

CDF Searches for New Physics with Photons

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Yale University

SUSY 2007, Karlsruhe, Germany,

July 26 - August 1, 2007



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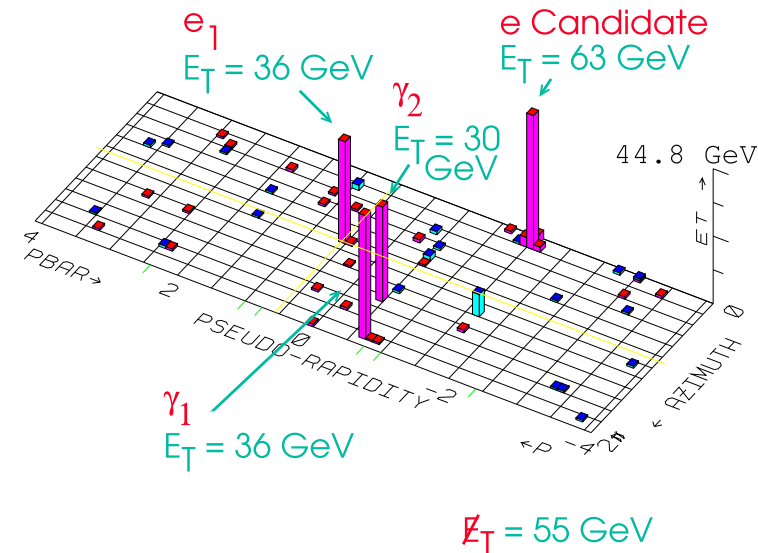
- Why
- Where
- Techniques
- Physics
- Papers
- Summary

Why: Experiment

✓ Run I Results

- Run I $ee\gamma\gamma\cancel{E}_T$ (10^{-6} expected, 1 observed)
- Run I $l\gamma\cancel{E}_T$: 7.6 ± 0.7 expected, 16 observed, 2.7σ

$ee\gamma\gamma\cancel{E}_T$ Candidate Event



✓ Properties of photon

- Coupled to electric charge; massless; stable

Why: Theory

✓ Models (many!) (Searches in the talk)

SUSY

$$\tilde{\chi}_1^0 \rightarrow \gamma G$$

$$\tilde{\chi}_2^0 \rightarrow \gamma G$$

$\gamma\gamma\cancel{E}_T$, displaced γX , $\gamma\gamma j\cancel{E}_T$, $e\gamma\cancel{E}_T$, $\mu\gamma\cancel{E}_T$, $\gamma b\cancel{E}_T$,
 $\gamma bj\cancel{E}_T$, $\gamma bc\cancel{E}_T$, $\gamma jj\cancel{E}_T$, $\gamma ee\cancel{E}_T$, $\gamma\mu\mu\cancel{E}_T$, $\gamma\gamma ee\cancel{E}_T$,
 $\gamma\gamma\mu\mu\cancel{E}_T$, $\gamma\cancel{E}_T$, $jj\gamma\cancel{E}_T$

Technicolor

$$\omega_T, \rho_T \rightarrow \gamma\pi_T$$

$$\pi_T \rightarrow \gamma\gamma$$

γbb , γjj , γtt , $\gamma\gamma\gamma$, $ee\gamma\gamma$
 $\mu\mu\gamma\gamma$, $ee\gamma\gamma\cancel{E}_T$, $\mu\mu\gamma\gamma\cancel{E}_T$

Compositeness

$$X^* \rightarrow \gamma X$$

$ee\gamma$, $ee\gamma\gamma$, $\mu\mu\gamma$, $\mu\mu\gamma\gamma$, $jj\gamma$, $bb\gamma$, $jj\gamma\gamma$, $bb\gamma\gamma$

Extra Dimensions (RS)

$$G \rightarrow \gamma\gamma$$

$\gamma\gamma$, $\gamma\cancel{E}_T$

Higgs

$$H \rightarrow \gamma\gamma, A \rightarrow \gamma\gamma$$

$\gamma\gamma$, $ee\gamma$, $\mu\mu\gamma$, $e\gamma\gamma\cancel{E}_T$, $\mu\gamma\gamma\cancel{E}_T$, $jj\gamma\gamma$, $\gamma\gamma\gamma\gamma$

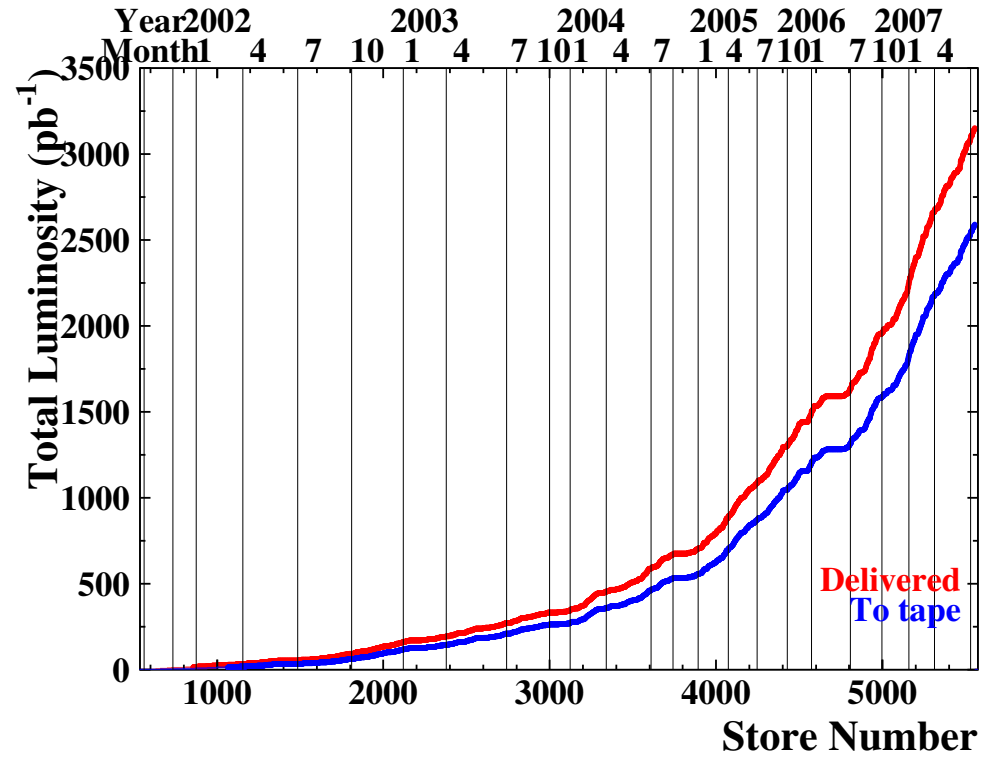
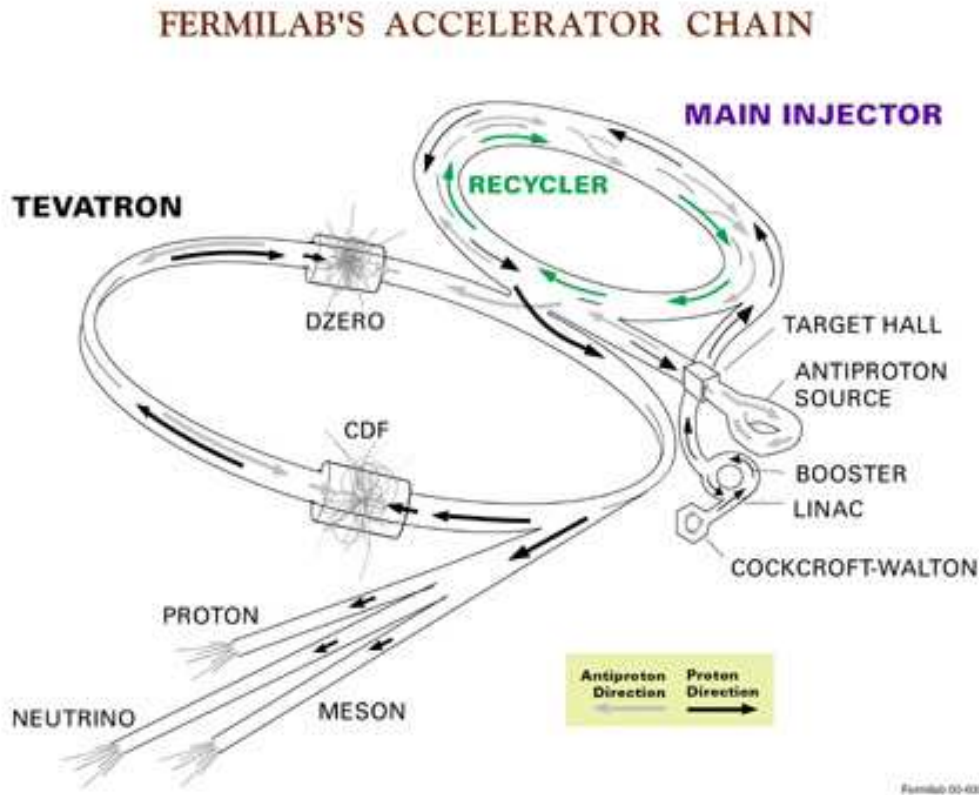
4th generation

$$b' \rightarrow \gamma b$$

$\gamma\gamma bb$, $ee\gamma bb$, $\mu\mu\gamma bb$, $jj\gamma\gamma bb$

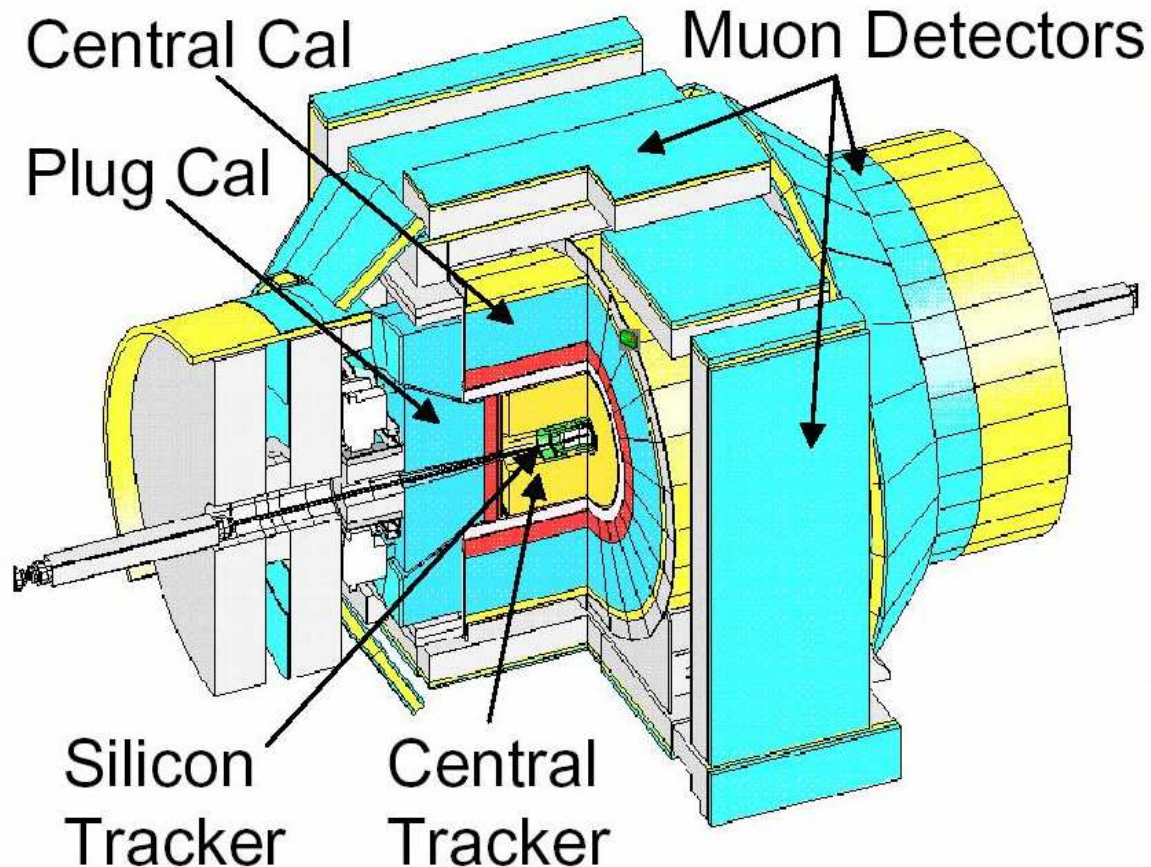
Where: Tevatron

- $p\bar{p}$ Collisions
- $\sqrt{s}=1.96$ TeV
- $\mathcal{L}_{peak} = 2.9 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
April, 2007



- 3 fb^{-1} delivered, 2.5 fb^{-1} on tape
- Expect $4\text{-}8 \text{ fb}^{-1}$ by 2009
- In this talk $\sim 1 \text{ fb}^{-1}$ results

Where: CDF

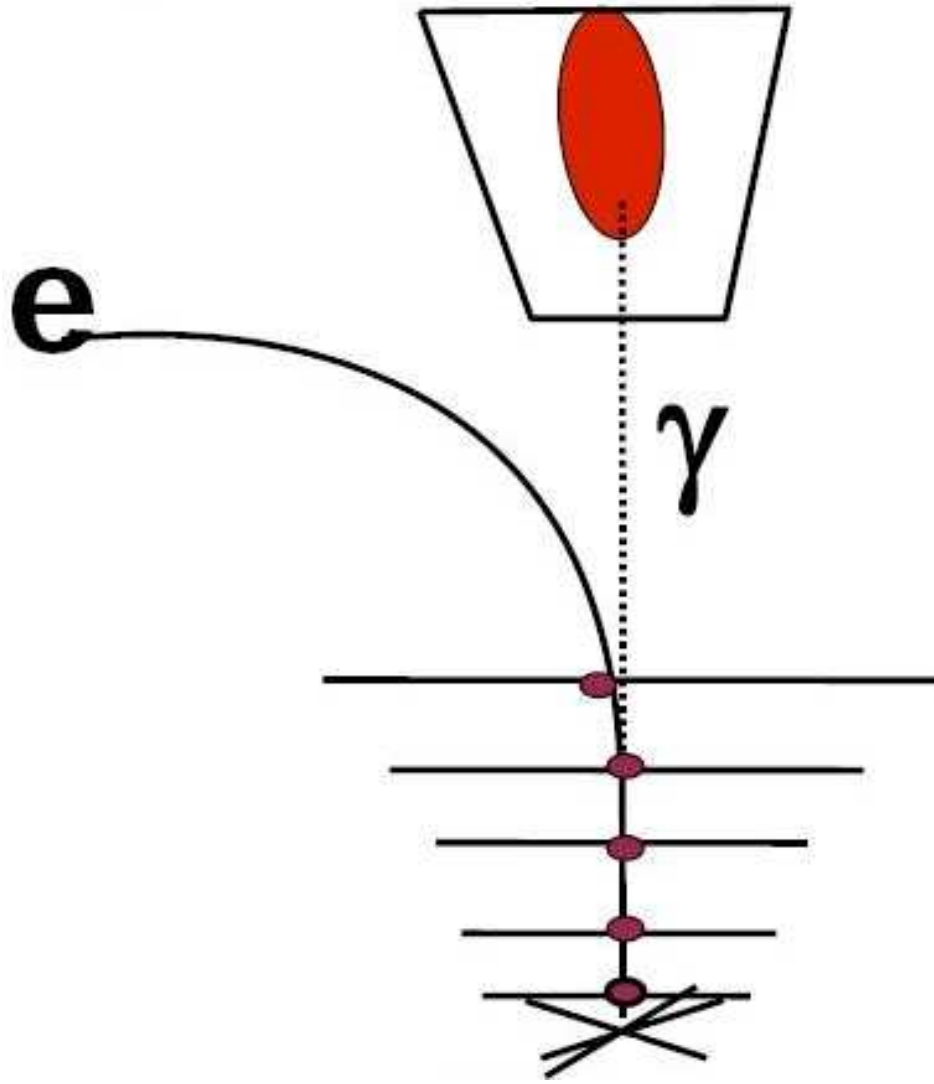


Photon candidates:

- shower in EM calorimeter
- no associated track with $P_T > 1 \text{ GeV}$
- at most one track with $P_T < 1 \text{ GeV}$, pointing at the EM cluster
- good profiles in both transverse dimensions at shower maximum
- minimal leakage into the HAD calorimeter

Techniques

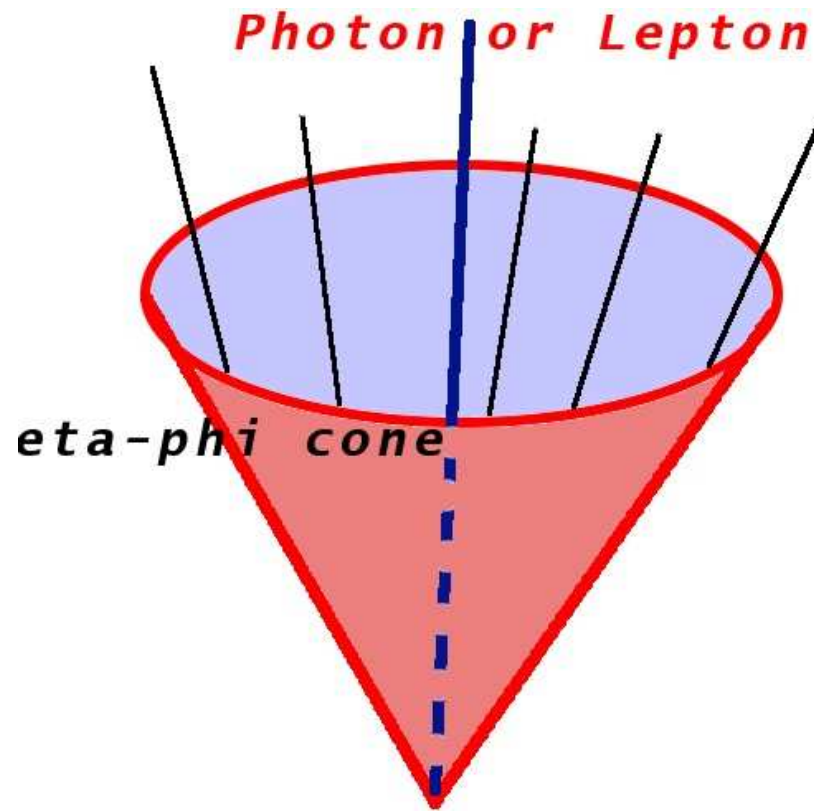
Main Sources of Non-Prompt (“Fake”) Photons



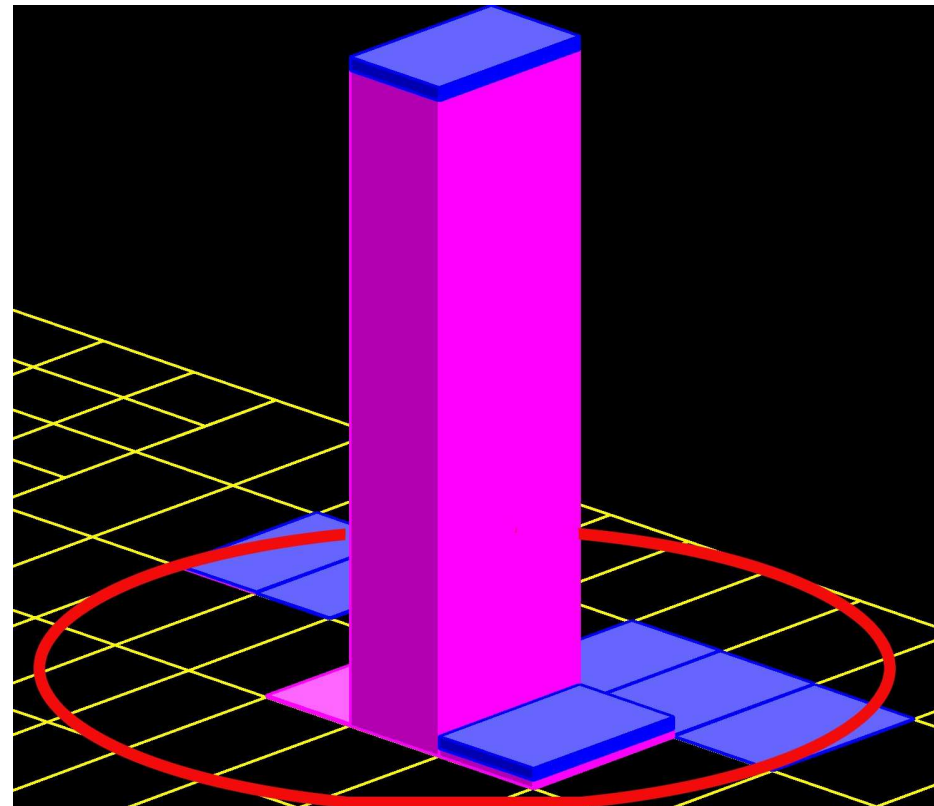
- $e \rightarrow \gamma$
bremsstrahlung or tracking inefficiency
 - Seed a “**phoenix**” track from EM cluster and event vertex
 - Search for hits along the expected arc
- $jet \rightarrow \gamma$
 - π^0, η etc.
 - EM shower profile should be consistent with a single photon
 - Photons are isolated

Techniques

✓ Isolation



(a) **Tracking Isolation:** $\sum p_T$
of extra tracks in $\eta - \phi$ cone



(b) **Calorimeter isolation:** $\sum E_T$
of extra towers in $\eta - \phi$ cone

Figure 1: Isolation is different for prompt leptons/photons and for fake ones

Techniques

✓ $e \rightarrow \gamma$

- “Z-like” $e\gamma$ Sample: ($\Delta\phi(e, \gamma) > 150^\circ$, $M(e, \gamma) \approx M(Z^0)$)
- Compare $Z^0 \rightarrow e^+e^-$ and $e\gamma$ “Z-like” events $\Rightarrow P_{e \rightarrow \gamma}$
- MC $\Rightarrow E_T$ dependence of $P_{e \rightarrow \gamma}$
- Normalize to DATA
- Compare $e \rightarrow \gamma$, $\mu \rightarrow \gamma$, $\tau \rightarrow \gamma$ in MC

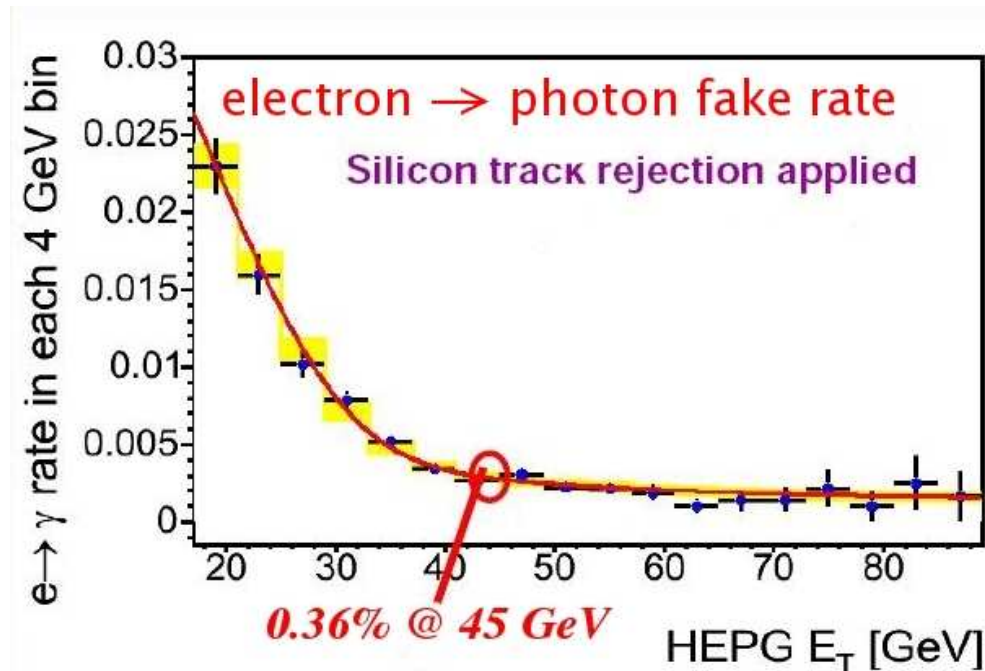
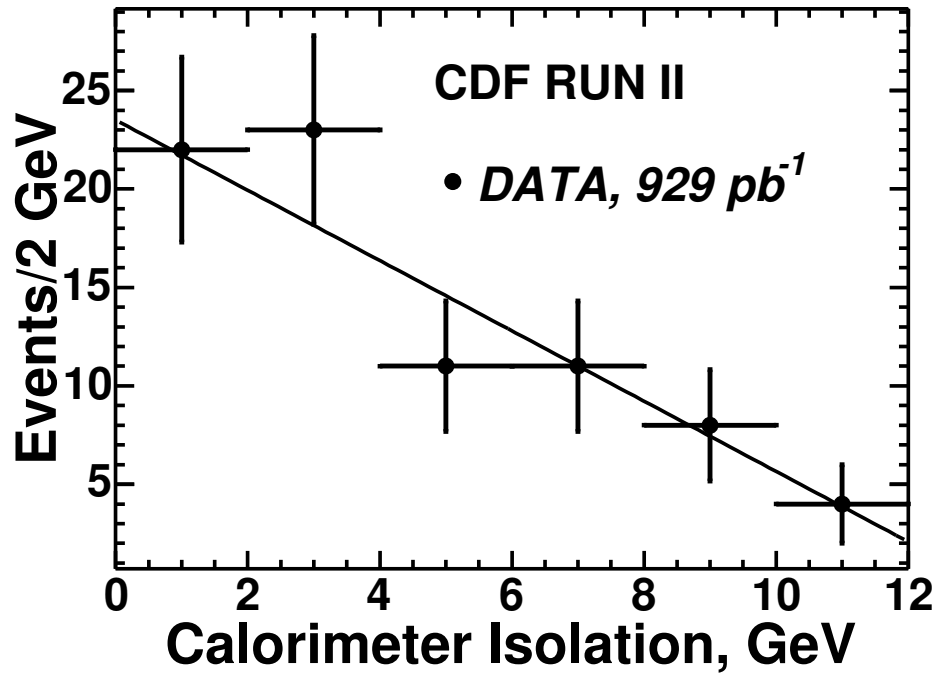


Figure 2: Probability that an electron is misidentified as a photon

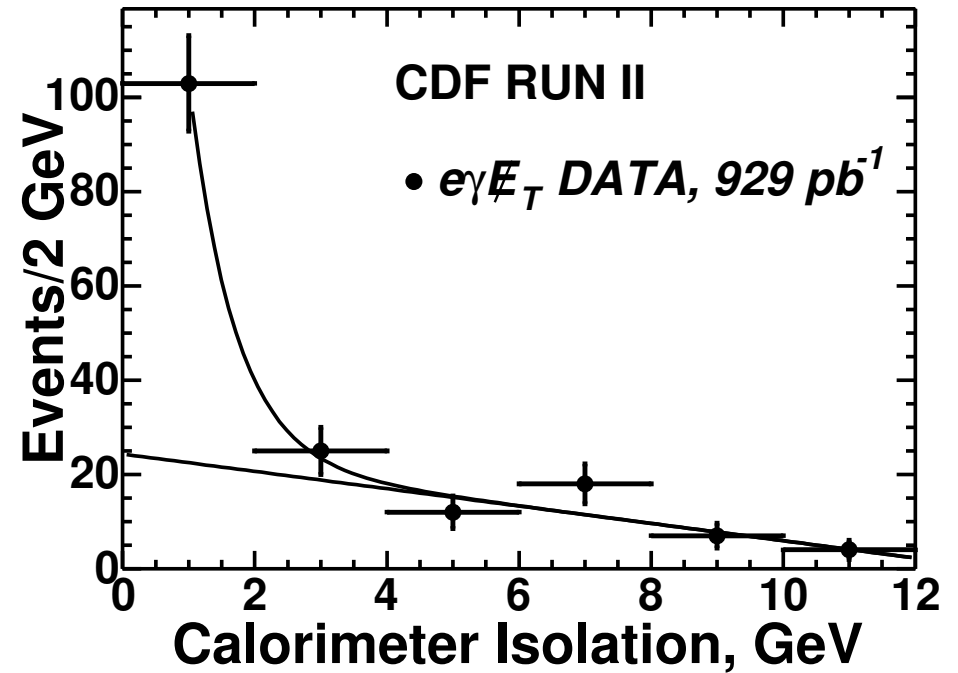
Techniques

✓ Isolation Technique for $jet \rightarrow \gamma$

hep-ex/0702029, Phys. Rev. D **75**, 112001 (2007)



(a) Calorimeter isolation for “ π^0 ”



(b) Background estimate for $e\gamma E_T$

Figure 3: **Linear behavior of the background** - from fake photon sample (“ π^0 ”): reject real photons (based on shower max detector) and omit calorimeter and track isolation requirements. **Signal behavior** - from $Z^0 \rightarrow e^+e^-$.

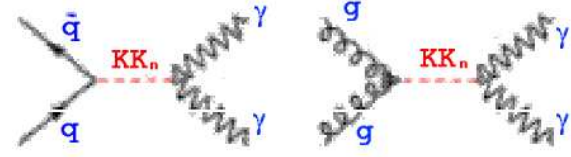
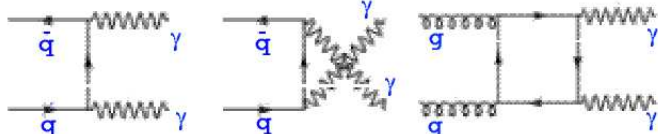
Physics

✓ Search for Diphoton Peaks

arXiv:0707.2294v2, submitted to PRL (july 2007)

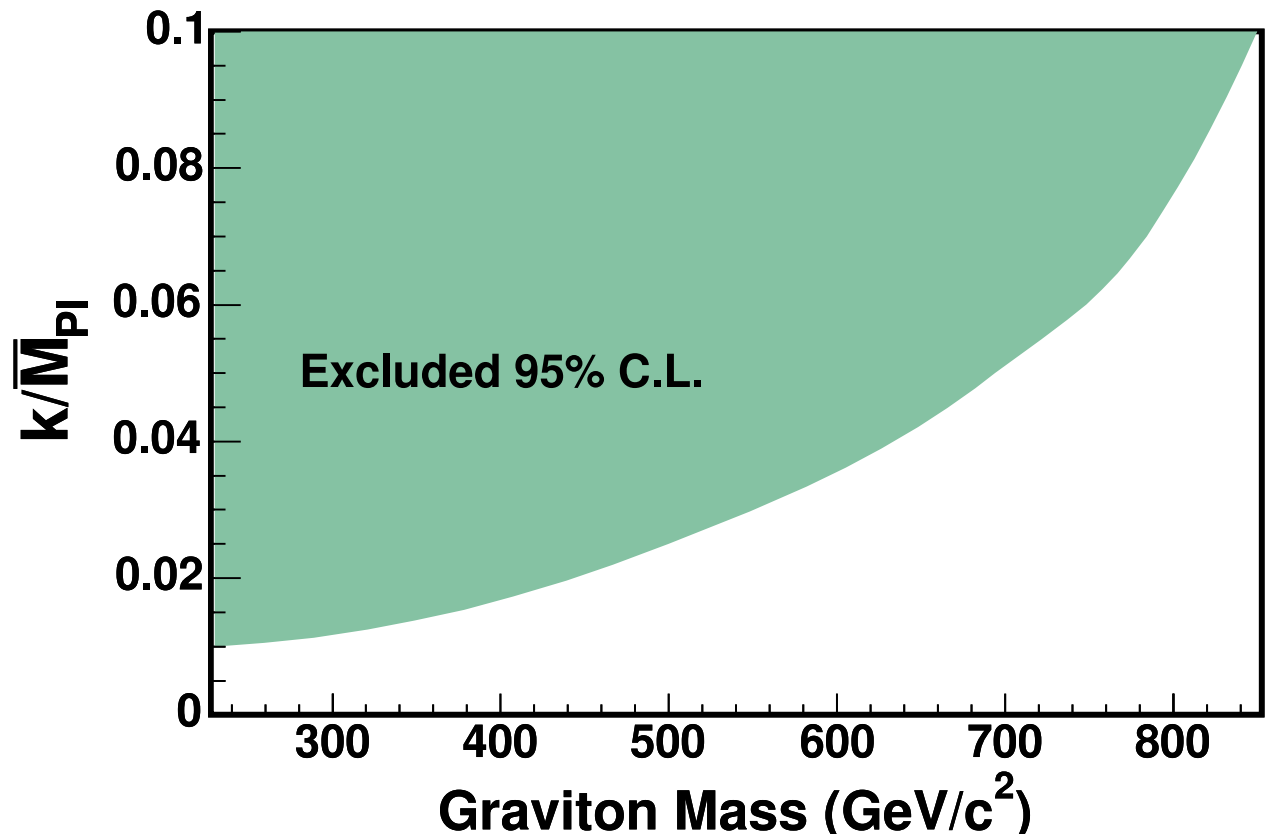
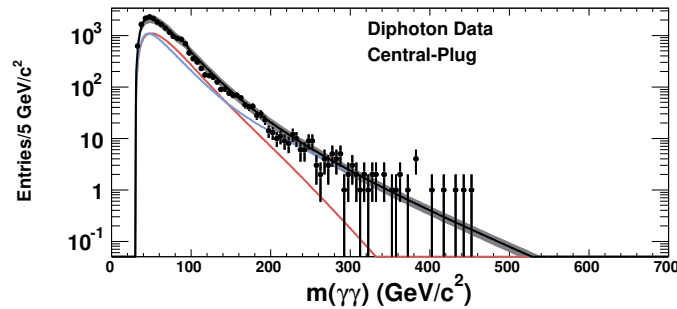
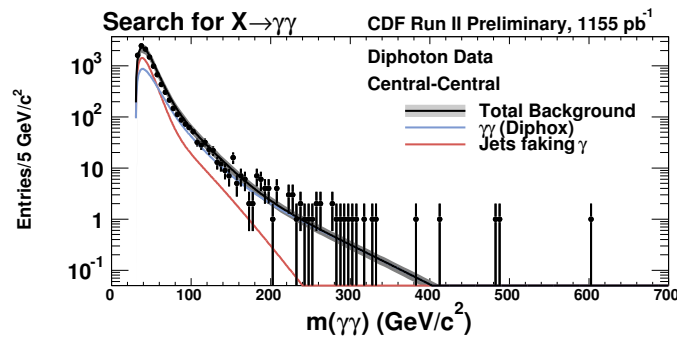
- SM Background

- NLO Diprox calculation



- Jets Faking Photon

- Usually a high- E_T π^0
 - normalize to low mass



$230\text{GeV} @ k/\bar{M}_{Pl} = 0.01, 850\text{GeV} @ k/\bar{M}_{Pl} = 0.1$

Physics

✓ $\gamma\gamma + X, X=e, \mu, \tau, \gamma, \cancel{E}_T, b \Rightarrow \gamma\gamma \cancel{E}_T$

Analysis

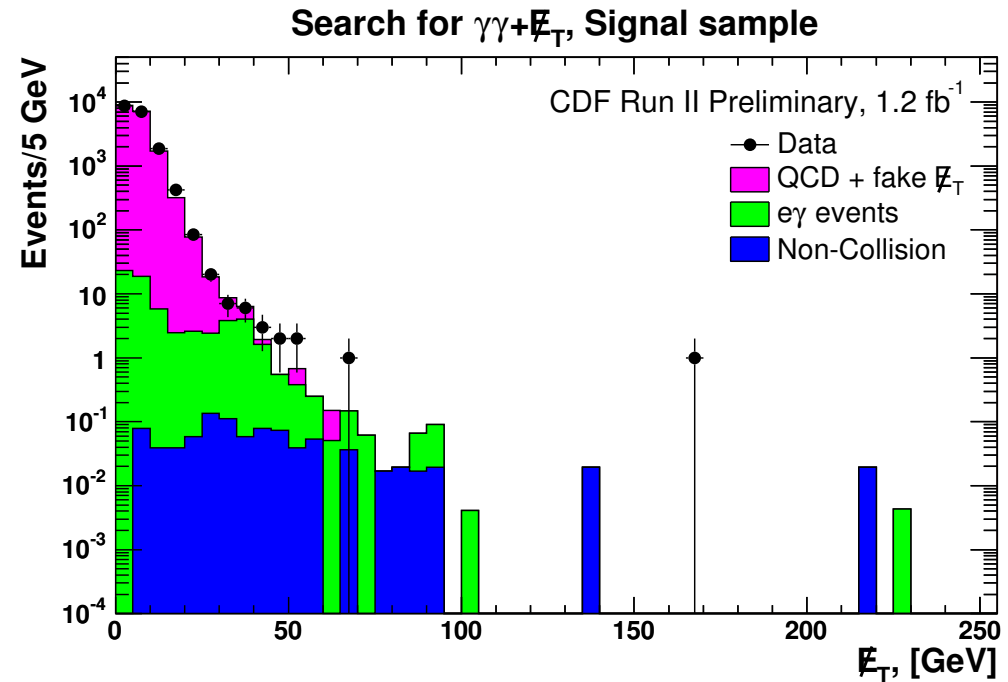
- Model independent search
- Two central photons $E_T > 13 \text{ GeV}$

Methods

- Remove fake \cancel{E}_T
 - Remove events where jet is not fiducial and $\Delta\phi(\text{jet}, \cancel{E}_T) < 0.1$
 - Use lowest \cancel{E}_T vertex
- Remove EWK
 - $W \rightarrow e\gamma$ by brem rejected by Phoenix
- Remove non-collision
 - EM Timing
 - No trackless μ segments in muon chambers with $\Delta\phi(\text{segment}, \gamma) < \pi/6$

Results

Backgrounds are estimated from DATA



$E_T > 50 \text{ GeV}: 1.6 \pm 0.3, 4 \text{ observed}$

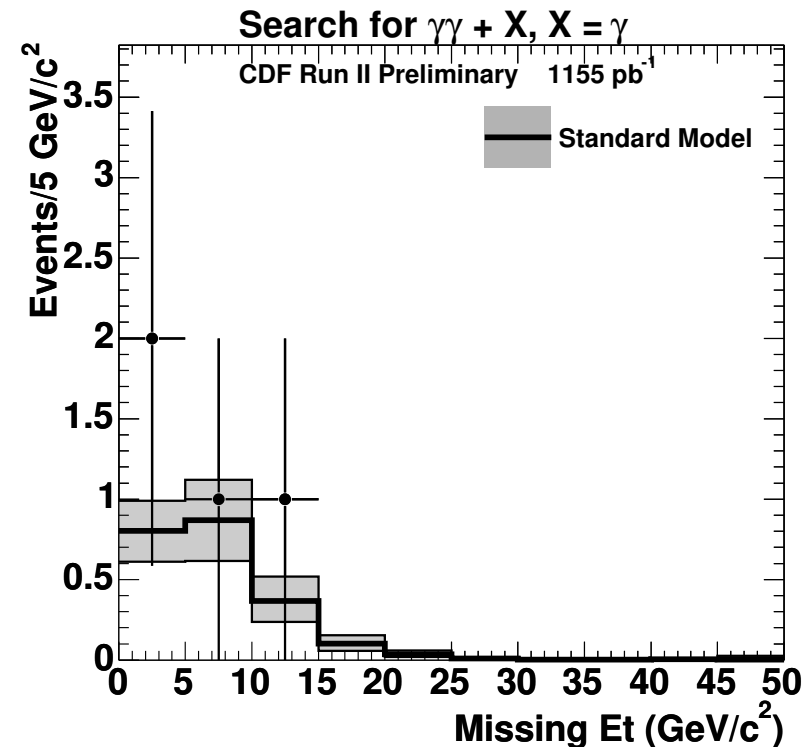
Physics

✓ $\gamma\gamma + X, X=e, \mu, \tau, \gamma, \cancel{E}_T, b \Rightarrow \gamma\gamma\gamma$

Analysis

- Model independent search
- Two central γ $E_T > 13$ GeV
- additional central γ $E_T > 13$ GeV

Results

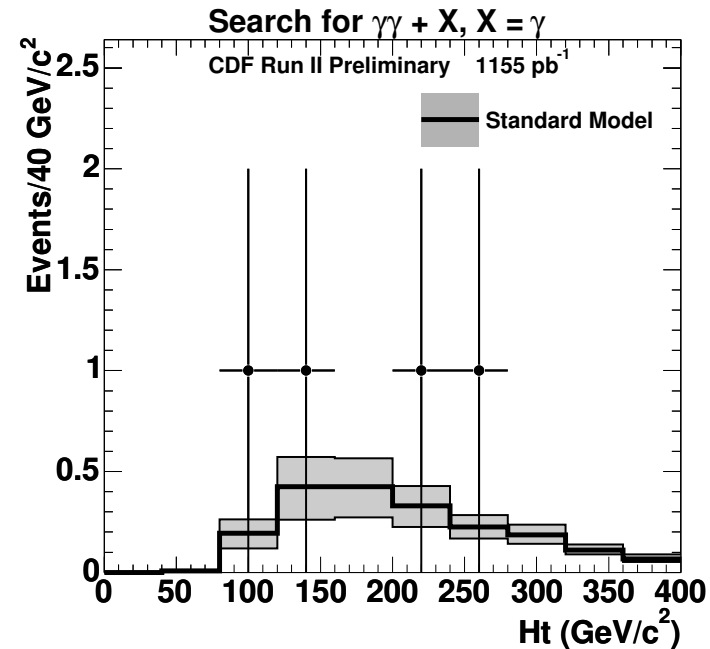


Backgrounds:

S.M. (MadGraph) 3γ 0.8 ± 0.15

At least one fake: 1.4 ± 0.6

Total: 2.2 ± 0.6 , Observed: 4



H_T : sum of E_T of ℓ, γ, j and \cancel{E}_T

Physics

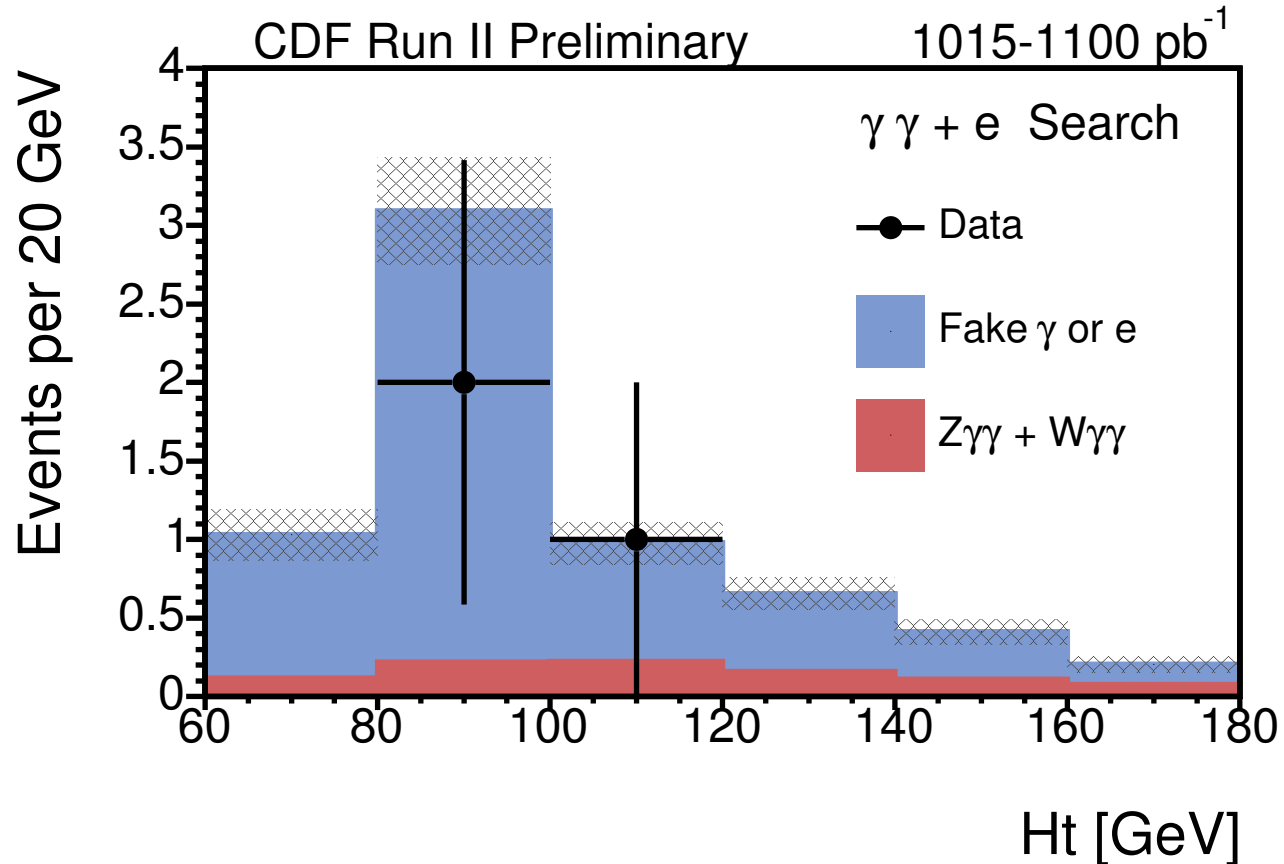
✓ $\gamma\gamma + X$, $X = e, \mu, \tau, \gamma, \cancel{E}_T, \mathbf{b} \Rightarrow \gamma\gamma\ell, \ell = e, \mu$

Analysis

- Model independent search
- Two central γ $E_T > 13$ GeV
- $E_T^e > 20$ GeV, $P_T^\mu > 20$ GeV
- $P_T^\tau > 15$ GeV

$\ell\gamma\gamma$	$e\gamma\gamma$	$\mu\gamma\gamma$
Total	6.8 ± 0.8	0.8 ± 0.1
Observed	3	0

Results



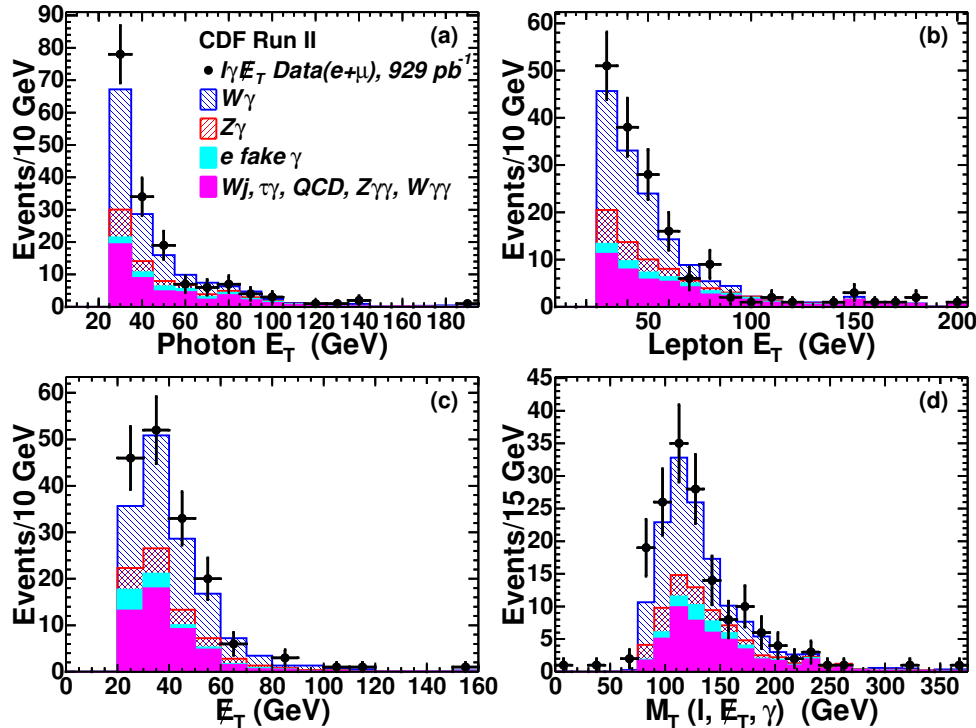
Physics

✓ $l\gamma + X, l=e, \mu; X=e, \mu, \gamma, \cancel{E}_T$ [hep-ex/0702029, Phys. Rev. D **75**, 112001 \(2007\)](#)

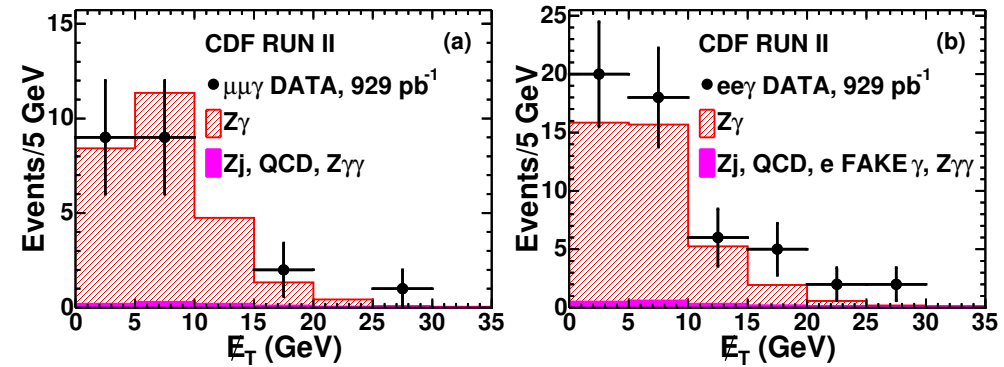
Analysis

- Signature-Based search
- Motivated by Run I $ee\gamma\gamma\cancel{E}_T$ and $l\gamma\cancel{E}_T$
- *a priori* defined cuts (same as in Run I)
- MadGraph, CompHep and Baur MC

Results



$l\gamma\cancel{E}_T$	$e\gamma\cancel{E}_T$	$\mu\gamma\cancel{E}_T$	$(e + \mu)\gamma\cancel{E}_T$
Predicted	94.8 ± 8.1	55.7 ± 7.1	150.6 ± 13.0
Observed	96	67	163



$ll\gamma$	$ee\gamma$	$\mu\mu\gamma$	$ll\gamma$
Total	39.0 ± 4.8	26.1 ± 3.1	65.1 ± 7.7
Observed	53	21	74

0 $e\mu\gamma$ vs. 1.0 ± 0.3 , 0 $l\gamma\gamma$ vs. 0.62 ± 0.15

3 $ll\gamma$ events with $\cancel{E}_T > 25$ GeV, vs. 0.6 ± 0.1 expected events, corresponding to a likelihood of 2.4 %.

Physics

✓ $t\bar{t}\gamma$

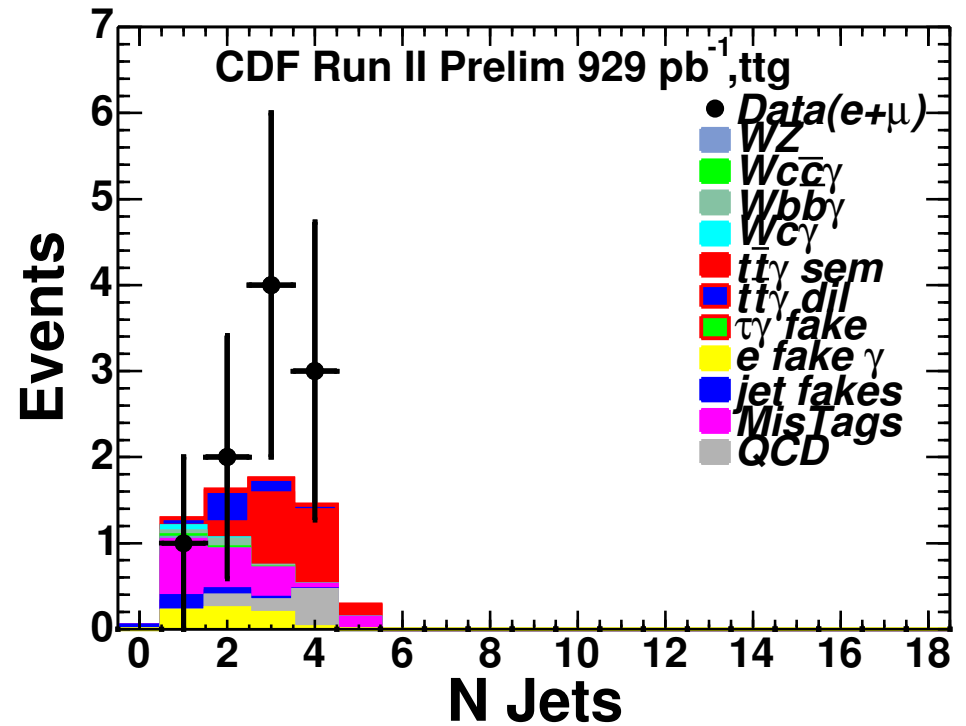
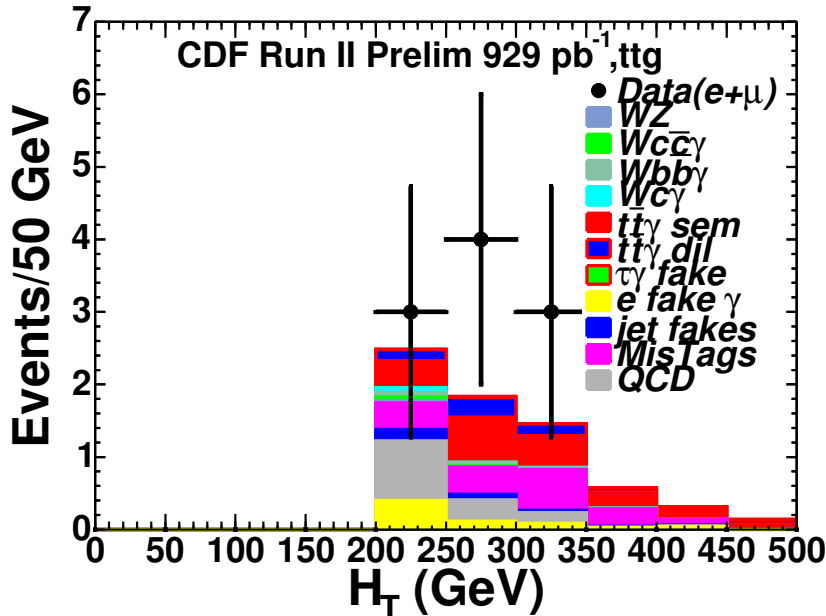
Analysis

- Signature-based search for $l\gamma\cancel{E}_T + b$
- $t\bar{t}\gamma$: Control Sample for $t\bar{t} + Higgs$
- $t\bar{t}\gamma$ cross-section measurement

Categories

- $l\gamma\cancel{E}_T + b$ jet
- $l\gamma\cancel{E}_T + b$ jet + H_T
- $t\bar{t}\gamma$: $l\gamma\cancel{E}_T + b$ jet + $H_T + N_{jets} > 2$

Results



$l\gamma\cancel{E}_T + b + H_T$ (929 pb⁻¹)

e	μ	$e + \mu$
4.9 ± 0.8	2.3 ± 0.6	7.2 ± 1.0
6	4	10

Physics

✓ $t\bar{t}\gamma$

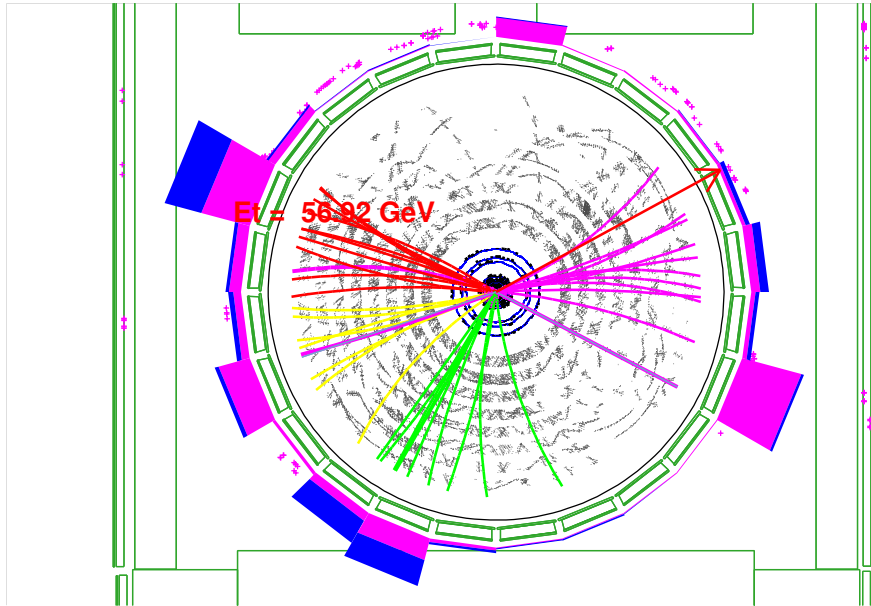
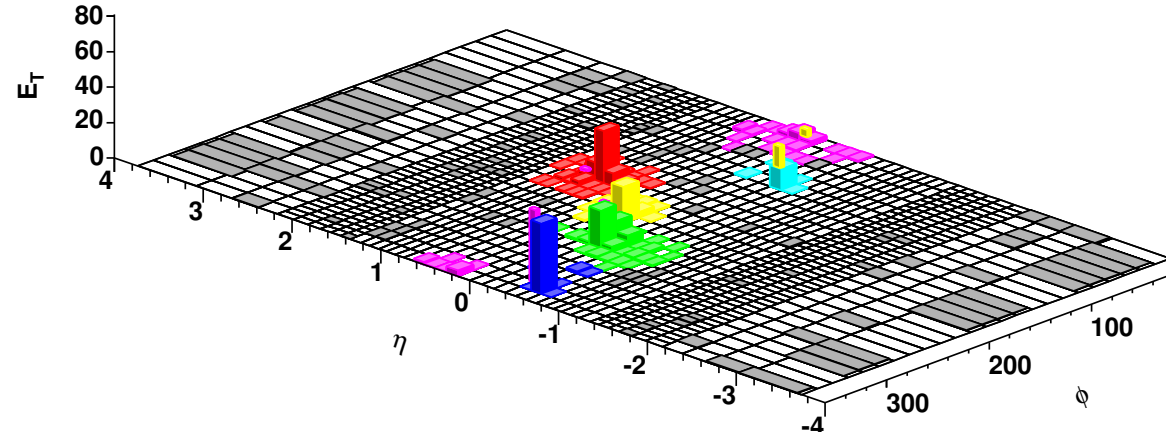
Analysis

- Signature-based search for $l\gamma\cancel{E}_T + b$
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- $t\bar{t}\gamma$ cross-section measurement

Categories

- $l\gamma\cancel{E}_T + b$ jet
- $l\gamma\cancel{E}_T + b$ jet + H_T
- $t\bar{t}\gamma$: $l\gamma\cancel{E}_T + b$ jet + $H_T + N_{jets} > 2$

DATA Event : 1050006 Run : 193396 | Prescaled: 4,6,9,15,24,26,27,29,33,36,38,46,47,59
Unprescaled: 4,6,9,11,15,19,23,24,26,27,29,33,34,35,36,37,38,41,46,47,51,53,55,59



Missing Et
Et=70.7 phi=0.5
Jet Collection:
JetCluModule

Particles: first 5			
pdg	pt	phi	eta
11	41.4	5.8	-0.4
13	15.0	4.2	-0.1
22	12.1	1.5	-0.3
11	5.0	3.5	0.3
22	4.2	0.2	0.3

Jets(R = 0.7): first 5			
Em/Tot	et	phi	eta
0.6	71.2	2.7	0.8
0.4	57.6	4.2	-0.3
0.9	41.9	5.8	-0.6
0.8	34.2	3.4	0.1
0.5	25.1	0.1	0.4

$$l\gamma\cancel{E}_T + b + H_T + N_{jets} > 2 \quad (929 \text{ pb}^{-1})$$

e	μ	$e + \mu$
2.3 ± 0.6	1.3 ± 0.5	3.6 ± 0.8
4	3	7

Physics

✓ Delayed Photons ($\gamma \cancel{E}_T + \text{jets}$) Model

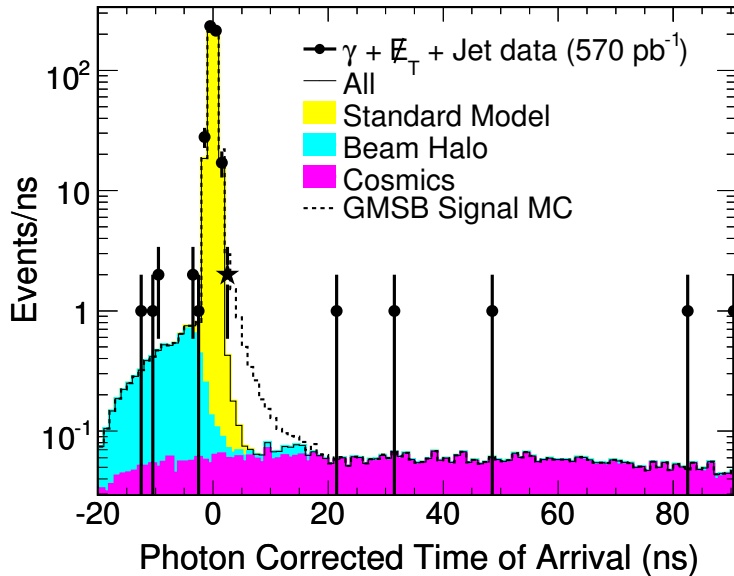
- GMSB decays of $\tilde{\chi}_1^0 \rightarrow \gamma G$

arXiv:0704.0760, accepted to PRL (july 2007)

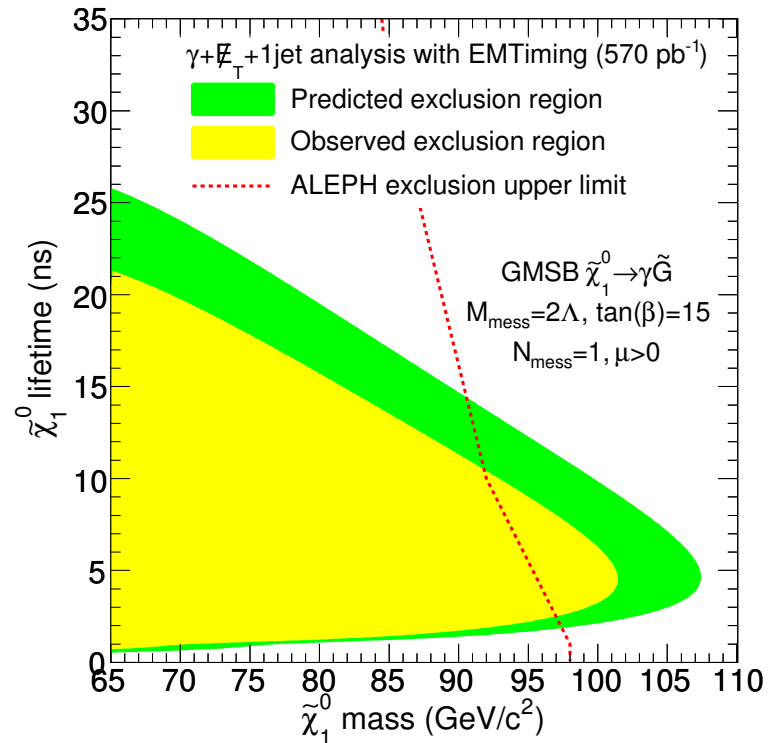
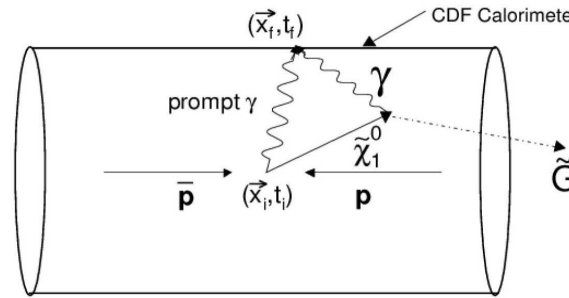
Technique

- measurement ($\sigma=0.6$ ns) of arrival time of γ in EM calorimeter

Results



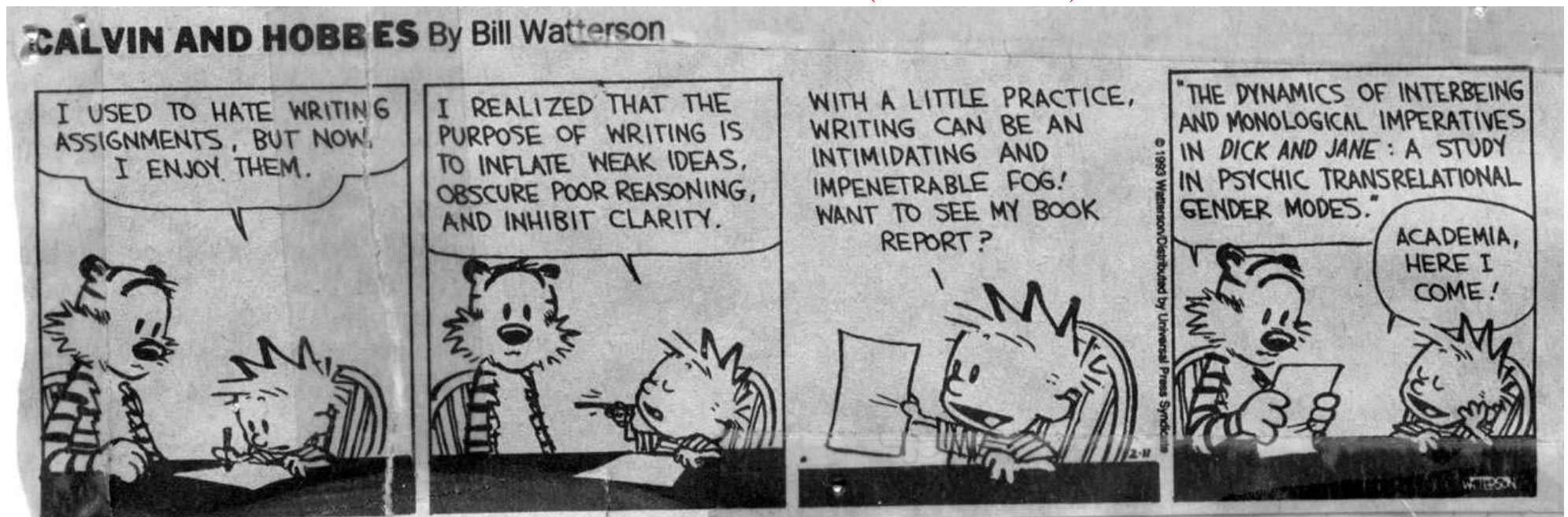
- Arrival time of photons in 2-10 ns
- 2 observed, 1.3 ± 0.7 expected
- 0.71 Standard Model, 0.46 Cosmics, 0.07 Beam Halo



Details in Slava Krutelyov's talk

CDF Photon Searches Publications (Last 6 months)

- “Search for New Physics in Lepton + Photon + X Events with 929 pb⁻¹ of ppbar Collisions at $\sqrt{s} = 1.96\text{TeV}$ ”, [hep-ex/0702029](#), *Phys. Rev. D* **75**, 112001 (2007)
- “Search for Heavy, Long-Lived Particles that Decay to Photons at CDF II,” [arXiv:0704.0760](#), accepted to PRL (july 2007)
- “Search For a High-Mass Diphoton State and Limits on Randall-Sundrum Gravitons at CDF”, [arXiv:0707.2294v2](#), submitted to PRL (july 2007)



Summary

- Many photon analyses at CDF are underway
- Techniques developed and experience gained will be useful for the Tevatron and for the LHC
- Keep publishing papers:
working on $t\bar{t}\gamma$, $\gamma\cancel{E}_T$, $\gamma\gamma\tau$, $\gamma\gamma b$, γ +b-jets
- Updating and improving analyses with new data
- We do understand the SM:
this will help to search for physics beyond it.

The Event

