Photon Searches at the Tevatron

Photon Triggers and Selections

Photon triggers

Et > 25, iso<0.2, had/em<0.2 (prescaled at high-lum)
Et > 30, iso<0.2, had/em<0.2

Central Cuts (η<1.1)

had/EM <0.04
calorimeter Iso,
cone 0.2→0.4/cone 0.2 < 0.07
good transverse shower profile
track isolation, cone 0.05→0.4 < 2 GeV
no good, high-pt track (anti-electron)
search for electron hits along a road

All analyses use Z→ee to study/correct ID efficiencies
Have started using Zγ sample to check efficiencies!!

Road Technique

Method

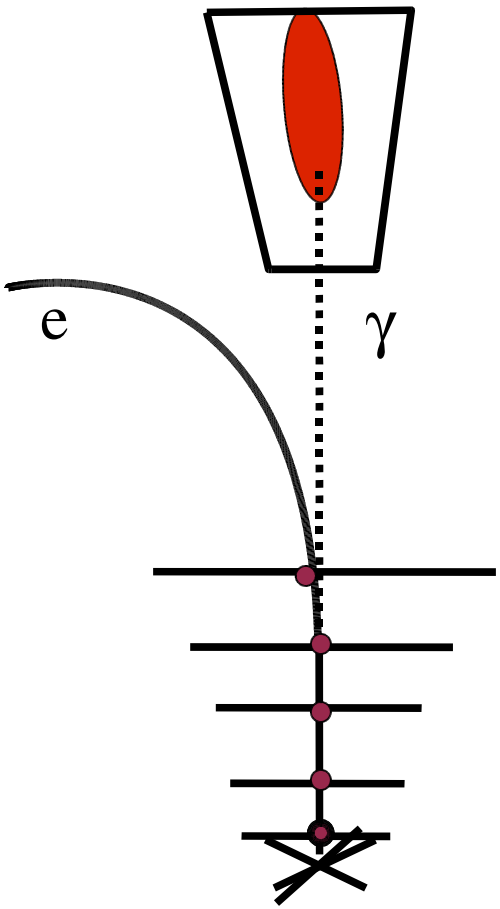
- seed a track from cal cluster and event vertex
- search for hits along the expected arc

Phoenix Tracking

- finding forward electrons
- rejecting electrons (lost due to brem)

Hits on a Road

- rejecting electrons (lost due to tracking eff)



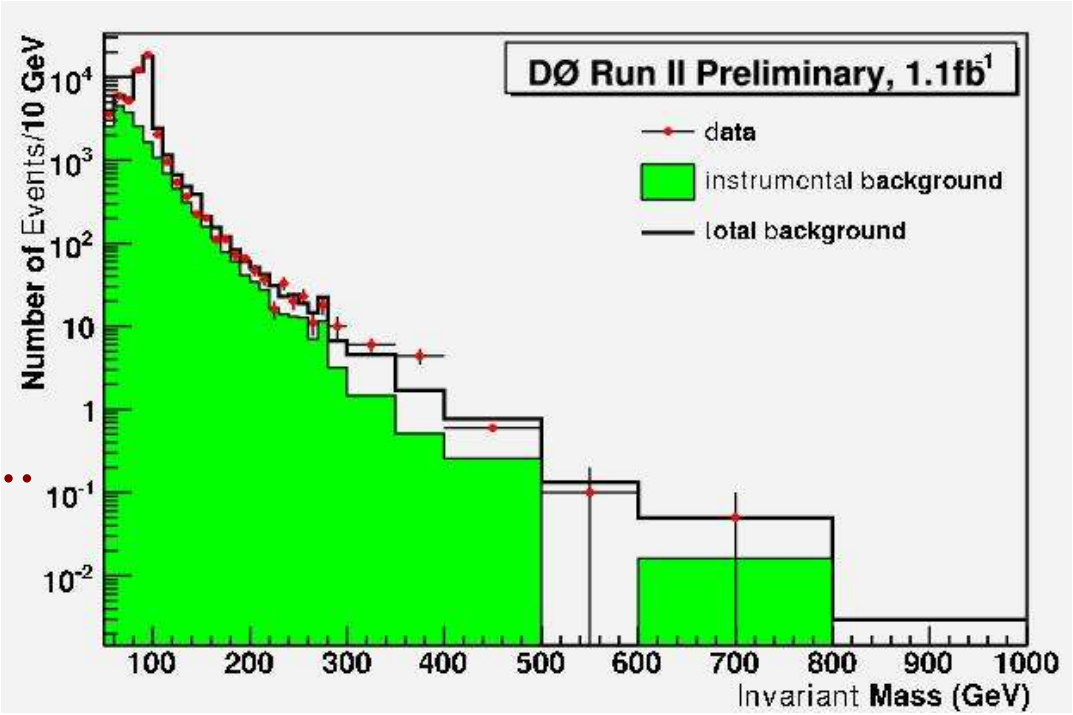
R-S Graviton Search

Model

- Randall-Sundrum Gravitons
- Extra dimension has warped metric - suppresses gravity
- S-channel Graviton couples with k/Mpl, yields e^+e^-,$\mu^+\mu^-$,$\gamma\gamma$,... peaks at high-mass

Analysis

- 1.1 fb^{-1}
- 2 central EM objects ($|\eta|<1.1$)
- Et>25 GeV
- allows electrons or photons (better total acceptance)

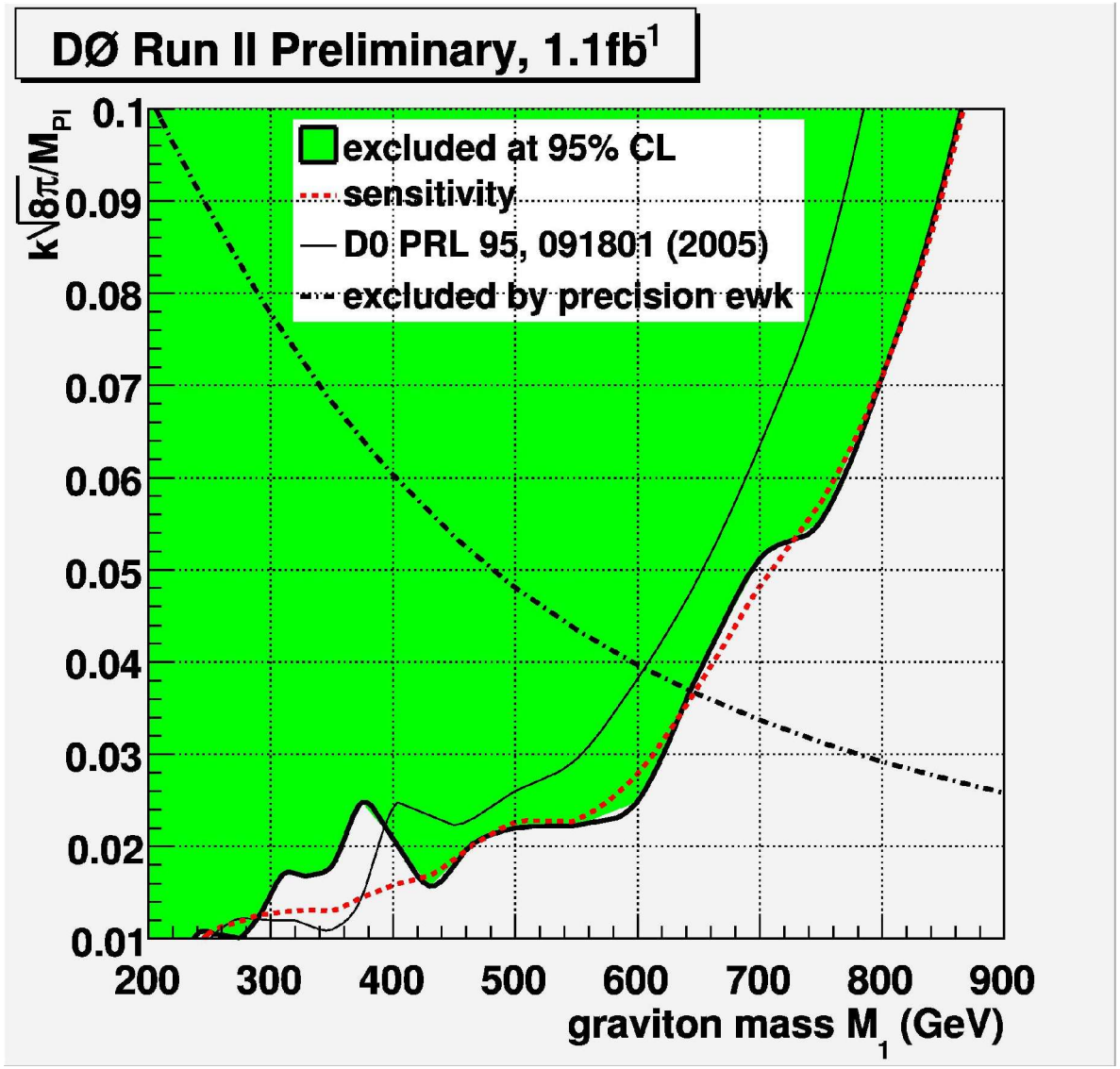


- this search would be sensitive to any narrow peak from dielectrons and/or diphotons

R-S Graviton Limits

Backgrounds
- D.Y. electron and diphotons from Pythia
- shape of fakes from almost-EM objects
- normalize in Z region

Results
- sliding mass window
- k-factor 1.34
- M>865 GeV for k/M=0.1



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

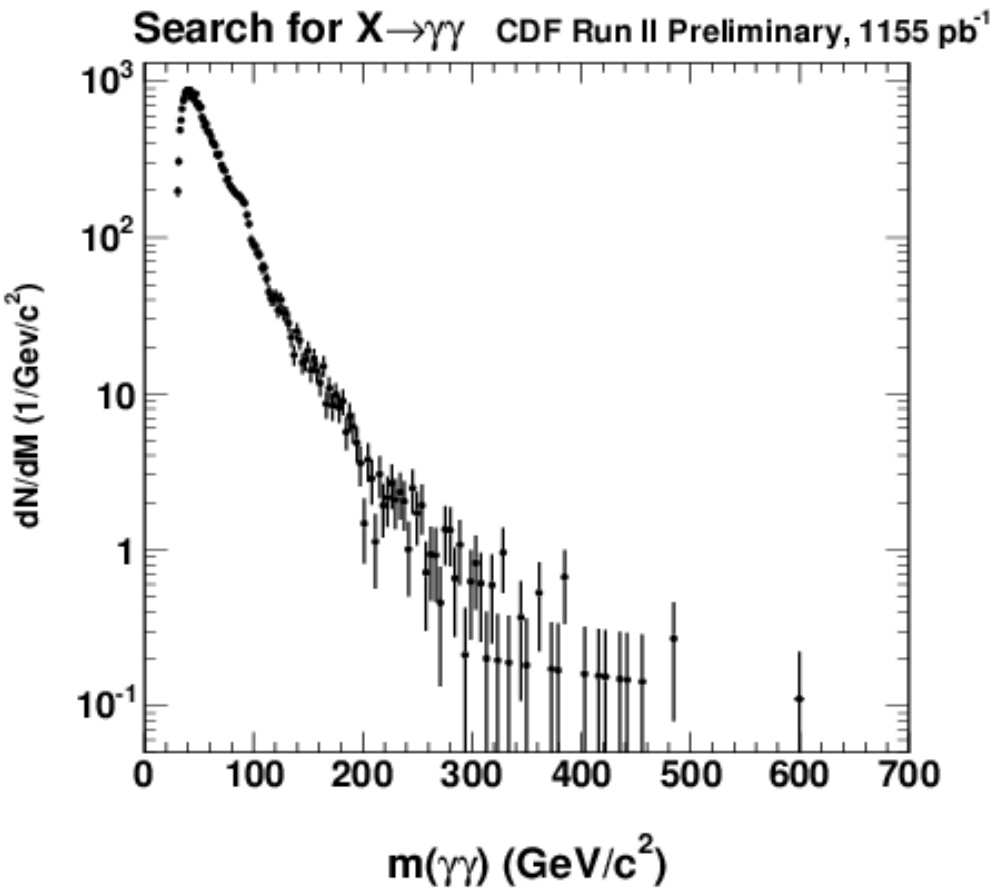
MEt search adds anti-cosmic cuts:

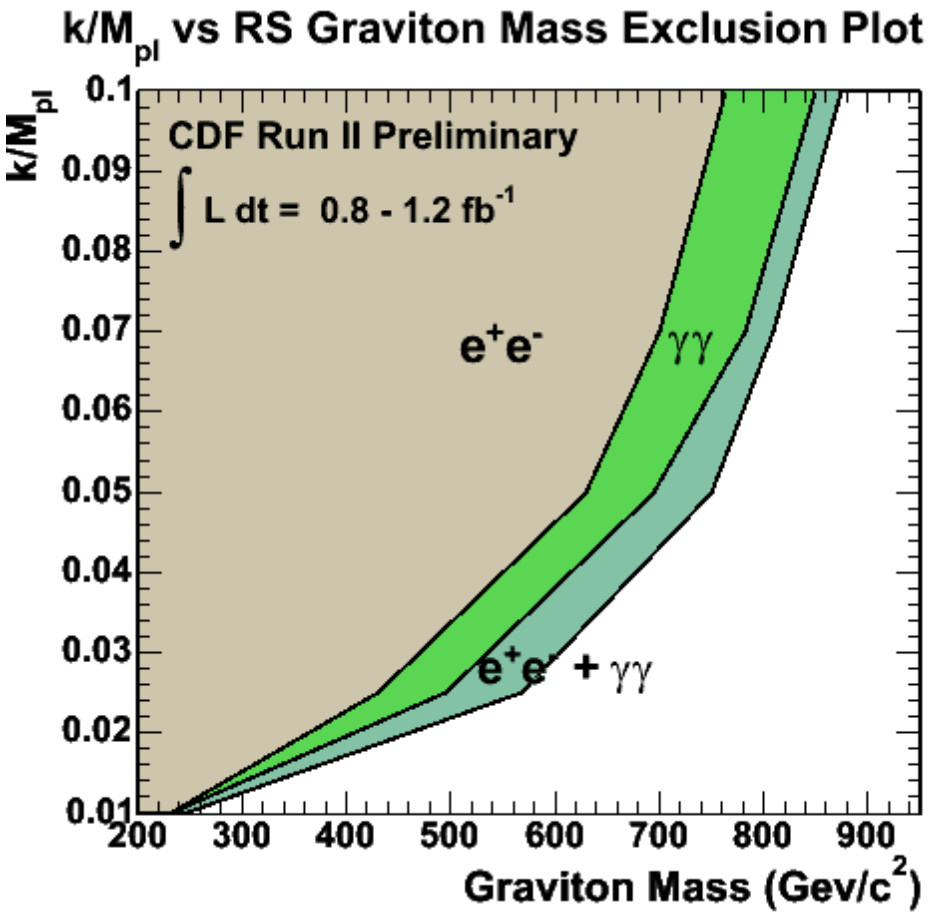
EM TDC times (when available), jet topology, unattached muon stubs

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

Search for Diphoton Peaks

- 2 central-central or central-forward photons
- Fit spectra to DiPhox and exponentials
- for k/M_{pl}=0.1, M(G)>850 GeV
- combined with e^+e^- RS search result: M(G)>875 GeV

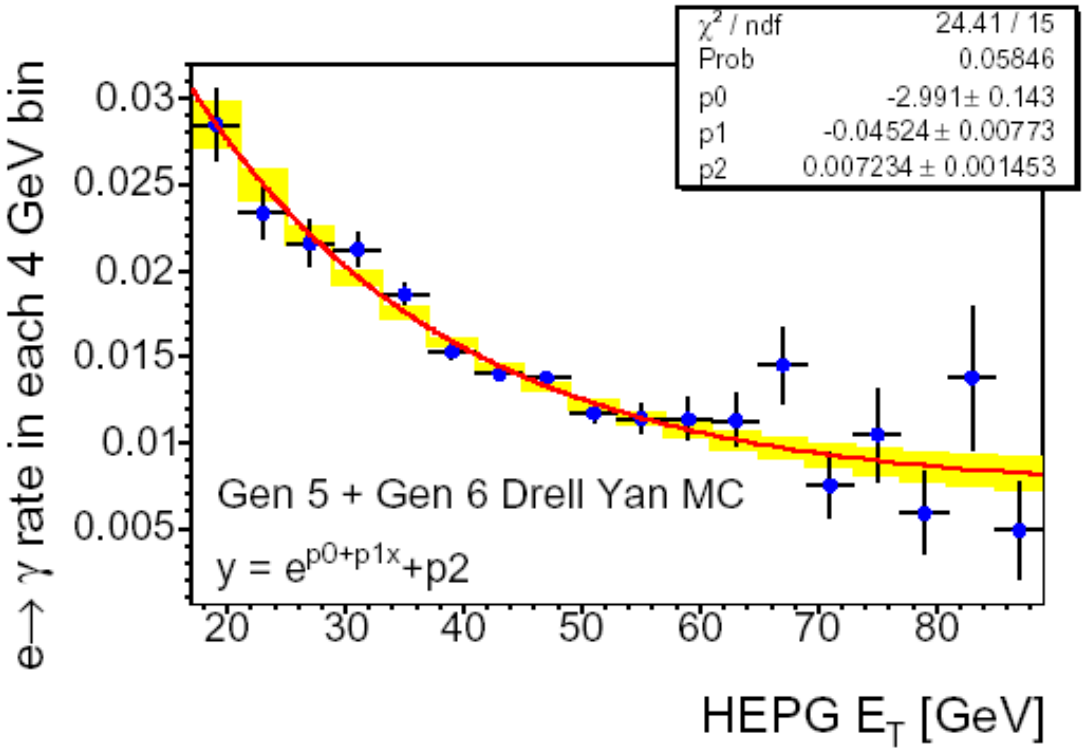




Fake Rate Technique

e →γ fake rate

- Compare:
  - Z peak in ee
  - Z peak in eγ
- take Et dependence from Monte Carlo



GMSB Diphoton and Met

Model

- GMSB decays of $\chi^0_1 \rightarrow \gamma G$
- pair production: $\gamma\gamma$MEtX

Sample

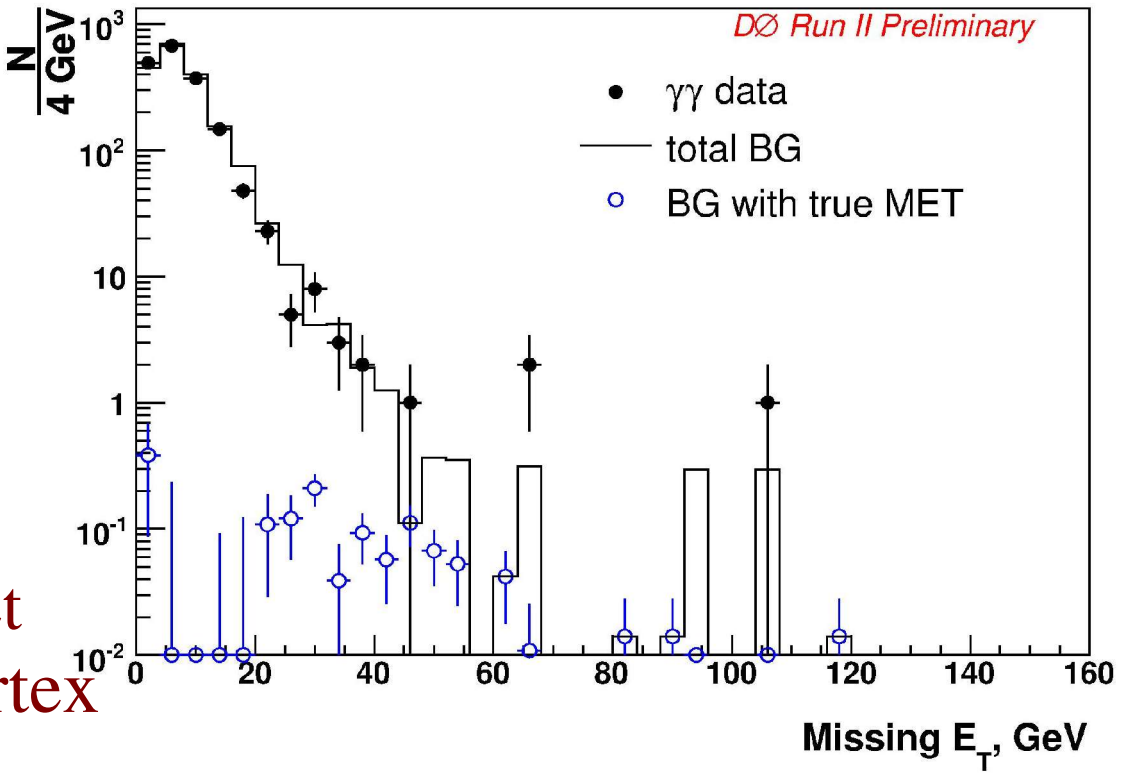
- 760 pb^{-1}
- 2 photons, Et>25, $|\eta|<1.1$

Remove fake MEt

- MEt not opposite the largest jet
- photon preshwr points to vertex

Background from jets

- Two loose photons sample
- Normalize to low MEt



Background from W→eν

- Identify eγ MEt sample
- Scale by prob for e to fake γ

GMSB Diphoton and Met

Results

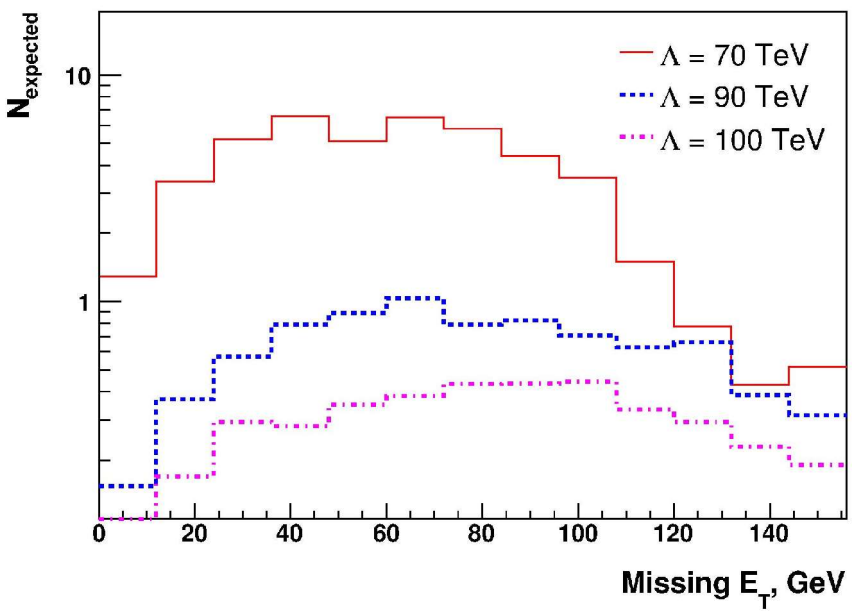
- MEt>45 GeV signal region

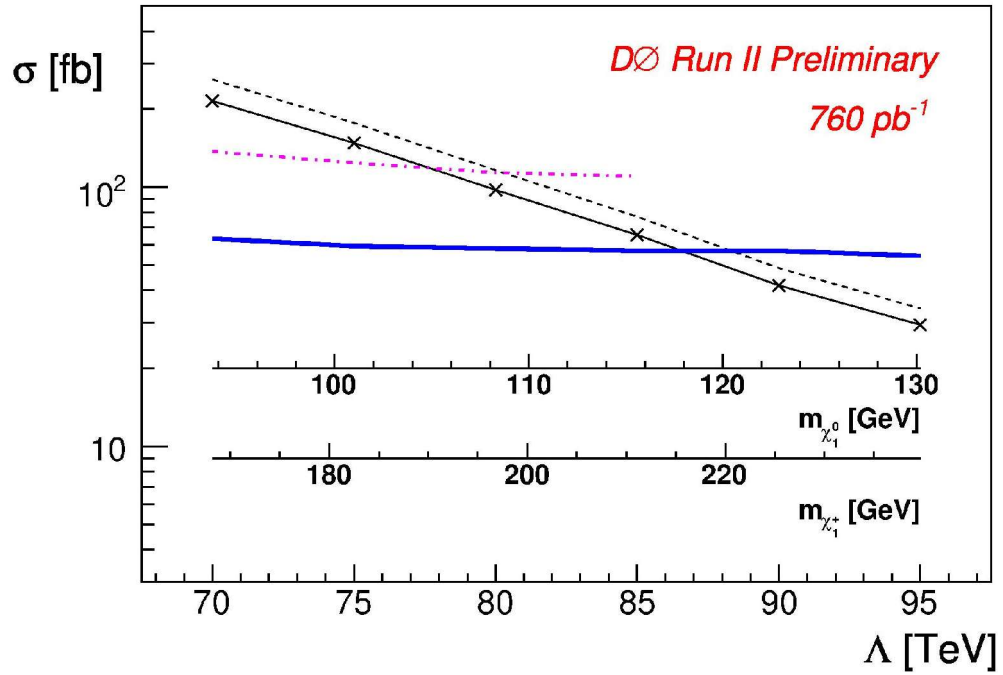
QCD 1.8 ± 0.7

Wγ 0.28 ± 0.06

2.1 ± 0.7

Observed 4





Model Limit

- Snowmass Slope SPS 8
- $\chi^0_2\chi^\pm_1$ and $\chi^\pm_1\chi^\pm_1$ production
- K-factor ~1.2
- Limit: $M(\chi^\pm_1)$>220 GeV

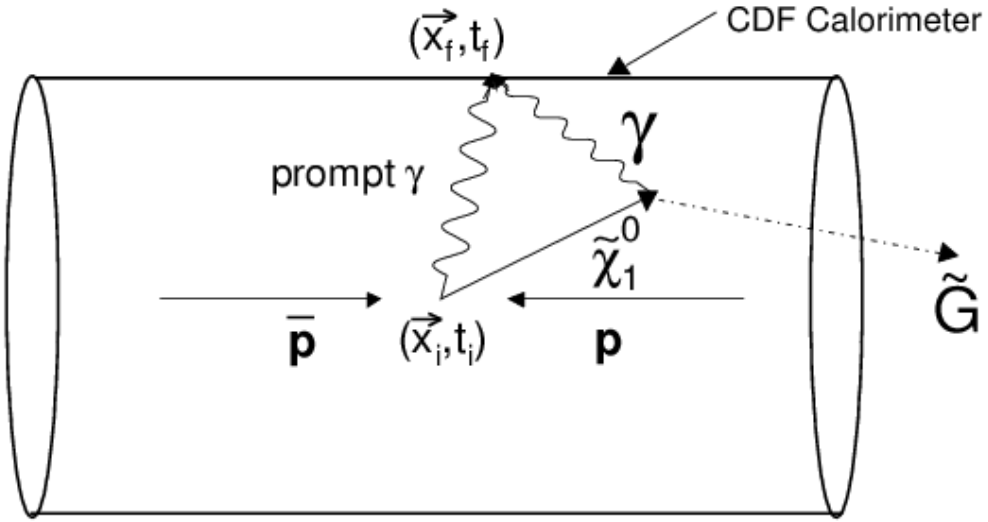
Delayed Photon Search

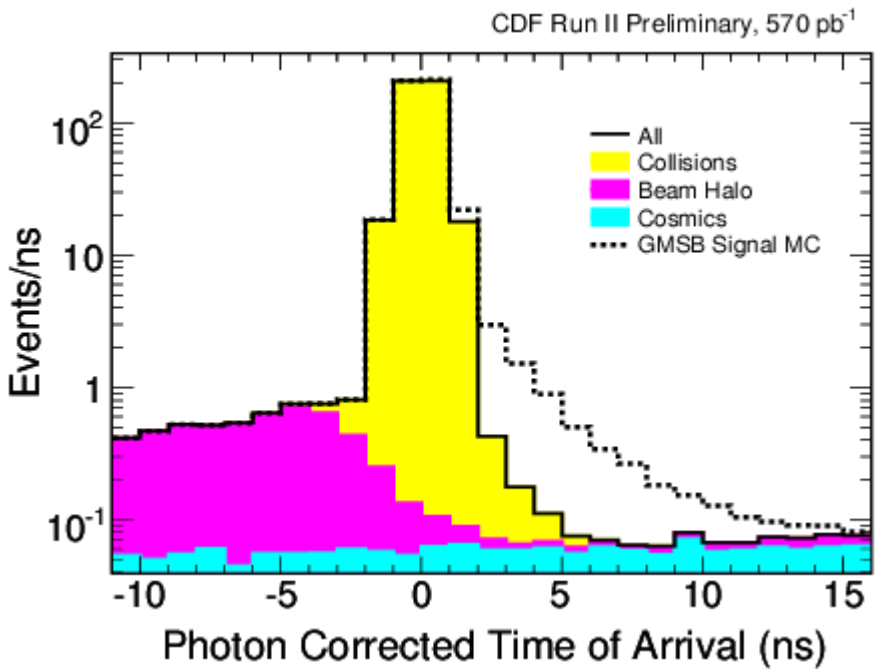
Model

- GMSB decays of $\chi^0_1 \rightarrow \gamma G$ can occur with finite lifetime

Technique

- measurement (σ=0.6ns) of arrival time of photons in EM calorimeter





Sample

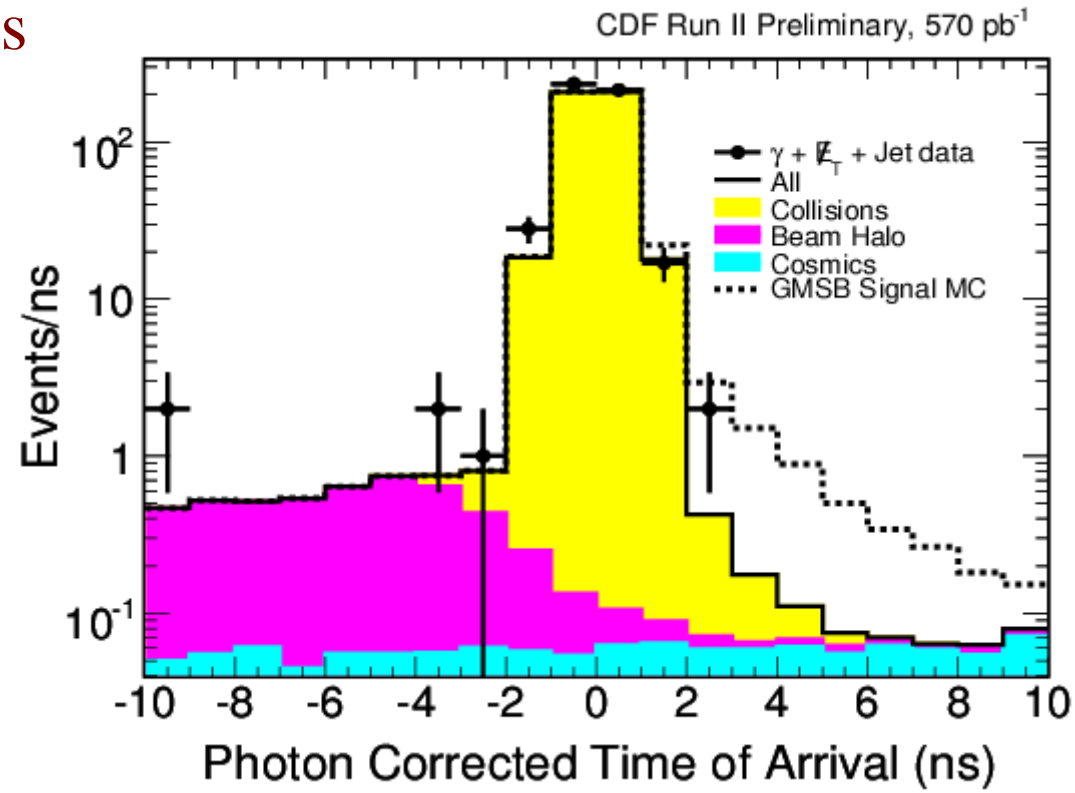
- γ Et>35 GeV, MEt> 40 GeV and jet> 35 GeV, 570 pb^{-1}

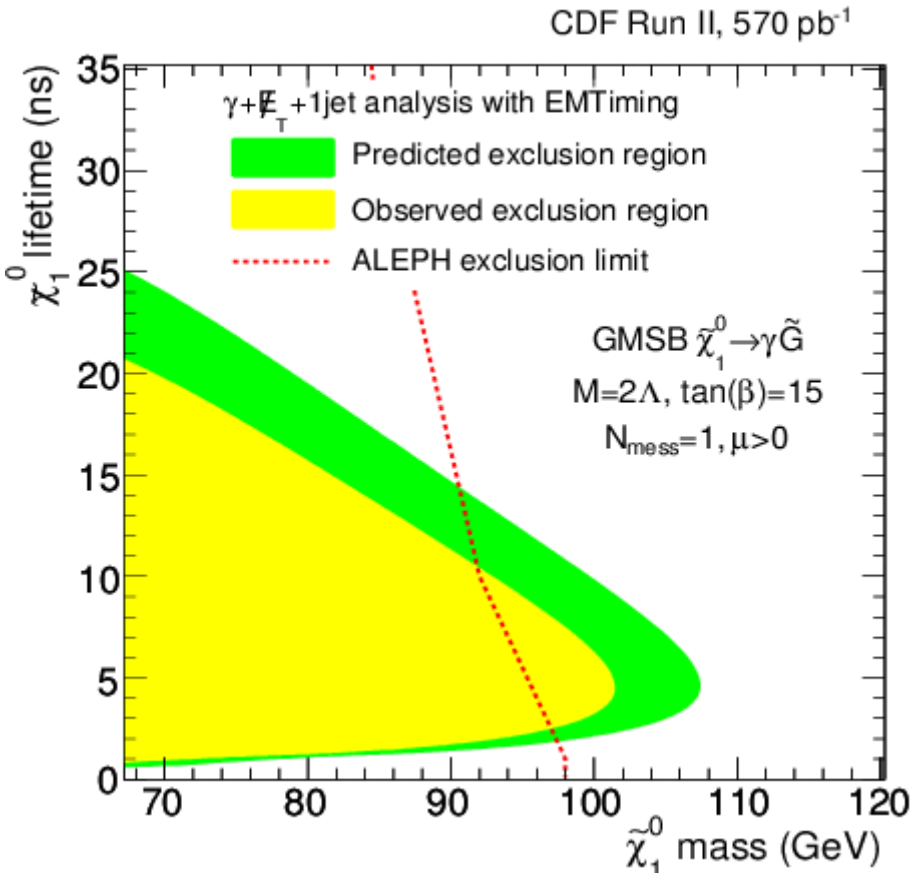
Backgrounds

- prompt
- cosmics causing EM clusters
- halo muons causing EM clusters

Delayed Photon Search

- Arrival time of photons in 2-10ns
- 2 observed, 1.3 ± 0.7 expected
0.71 SM, 0.07 BH, 0.46 cosmics





- Limits in the lifetime-mass plane

Some Photon Models

SUSY

$\chi^0_1 \to \gamma$ G	$\gamma\gamma$ MEt, displaced γX, $\gamma\gamma$ jMEt, eγMEt, $\mu\gamma$MEt γbMEt,
$\chi^0_2 \to \gamma\chi^0_1$	γbjMEt, γbcMEt, γjjMEt, γeeMEt, $\gamma\mu\mu$MEt, $\gamma\gamma$eeMEt, $\gamma\gamma\mu\mu$MEt, γ Met, jjγMEt

Technicolor

$\omega_T, \rho_{T\pi T} \to \gamma\, \pi_T$	γbb, γjj, γtt, $\gamma\gamma\gamma$, ee$\gamma\gamma$,
$\pi_T \to \gamma\gamma$	$\mu\mu\gamma\gamma$, ee$\gamma\gamma$ Met, $\mu\mu\gamma\gamma$ Met

Compositness

$X^* \to \gamma X$	eeγ, ee$\gamma\gamma$, $\mu\mu\gamma$, $\mu\mu\gamma\gamma$, jjγ, bbγ, jj$\gamma\gamma$, bb$\gamma\gamma$

LED

$G \to \gamma\gamma$	($\gamma\gamma$), $\gamma\gamma$, γ Met

Higgs

$H \to \gamma\gamma$, $A \to \gamma\gamma$	$\gamma\gamma$, eeγ, $\mu\mu\gamma$, e$\nu\gamma\gamma$, $\mu\nu\gamma\gamma$, jj$\gamma\gamma$, $\gamma\gamma\gamma\gamma$

4th gen

$b' \to \gamma b$,	$\gamma\gamma$bb, eeγbb, $\mu\mu\gamma$bb, jj$\gamma\gamma$bb

May be more efficient for experimentalists to survey final states with variations of nominal cuts...

Search in Diphotons and Met

Sample

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

Remove fake MEt

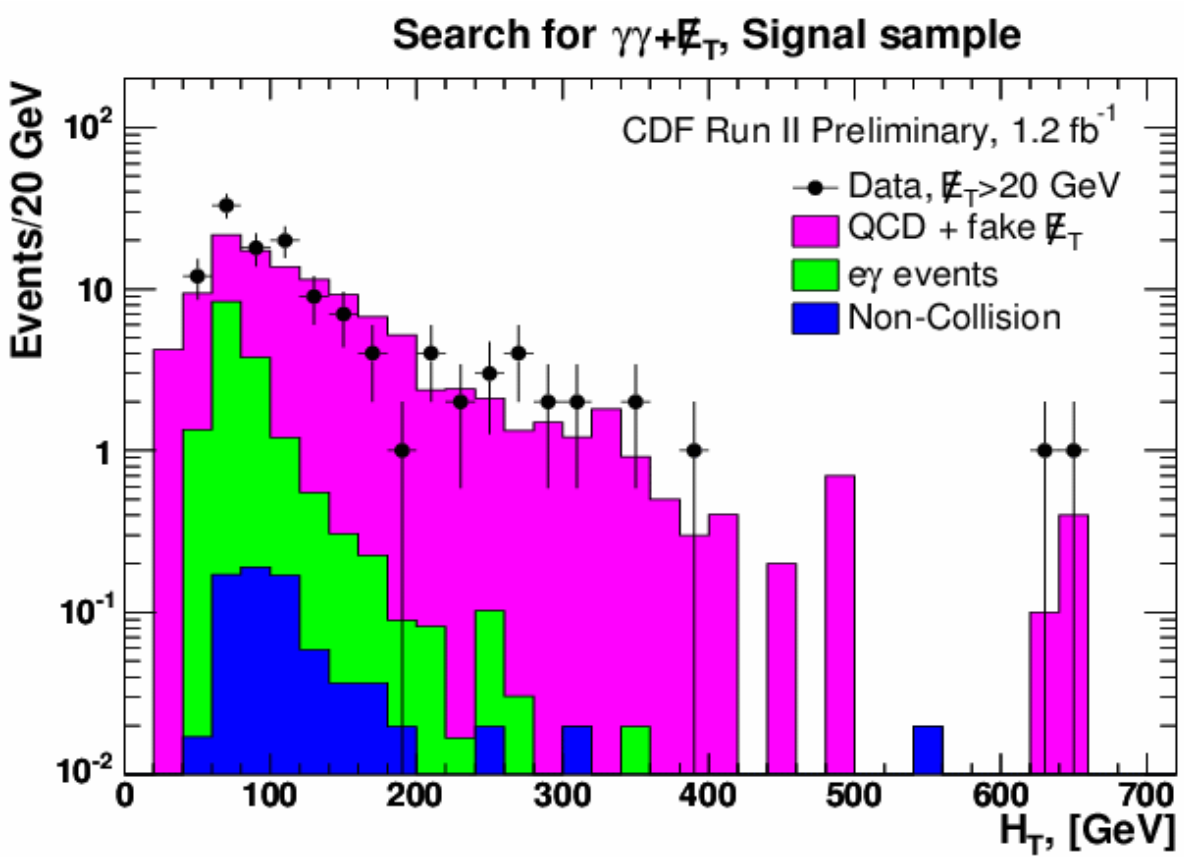
- remove jets along MEt
- use lowest MEt vertex

Remove Ewk

- $W \rightarrow e \rightarrow \gamma$ by brem rejected by Phoenix

Remove non-collision

- EM timing
- no extra muon stubs



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

Search in Diphotons and Met

QCD background

- Shapes modeled from jet control samples

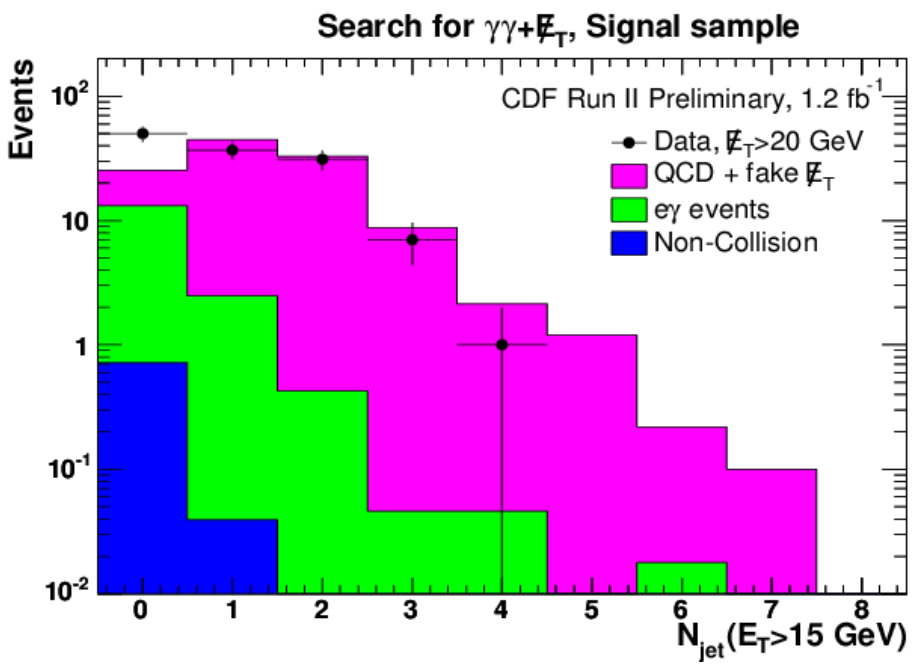
Ewk background

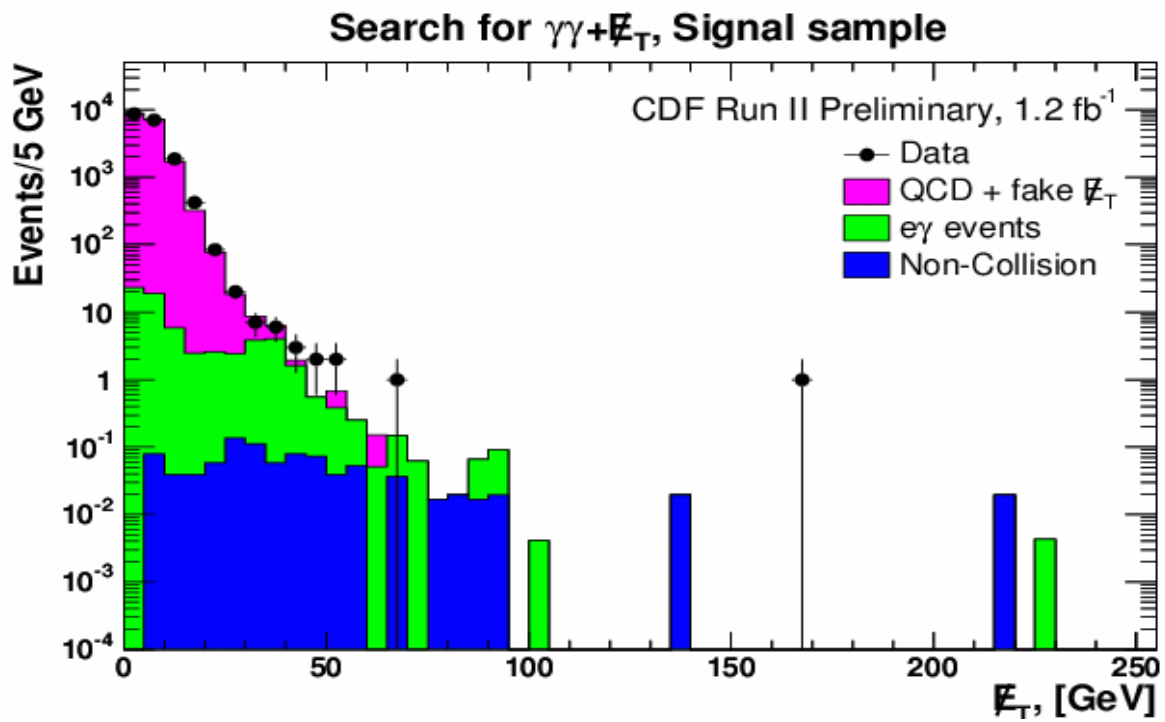
- e+γ sample times e→γ fake rate

Non-Collision background

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

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

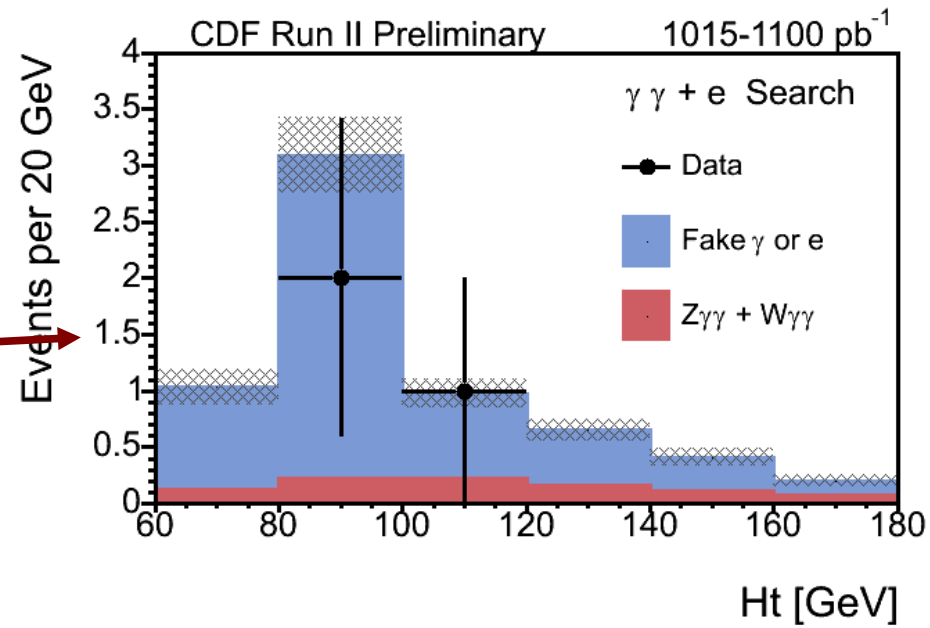




Search for Diphotons and Leptons

Sample

- Same diphotons
- 1.0 to 1.1fb^{-1}
- central/forward e>20 GeV
or central/forward μ>20 GeV



Backgrounds:

- Ewk $l\gamma\gamma$ (MadGraph)
A denominator
times fake rate for:
- jets faking leptons
- jets faking photons
- electrons faking photons

Before applying Phoenix rejection		
Source	electron	muon
$Z\gamma\gamma$	$0.904 \pm 0.023 \pm 0.083$	$0.552 \pm 0.017 \pm 0.050$
$W\gamma\gamma$	$0.170 \pm 0.012 \pm 0.016$	$0.086 \pm 0.008 \pm 0.008$
Fake $l+\gamma\gamma$	$0.131 \pm 0.004 \pm 0.053$	$0.004 \pm 0.003 \pm 0.002$
$l\gamma + \text{jet} \rightarrow \gamma$	$0.475 \pm 0.025 \pm 0.312$	$0.133 \pm 0.013 \pm 0.090$
$l\gamma + e \rightarrow \gamma$	$5.140 \pm 0.340 \pm 0.584$	$0.017 \pm 0.017 \pm 0.002$
Total	6.82 ± 0.75	0.79 ± 0.11
Data	3	0

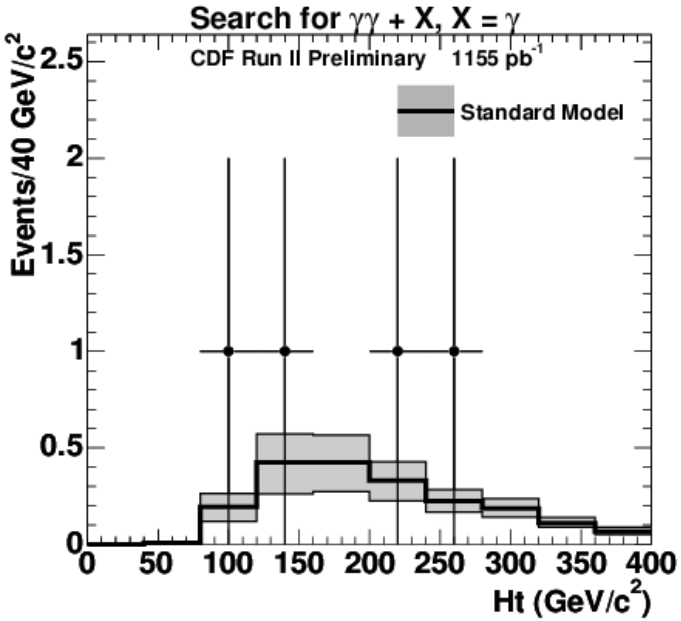
Search for Triphotons

Sample

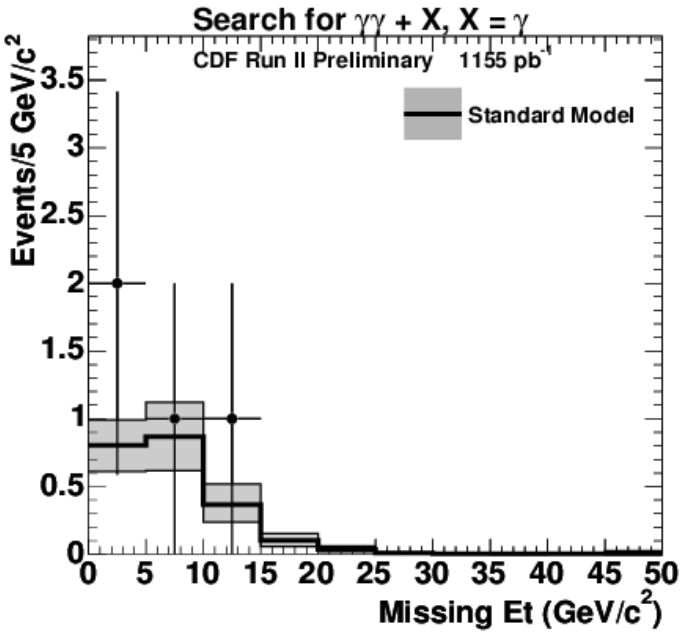
- 1155 pb^{-1}
- Start with same diphotons
- add a third central photon with Et>13 GeV

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

Higgs Search in Triphotons

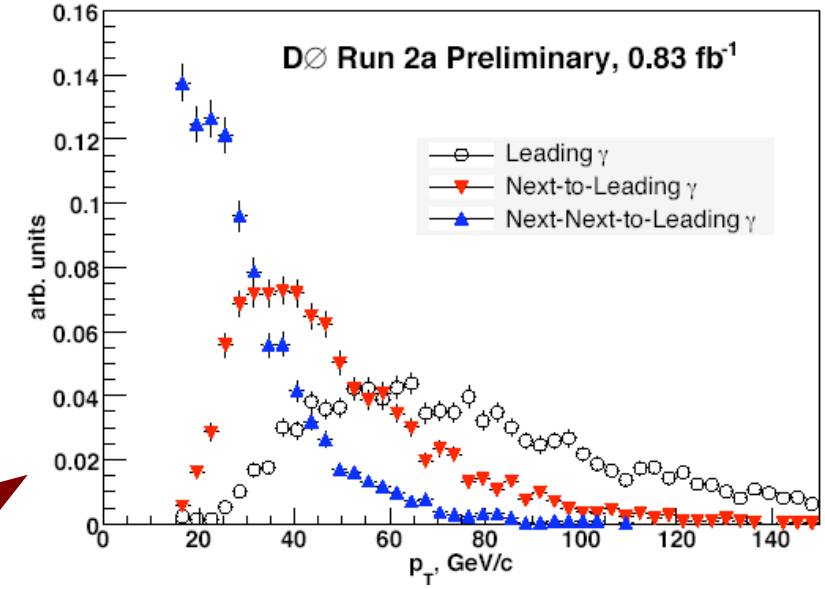
New!

Model

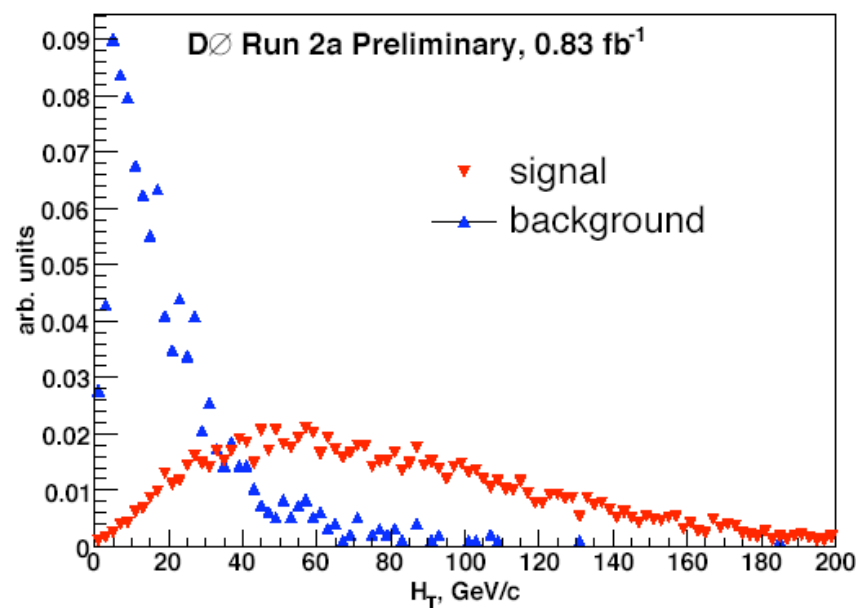
- 2 Higgs doublets
- Fermiophobic, $h \rightarrow \gamma\gamma$
- hVV coupling suppressed
- $hH^{\pm} \rightarrow h(hW^{\pm}) \rightarrow (\gamma\gamma)(\gamma\gamma)X$
- Search for $\gamma\gamma\gamma X$

Data

- 3 central photons
- Et > 30, 20, 15 GeV
- 830 pb^{-1}
- Total Pt of the 3γ > 25 GeV



Distribution of 3-body transverse momentum



Triphoton Background Technique

Define fake rate/efficiency

ε_b = prob $j \rightarrow \gamma$ = 0.043±0.004

ε_s = prob $\gamma \rightarrow \gamma$ = 0.75±0.05

Define matrices:

- True **n** = ($n_{\gamma\gamma\gamma}$ $n_{\gamma\gamma j}$ $n_{\gamma jj}$ n_{jjj})
- Meas **N** = ($N_{\gamma\gamma\gamma}$ $N_{\gamma\gamma j}$ $N_{\gamma jj}$ N_{jjj})
  (here "j" is a EM-like object)
- matrix eq. **n = E N**

$$\mathbf{E} = \begin{pmatrix} \varepsilon_s^3 & \varepsilon_s^2\varepsilon_b & \varepsilon_s\varepsilon_b^2 & \varepsilon_b^3 \\ 3(1-\varepsilon_s)\varepsilon_s^2 & \varepsilon_s^2(1-\varepsilon_b)+2(1-\varepsilon_s)\varepsilon_s\varepsilon_b & \varepsilon_b^2(1-\varepsilon_s)+2(1-\varepsilon_b)\varepsilon_b\varepsilon_s & 3(1-\varepsilon_b)\varepsilon_b^2 \\ 3(1-\varepsilon_s)^2\varepsilon_s & \varepsilon_b(1-\varepsilon_s)^2+2(1-\varepsilon_s)(1-\varepsilon_b)\varepsilon_s & \varepsilon_s(1-\varepsilon_b)^2+2(1-\varepsilon_b)(1-\varepsilon_s)\varepsilon_b & 3(1-\varepsilon_b)^2\varepsilon_b \\ (1-\varepsilon_s)^3 & (1-\varepsilon_s)^2(1-\varepsilon_b) & (1-\varepsilon_s)(1-\varepsilon_b)^2 & (1-\varepsilon_b)^3 \end{pmatrix}$$

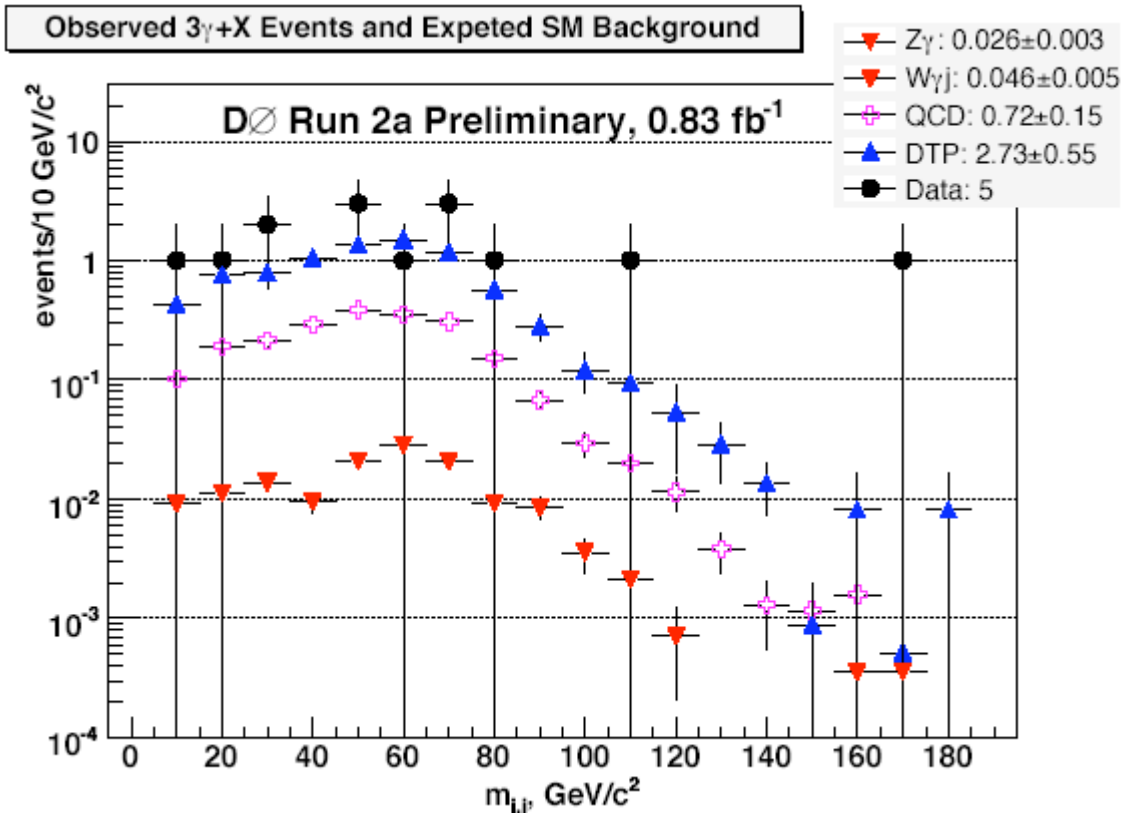
- Invert to solve for true event counts

Higgs Search in Triphotons

Background

- before final Pt(γγγ) cut
- QCD = 0.72 ± 0.15
– Direct γγγ derived from γγ with a similar matrix, and Pythia γγγ/γγ rate: 2.73±0.55
- W/Zγ and γγ is small

- Total: 3.5 ± 0.6
  Observed: 5 events

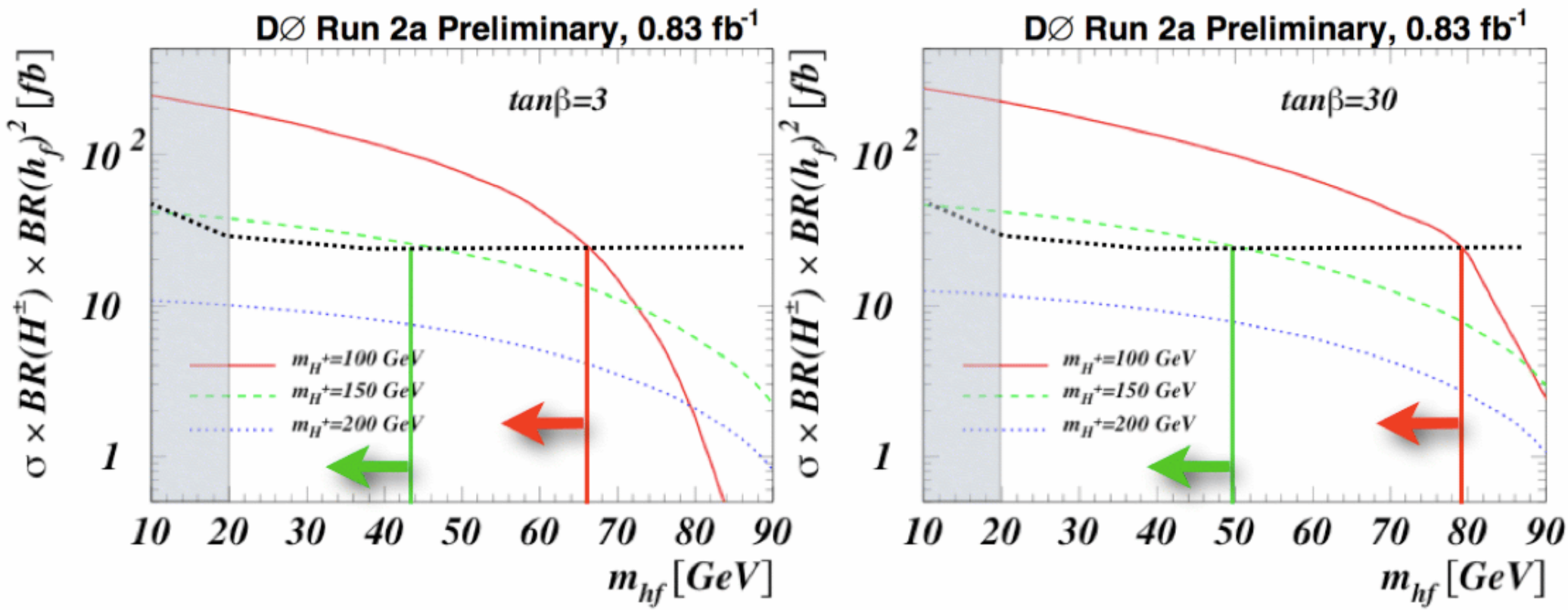


- mass of all pairs

Higgs Search in Triphotons

Limits

- After the final Pt cut: 1.1±0.2 expected, 0 observed
- Higgs mass greater than 44 to 80 GeV, depending on $H^{\pm}$ mass and tanβ



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

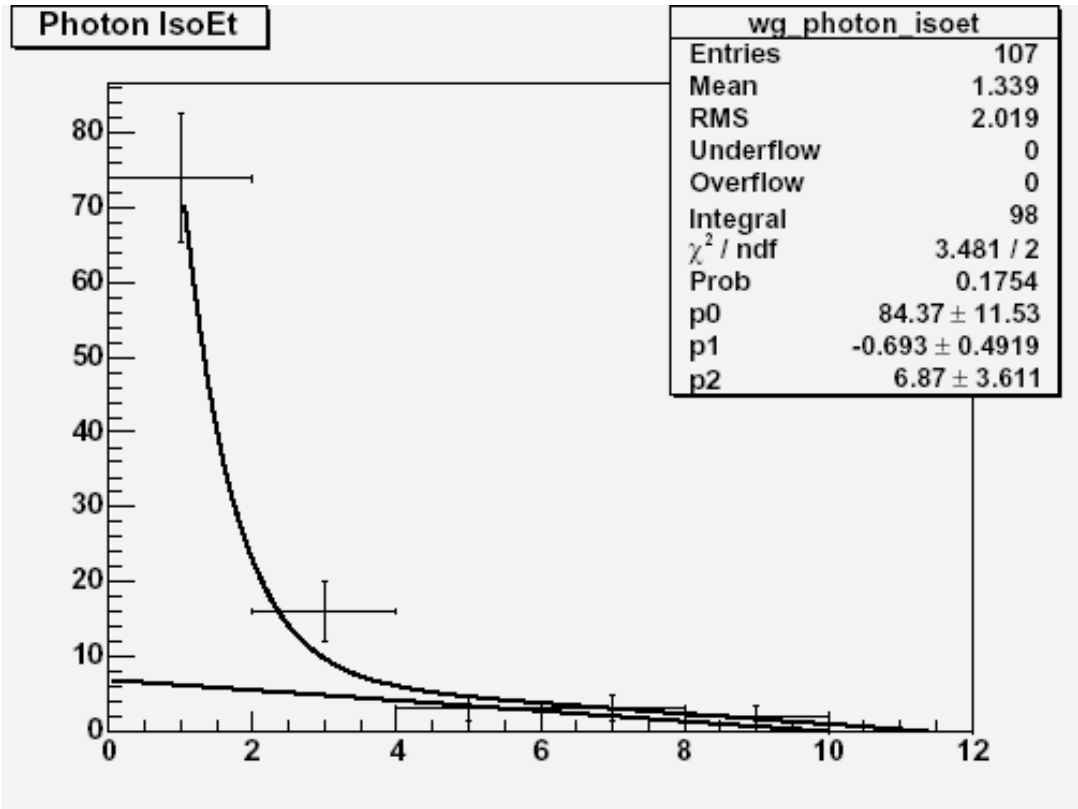
Backgrounds

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

Isolation Technique

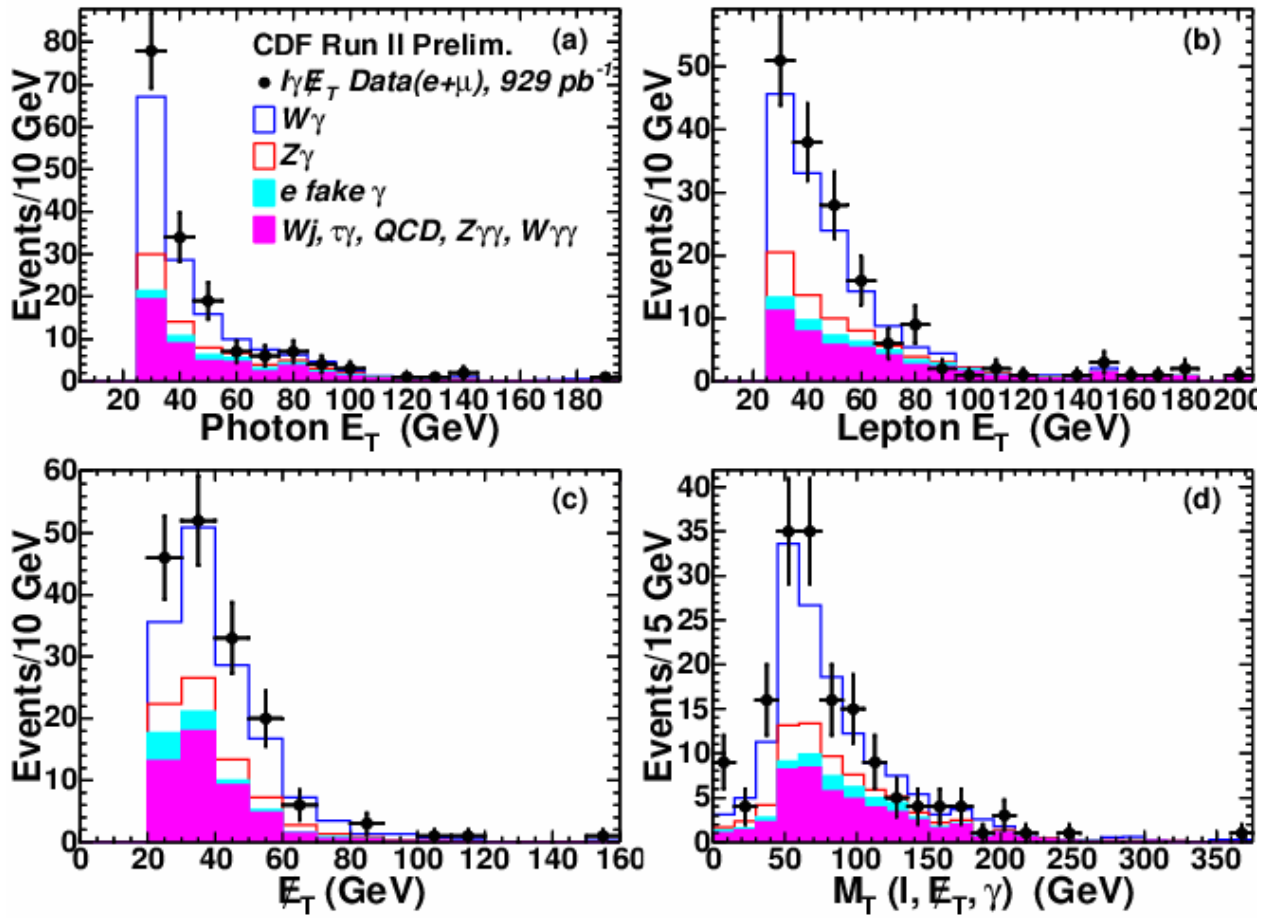
- Find colorimeter isolation Et distribution
1) from $Z \rightarrow e^- e^+$
2) from jets

- Fit candidates distribution to the two shapes



Search for Lepton+Photon+X

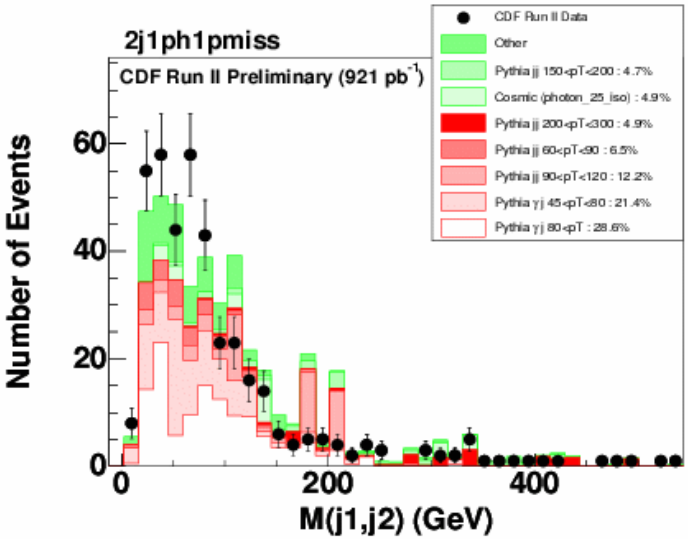
	exp.	obs.
eγMEt	94.2± 8.1	96
μγMEt	53.9± 7.1	67
eeγ	39.0±4.8	53
μμγ	26.0±3.1	21
eμγ	1.0±0.3	0
lγγ	0.5±0.1	0
*ll*γ MEt	0.6±0.1	3

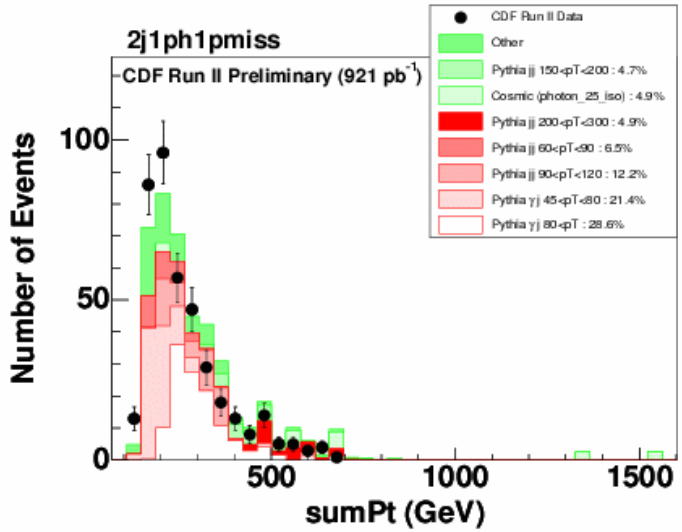


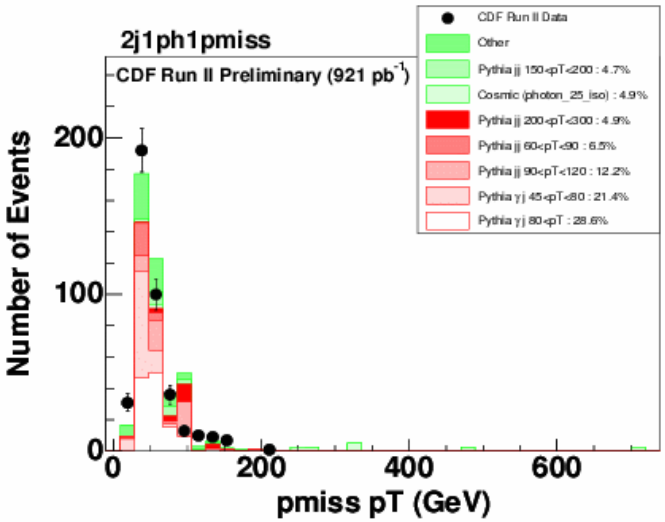
Ultimate Signature-based Search

- 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

Distributions for photon+2jets+MEt:







Last Slide

CDF and DØ have released recently:

$\gamma\gamma$MEt $\gamma\gamma$ mass $\gamma\gamma$ e/μ

lγX $\gamma\gamma\gamma$ delayed photons

Reasonably good coverage of photon signatures

Could use: γb, γjj, $\gamma\tau$, $\gamma\gamma$b, $\gamma\gamma$jj, $\gamma\gamma\tau$, ...

Tevatron photon program is going strong with room for more (techniques too)...