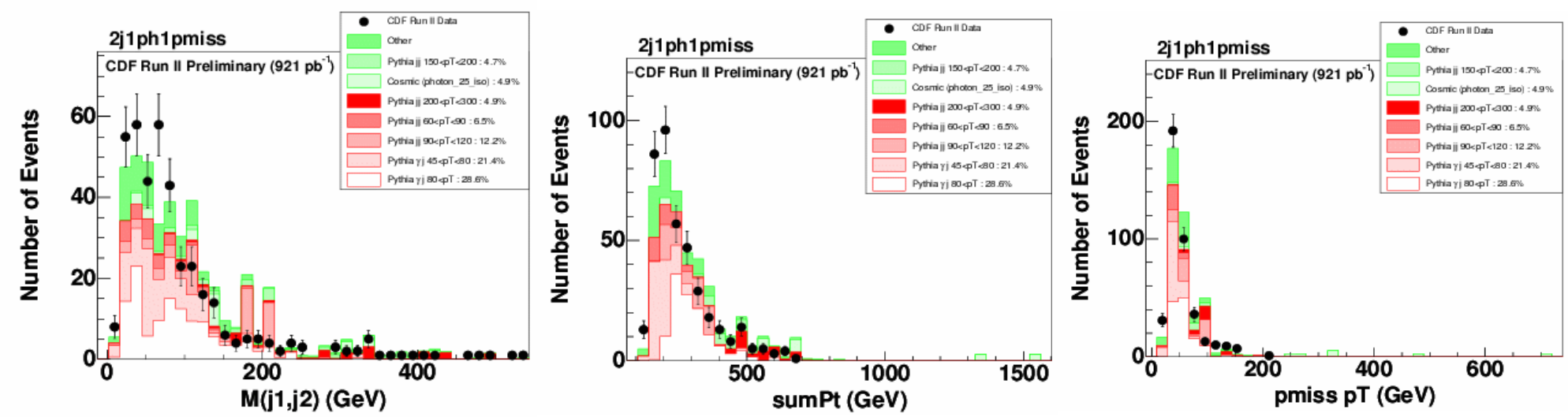
Ultimate Signature-based Search

- Several of these photon results were "signature-based"
- This idea, taken to the logical conclusion is Sleuth
- Automate searches to all high-Pt regions, all signatures
- Fit efficiencies, fake rates and k-factors to the data,

Apply these to a complete Monte Carlo description of the data

(*See talk by Georgios Choudalakis on Wednesday*)

Distributions for photon+2jets+MEt:



Last Slide

CDF has released recently, shown here:

γγMEt	γγ mass	γγ l
lγX	γγγ	lγbMEt

Also Appearing Now at DPF

γb Cross section
delayed photons
Sleuth

CDF photon program is going strong...