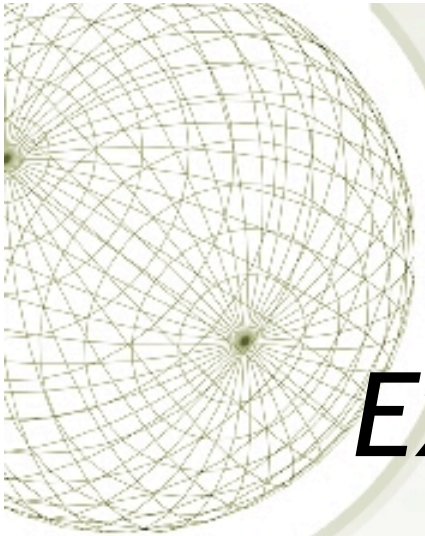
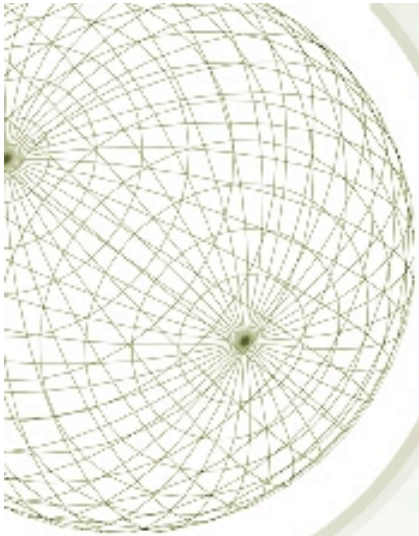


Exotic Photon Searches at CDF

Eunsin Lee
Texas A&M University
for the CDF Collaboration

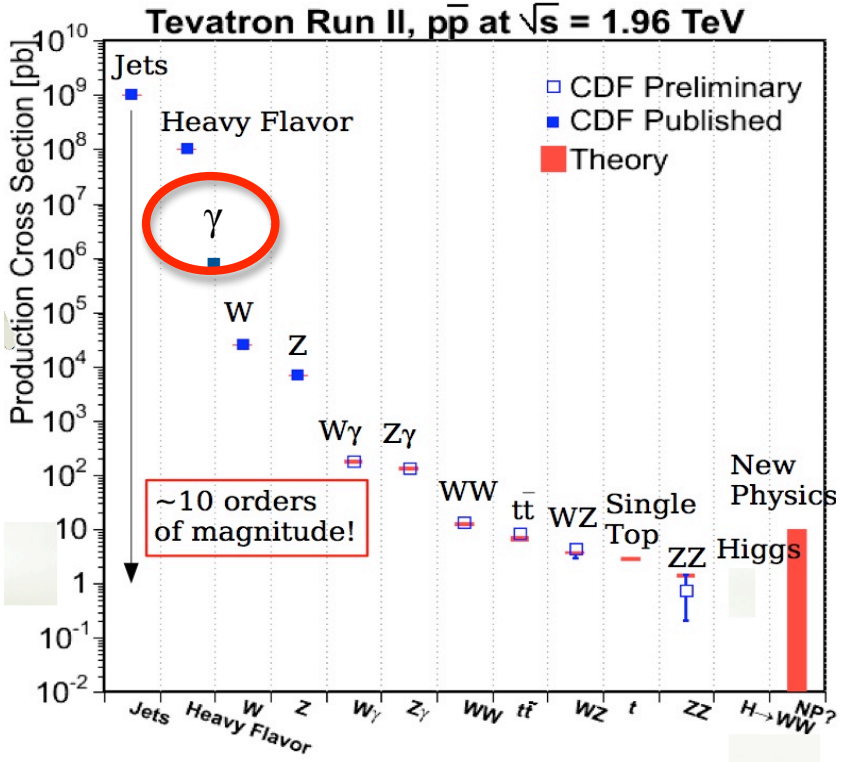
Outline

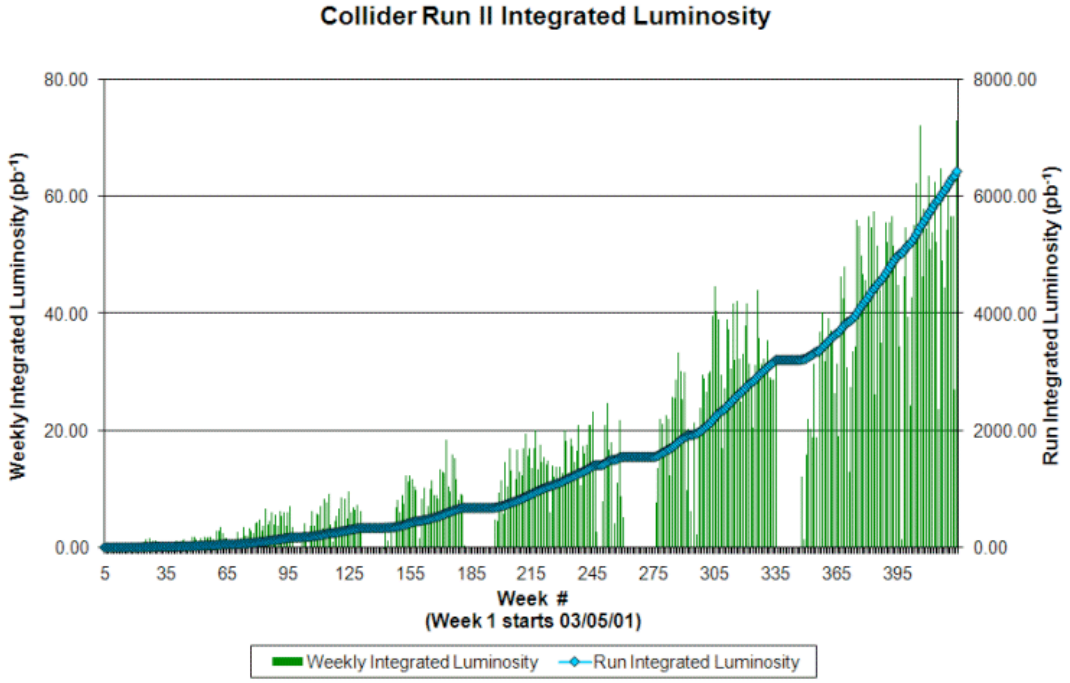
- Introduction
- Search for Anomalous $\gamma\gamma$+X and GMSB limit on $\gamma\gamma$+ME_T
- Search for Anomalous γ+b+j+ME_T
- Search for Fermiophobic Higgs$\rightarrow\gamma\gamma$
- Conclusion



Introduction

Photons at the Tevatron

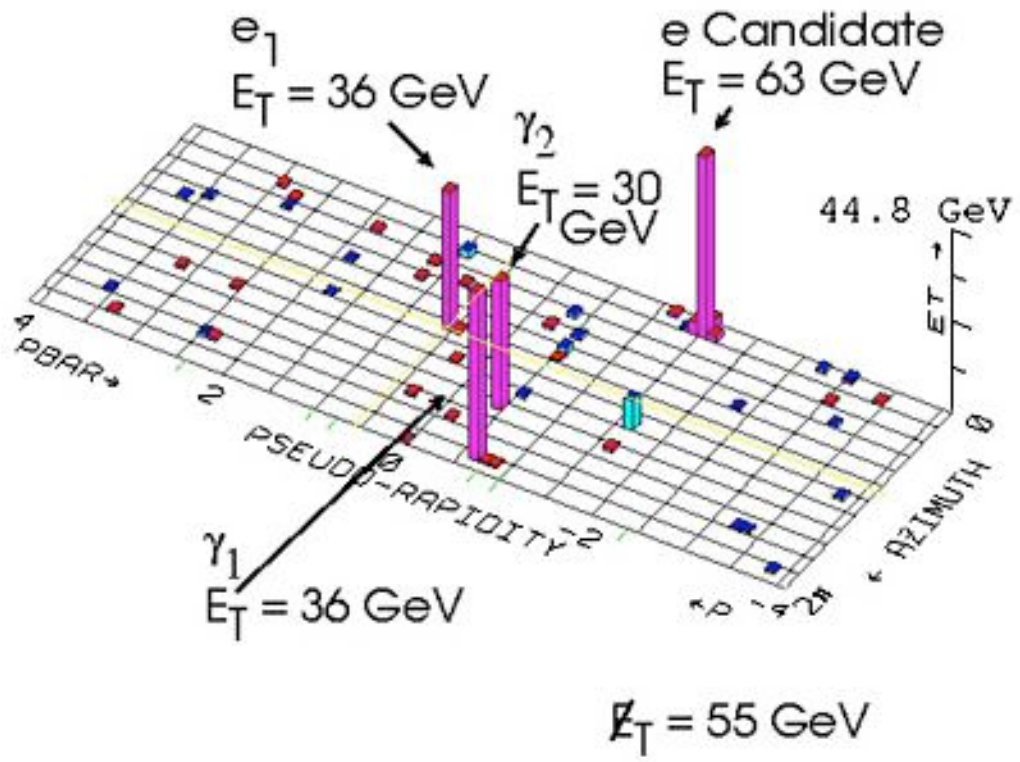




Photons (γ) are 2nd most frequent objects after jets (j)

- ~60 pb^{-1} per week
- ~5.8 fb^{-1} up to now
- Results in this talk based on 1-3 fb^{-1}

Exotic Event at CDF?



- In late 1990's an unusual $ee\gamma\gamma ME_T$ candidate event was observed at CDF in Run I
- Very rare in SM: ~10^{-6} events
- From New Physics?

New Physics with Photons

- SUSY:

  $\gamma\gamma+ME_T$, $\gamma\gamma+ll+ME_T$, $\gamma\gamma+j+ME_T$, $\gamma\gamma+jj+ME_T$, $\gamma\gamma+b+ME_T$, $\gamma+ll+ME_T$, $\gamma+j+ME_T$

- Extra Dimension:

  $\gamma\gamma$, $\gamma+ME_T$, $\gamma\gamma+j's+ME_T$

- Higgs:

  $\gamma\gamma$, $\gamma+ll$, $\gamma\gamma+jj$, $\gamma\gamma+l+ME_T$,, $\gamma+ME_T$, $\gamma+ME_T$

- Technicolor:

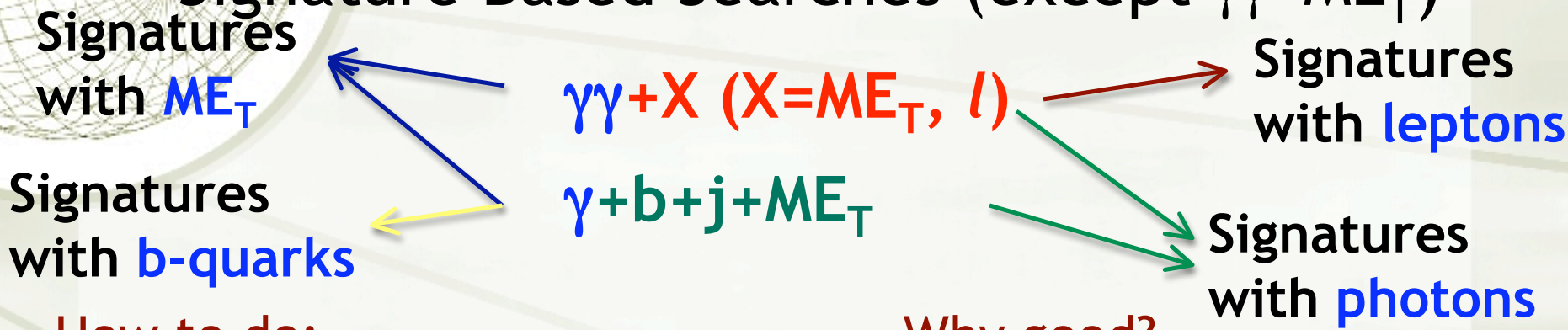
  $\gamma\gamma$, $\gamma+bb$, $\gamma\gamma+ll$, $\gamma+tt$, $\gamma\gamma\gamma$, $\gamma\gamma+ll+ME_T$

No Deficit of Models, but it's too many

⇒Signature Based Search

Signature Based Searches

- First two of three results shown here are Signature Based Searches (except $\gamma\gamma+ME_T$)

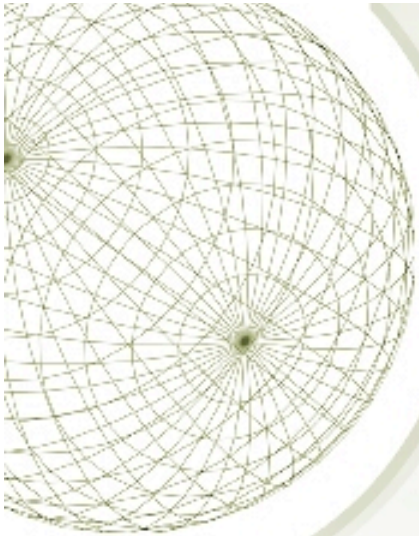


How to do:

- Choose a signature
- Define a nominal selection
- Compute SM backgrounds
- Report event yields and kinematics
- Investigate discrepancies

Why good?

- Many models, but few are obviously more likely than others
- Model limits usually do not provide critical insight
- Save time: cover more signature



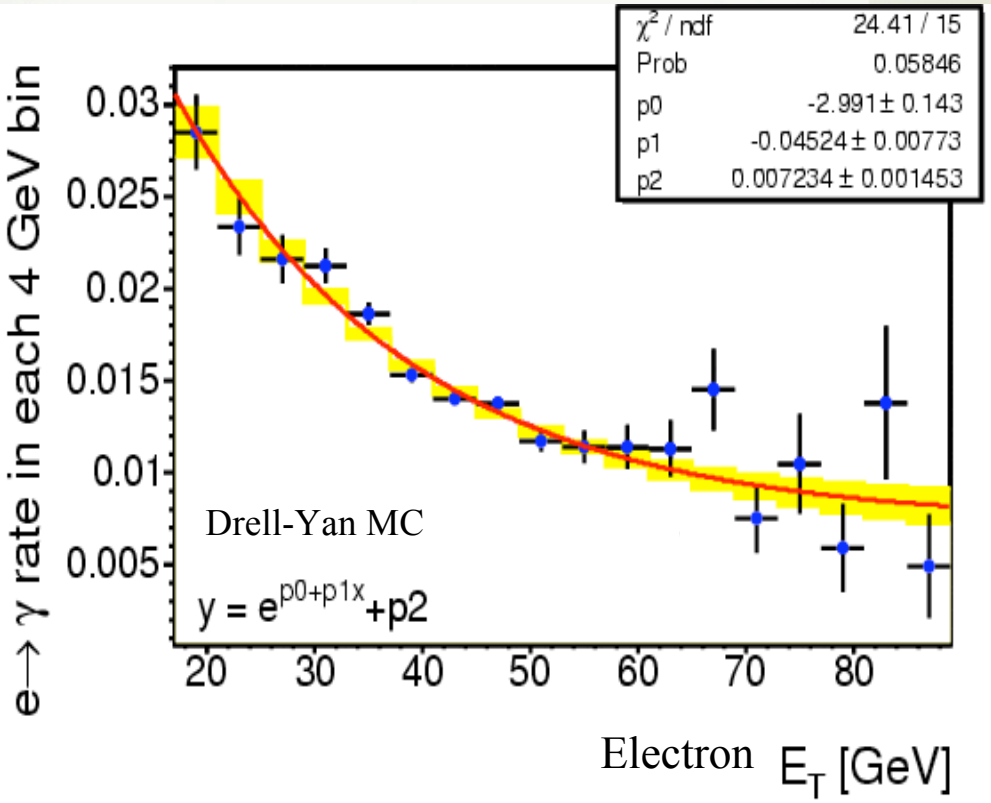
Search for Anomalous $\gamma\gamma$+X
X=e/μ, τ, ME_T

CDF Public Note 9339

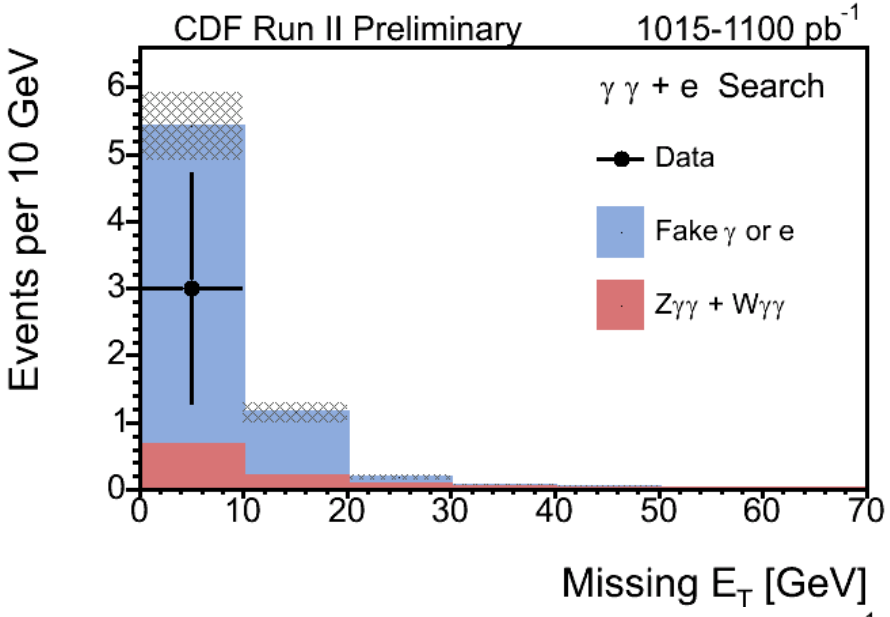
To be submitted to PRD

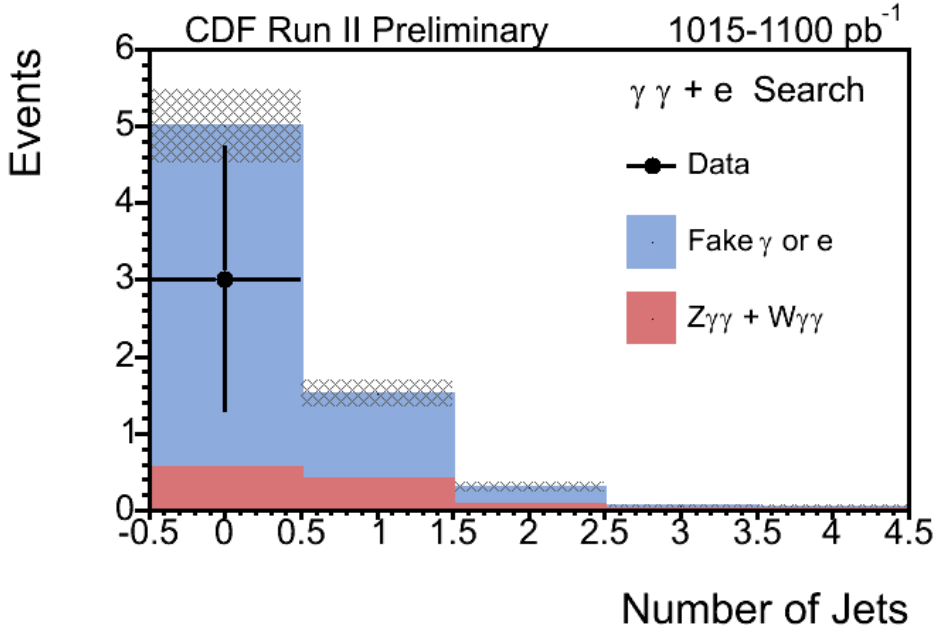
Search for Anomalous $\gamma\gamma$+e/μ

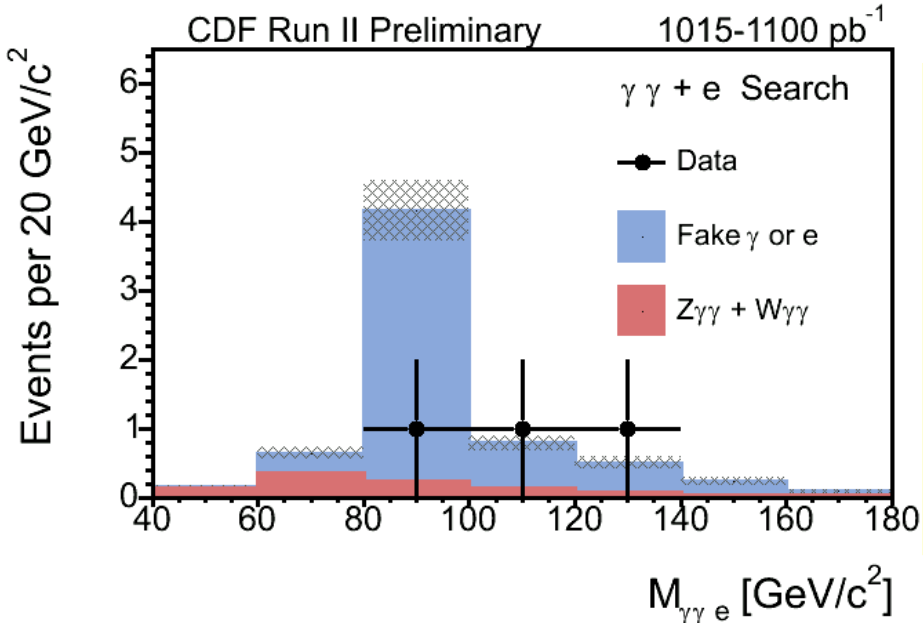
- Event Selection (1 fb^{-1})
  - Two photons: E_T>13 GeV, $|\eta|$<1.1
  - Electron: E_T>20 GeV, central ($|\eta|$<1.0) or forward (1.2<$|\eta|$<2.0)
  - Muon: P_T>20 GeV, $|\eta|$<1.0
- Backgrounds
  - "Physics": W$\gamma\gamma$ and Z$\gamma\gamma$
  - "Instrumental":Wγ/Zγ+(e→γ_{fake}) ⇒ e→γ fake rate from Z
    $\gamma\gamma$+l_{fake}, γ+l+(j→γ_{fake})



$\gamma\gamma$+e/μ kinematics



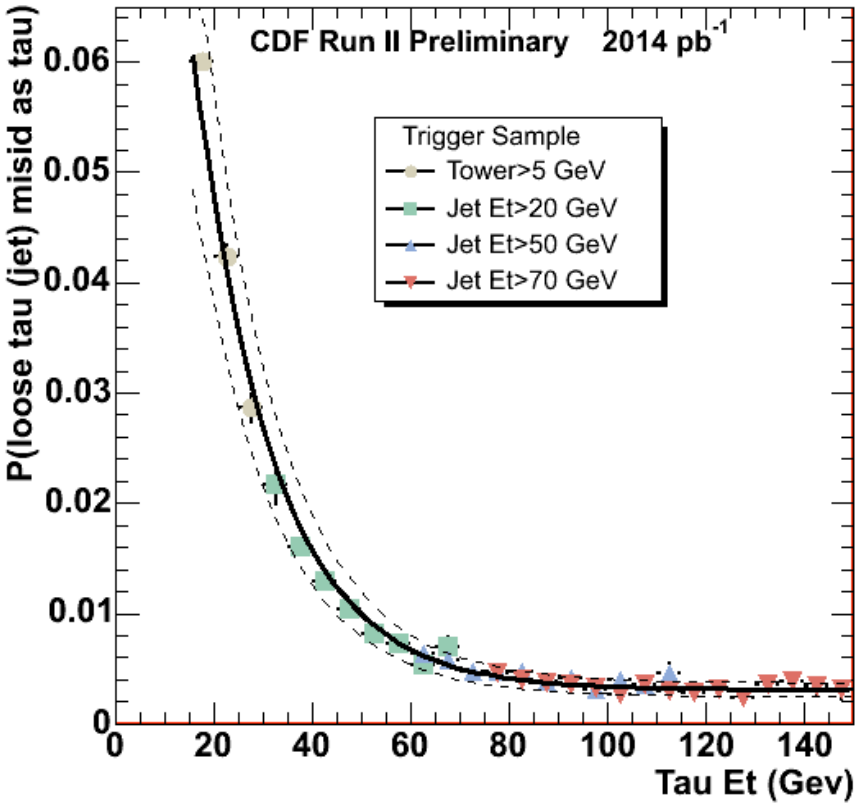




	γγ+e	γγ+μ
Data, 1 fb^{-1}	3	0
Total Bckg	6.82±0.75	0.79±0.11
"Physics"	16%	81%
γ+l+(e→γ_{fake})	75%	2%
γ+l+(j→γ_{fake})	7%	16%

Search for Anomalous $\gamma\gamma+\tau$

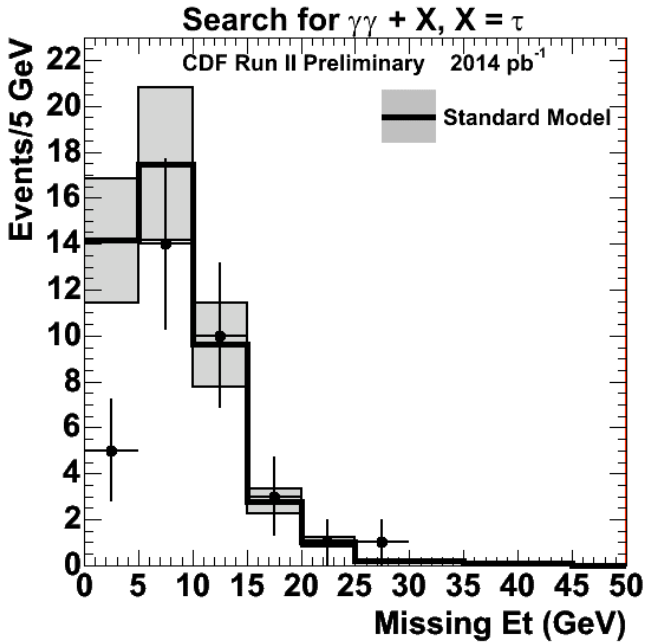
- Event Selection (2 fb^{-1})
  - Two photons: E_T>13 GeV, $|\eta|$<1.1
  - Hadronic tau: E_T>15 GeV, narrow calorimeter cluster, 1 or 3 tracks, isolation cone

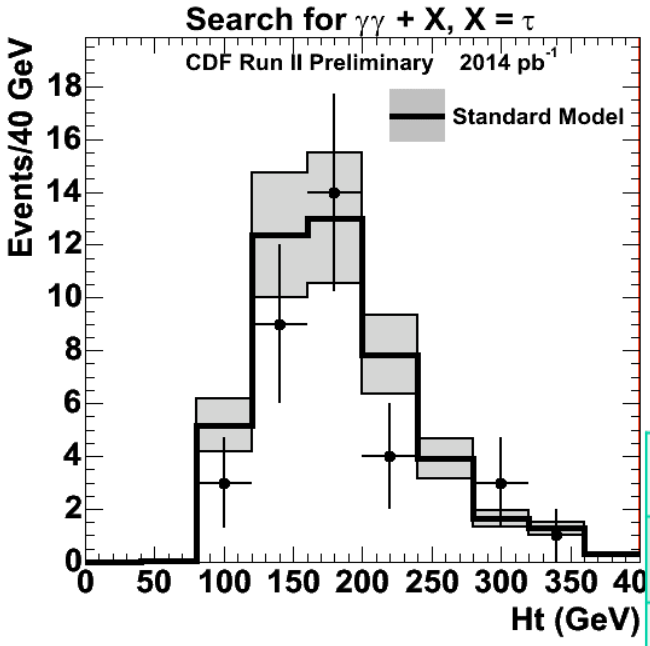


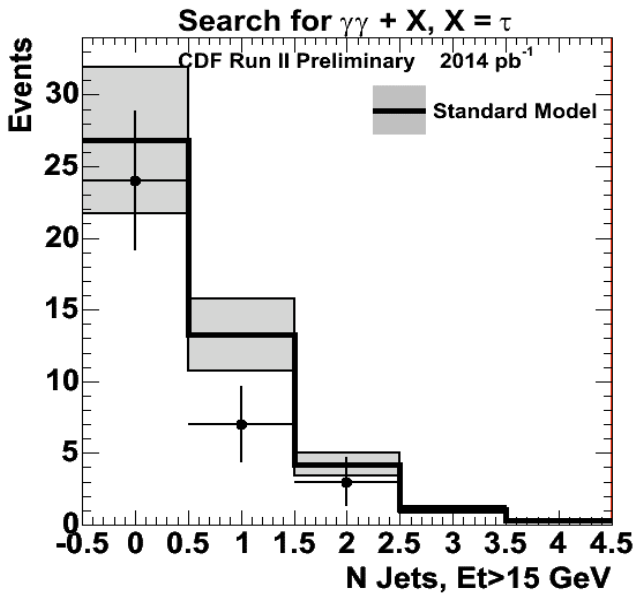
- Backgrounds
  - "Physics": $W\gamma\gamma$ and $Z\gamma\gamma$
  - "Instrumental": $\gamma\gamma+(j\rightarrow\tau_{fake})$

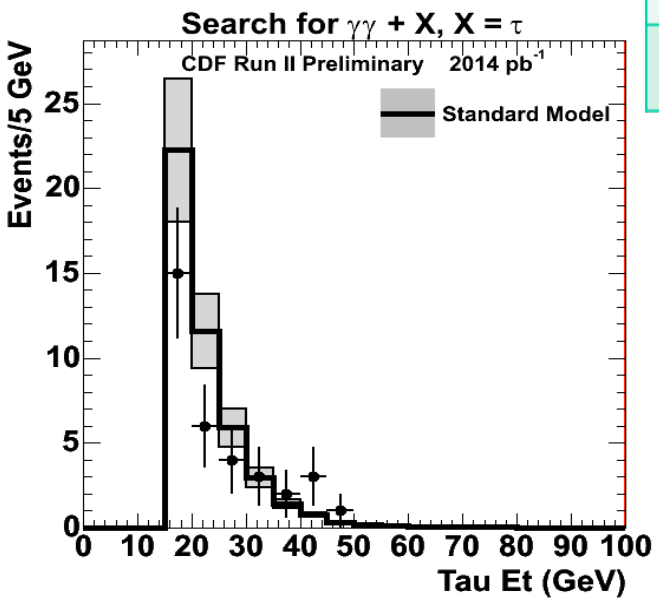
$\Rightarrow$ $j\rightarrow\tau$ fake rate from jj events

$\gamma\gamma+\tau$ kinematics





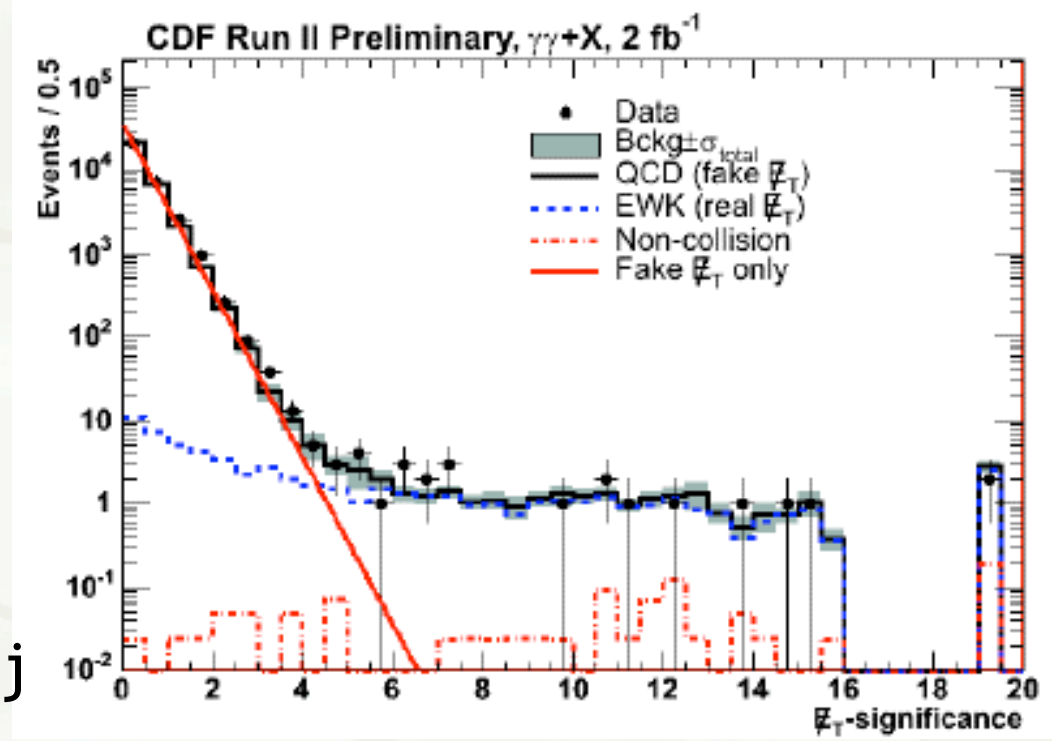




Data, 2 fb^{-1}	40
Total Bckg	46±10
"Instrumental"	44±10
"Physics"	2.2±1.0

Search for Anomalous $\gamma\gamma$+ME_T

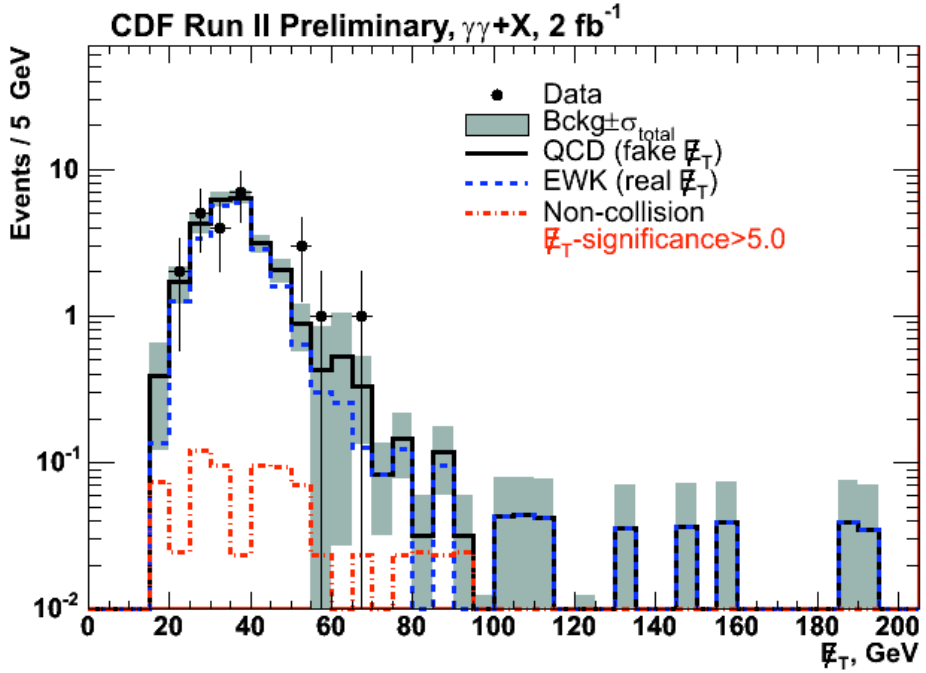
- Event Selection (2 fb^{-1})
  - Two photons:
    E_T>13 GeV, $|\eta|$<1.1

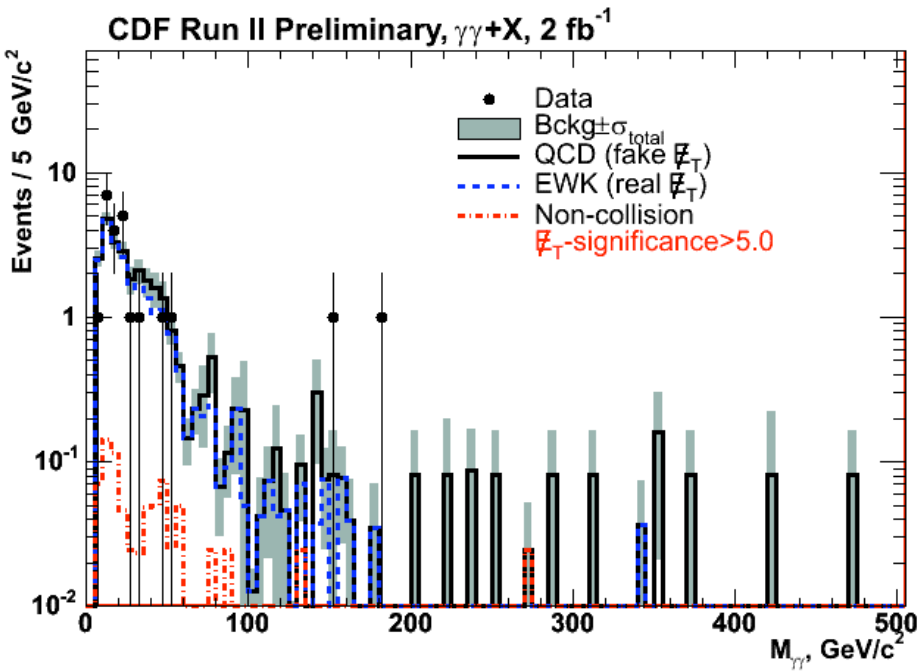


- Backgrounds
  - QCD with fake ME_T: $\gamma\gamma$, γj, jj
    ⇒ dominant backgrounds
  - EWK with true ME_T: $W/Z+\gamma$, $W/Z+j$, $Z \rightarrow \tau\tau \rightarrow \gamma_{fake}\gamma_{fake}$
  - Non-collision: Beam Halo, Cosmic Rays

METMODEL: Use event topology to predict fake ME_T due to energy measurement fluctuations ⇒ Measure how significant the observed ME_T is

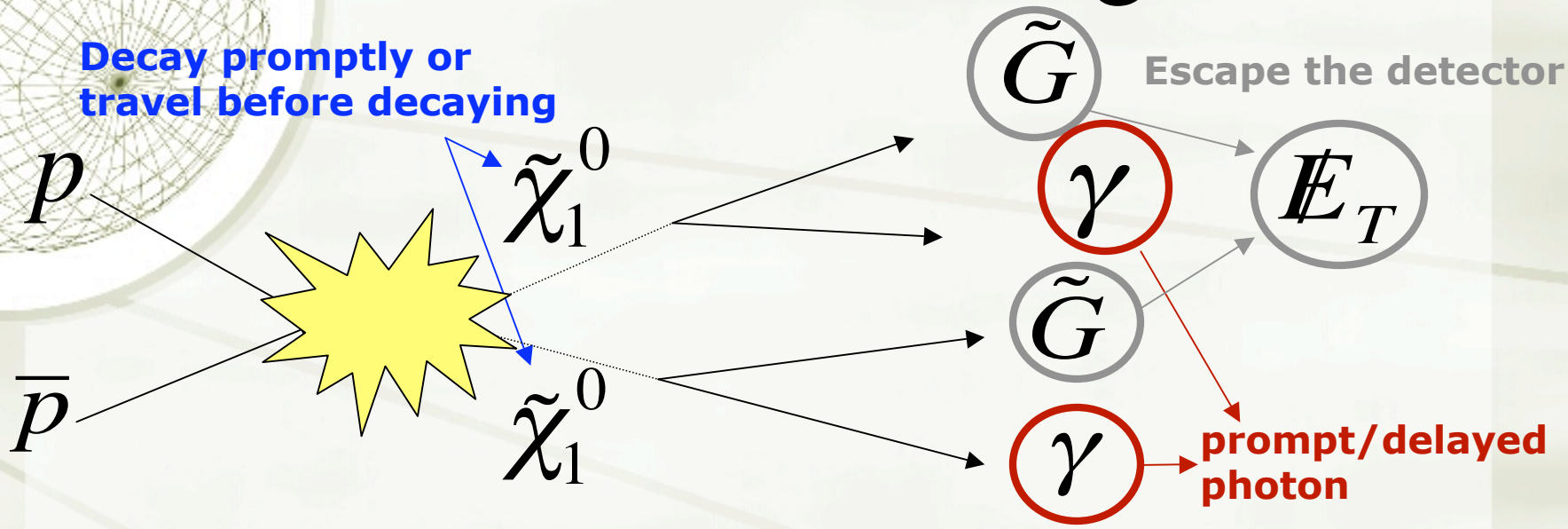
$\gamma\gamma$+ME_T kinematics





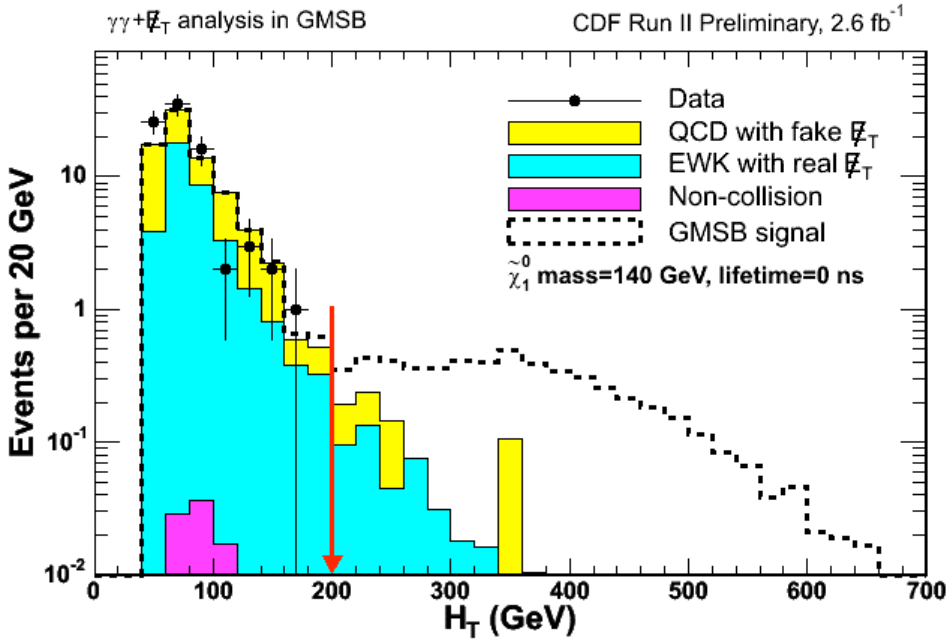
	MetSig>3.0	MetSig>4.0	MetSig>5.0
Data, 2 fb^{-1}	82	31	23
Background	67.9±7.5	35.8±3.0	27.3±2.3
EWK	47%	75%	84%

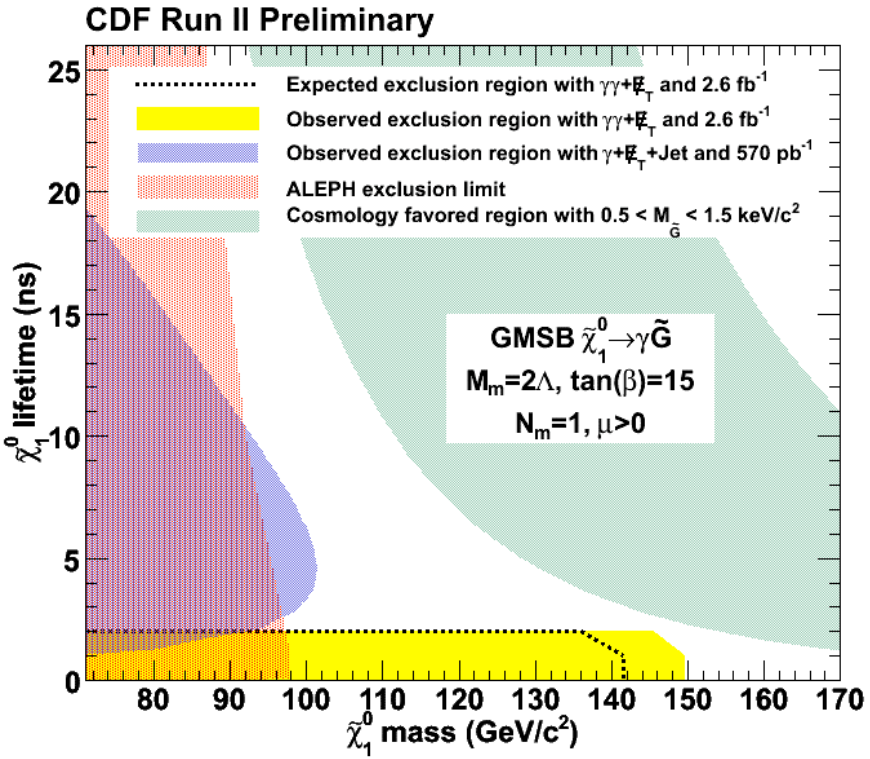
GMSB Event Signature



- In the Tevatron ($p\bar{p}$ collision) $\tilde{\chi}_1^0$ pairs produced
- Both or either $\tilde{\chi}_1^0$ decays in the detector
  - $\gamma + \not\!\!E_T$: optimal for high lifetimes (τ > 2 ns)
  - $\gamma\,\gamma + \not\!\!E_T$: optimal for low lifetimes (τ < 2 ns)

GMSB Limits in $\gamma\gamma$+ME_T

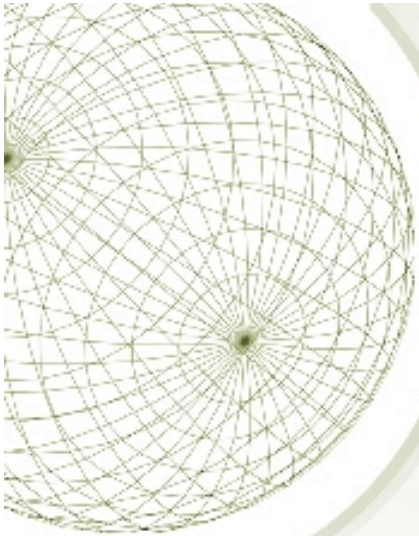




$H_T=E_T(\gamma_1)+E_T(\gamma_2)+E_T(j_1)+E_T(j_2)+ME_T+\ldots$

After ME_T-sig>3 & $\Delta\varphi_{\gamma\gamma}$<3

- Re-optimize: H_T>200 GeV, ME_T-sig>3, $\Delta\varphi(\gamma_1,\gamma_2)$<2.8
- 95% C.L. limits on Neutralino mass and lifetime
- $M(\chi_1^0)$>149 GeV for $\tau(\chi_1^0)$=0 ns ⇒World's Best Limit
- Public Note 9625, to be submitted to PRL

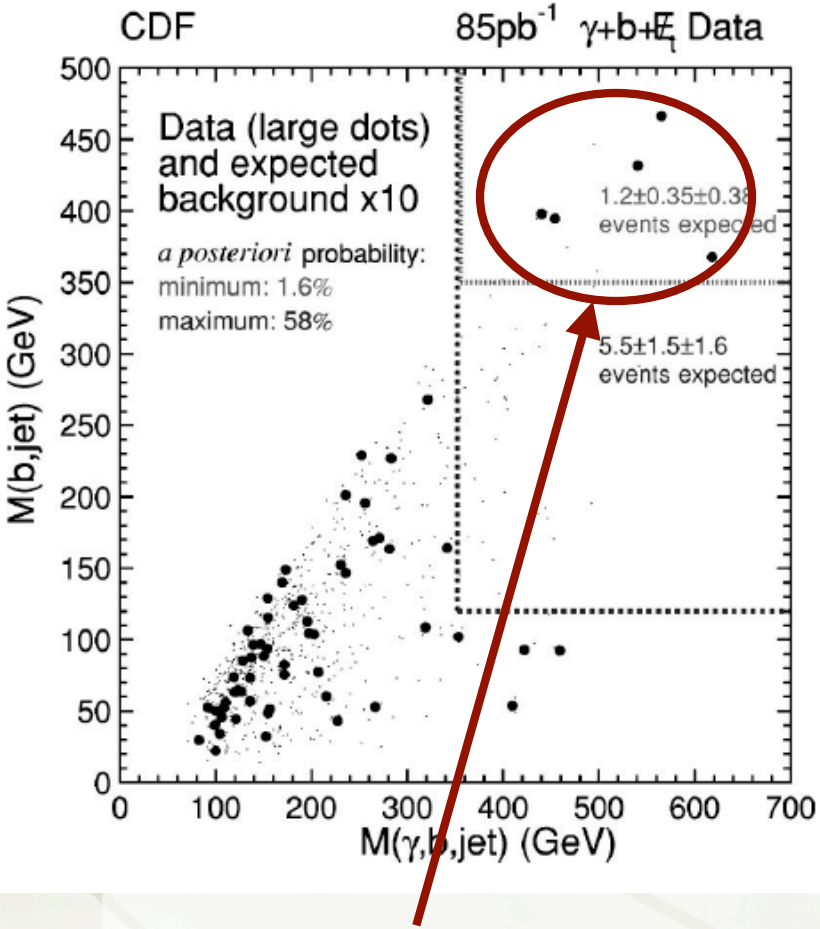


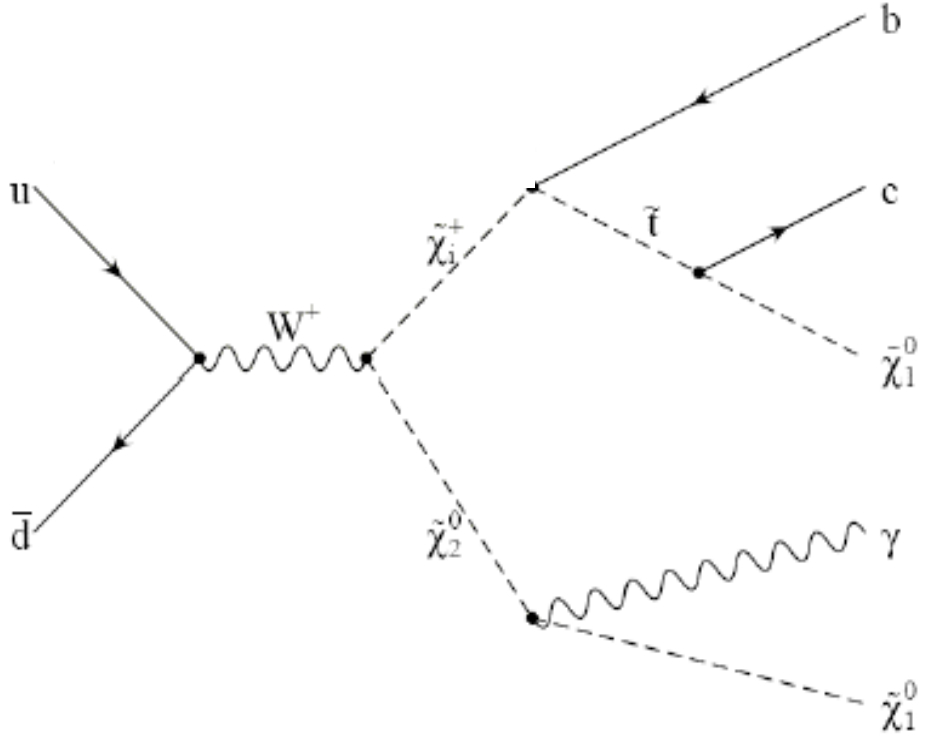
Search for Anomalous γ+*b*+*j*+ME_T

arXiv:0905.0231v1

Submitted to PRD

γ+b+j+ME_T Overview

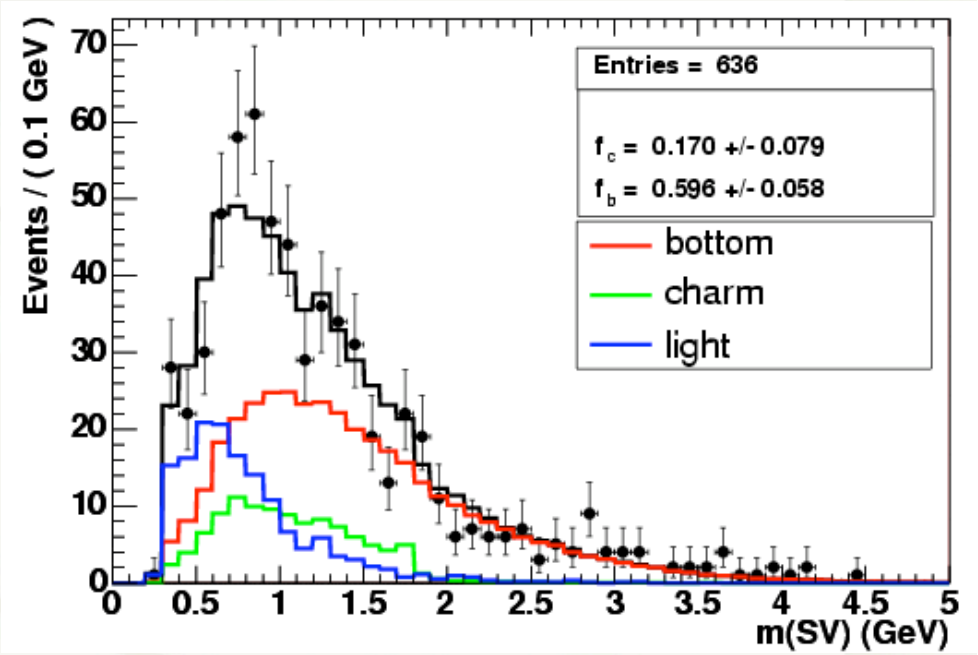




- Run I observed hint of an excess of events
- SM with γbjME_T is very rare <3%
- Several models beyond SM exist (e.g., SUSY)

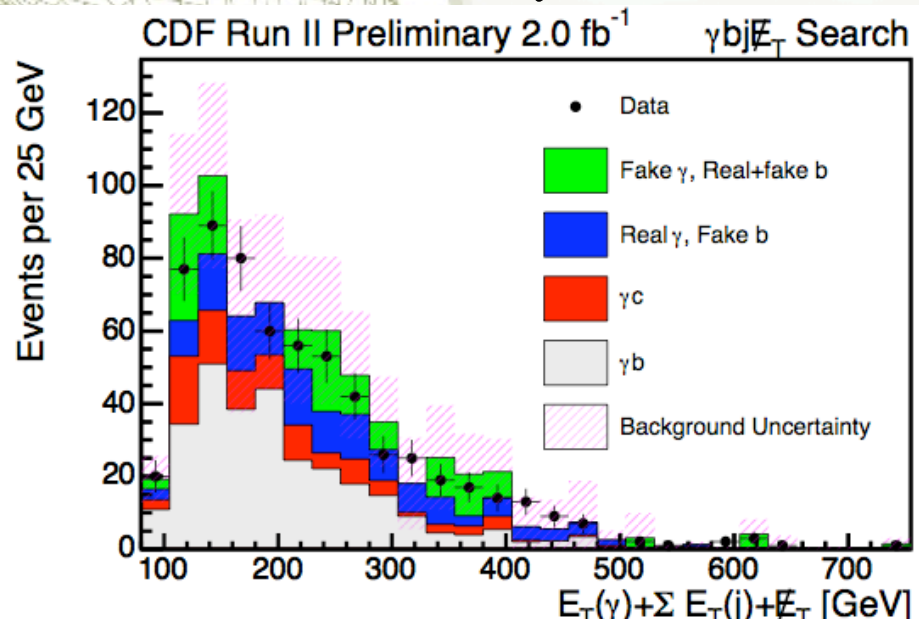
Anomalous γ+b+j+ME_T

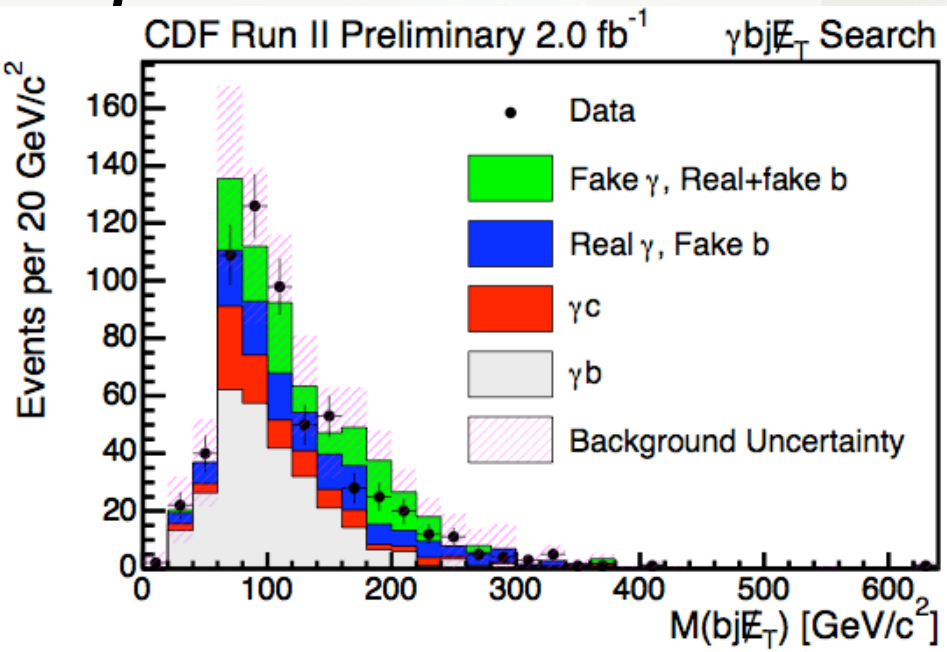
- Event Selection (2 fb^{-1})
  - Photon: E_T>25 GeV, $|\eta|$<1.1
  - 2 jets: E_T>15 GeV, $|\eta|$<2.0
  - ΔR>0.4 for γj_1, γj_2 and $j_1 j_2$
  - ME_T>25 GeV
  - $\Delta\phi(j, ME_T)$>0.3
  - At least one j is b-tagged by secondary vertex (SECVTX)

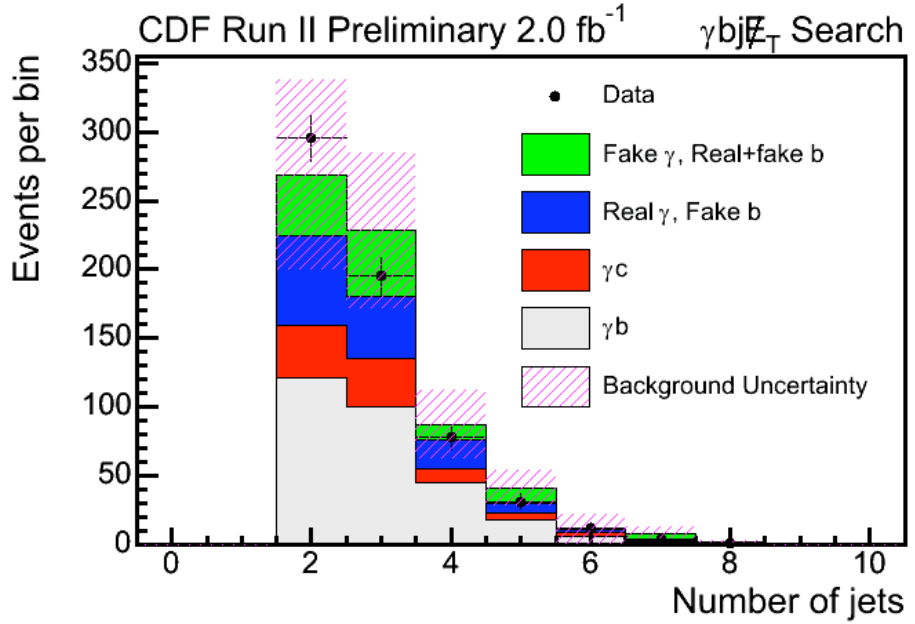


- γ_{fake}, γ+b_{fake} backgrounds
  - Use the CES/CPR method
- γb, γc backgrounds
  - Use Heavy Flavor Normalization
  - Fit SECVTX mass of tagged jets

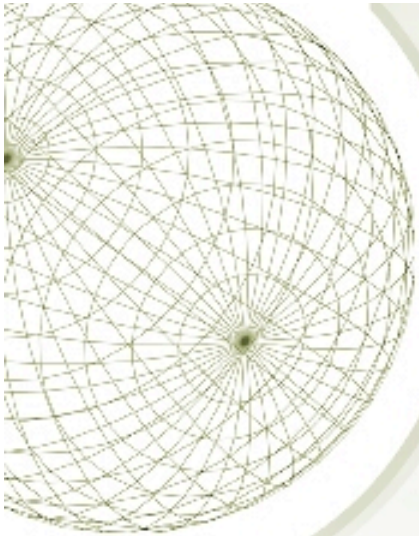
γ+b+j+ME_T kinematics







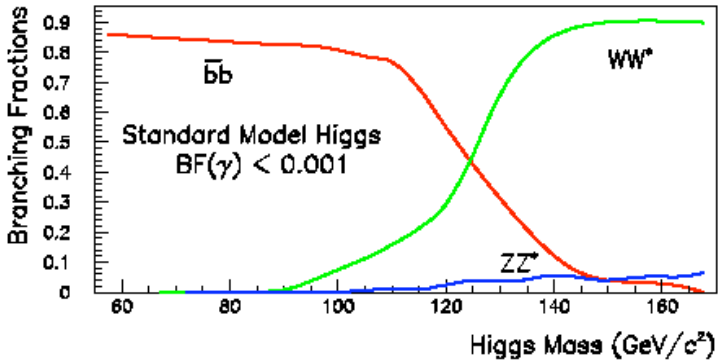
Data	**617**
Total Bckg	**607±113**
fake γ	**115±73**
real γ, fake b	**141±30**
γb	**341±93**
γc	**9±54**

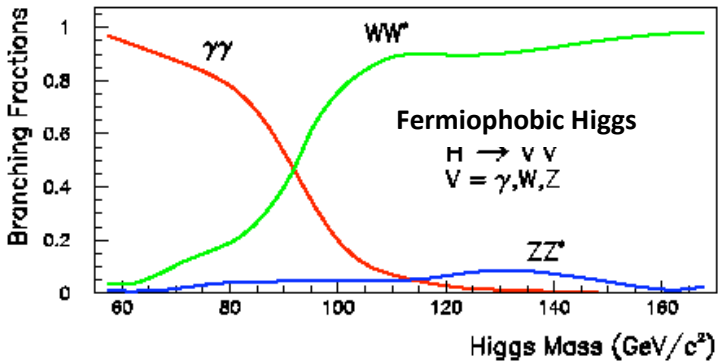


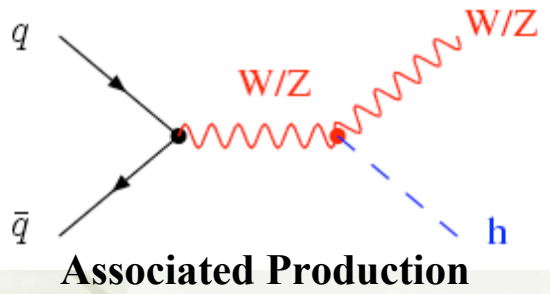
Search for Anomalous Fermiophobic Higgs→γγ

arXiv:0905.0413v2

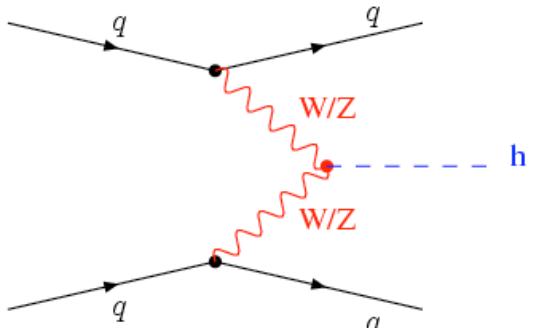
Accepted to PRL







Associated Production



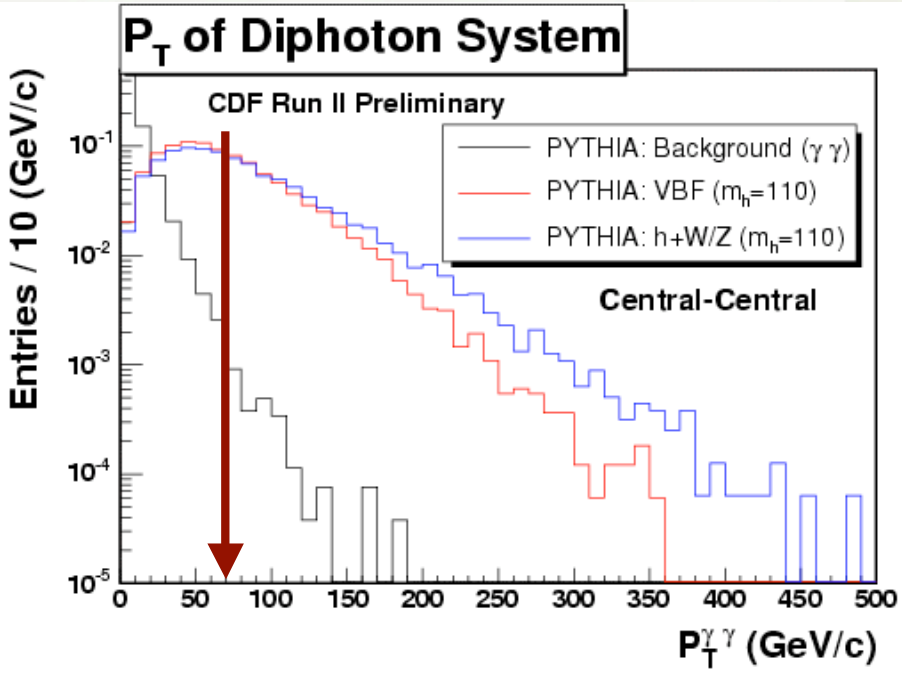
Vector Boson Fusion

Fermiophobic Higgs

- SM prediction H→γγ branching fraction is small
  (~0.2% at m_H~120 GeV)
- In "fermiophobic" models, where fermion couplings suppressed, boson couplings unaffected
- The γγ final state dominates at low Higgs mass ⇒preferred channel
- Production dominated by two process:
  - Associated Production
  - Vector Boson Fusion

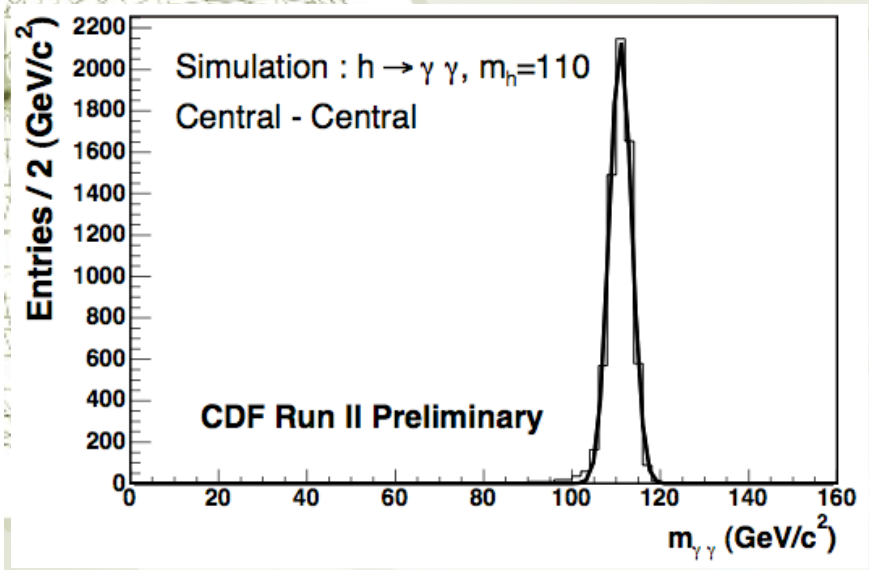
Analysis Overview

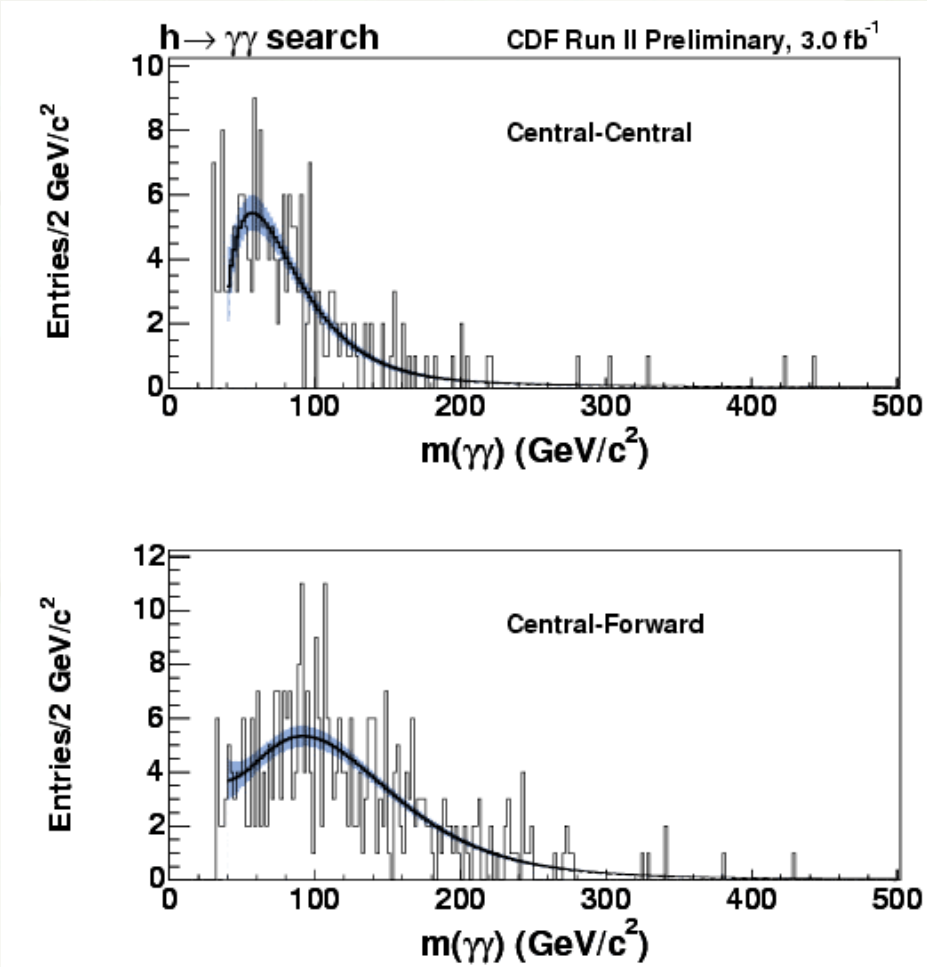
- Event Selection ($3fb^{-1}$)
  - Two isolated photons:
    E_T>15 GeV
    central-central (|η|<1.1) or
    central-forward (1.2<|η|<2.8)
  - $m_{\gamma\gamma}$>30 GeV



- Optimization
  - Look for evidence of W/Z: ME_T, isolated tracks, $P_T(j_2)$..
  - Simple $P_T(\gamma\gamma)$ cut > 75 GeV: Clear winner!
  - Reject 99.7% backgrounds ($\gamma\gamma$, γj, jj), but only 33% signal
  - $P_T(\gamma\gamma)$ spectrum stable LO to NLO

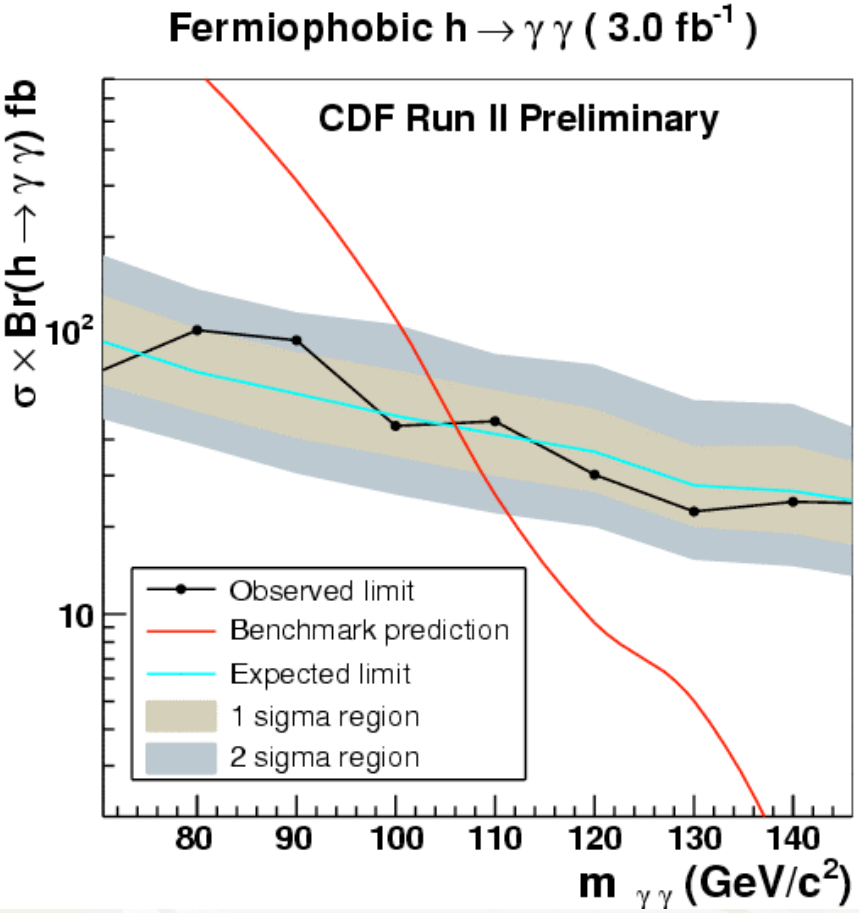
$\gamma\gamma$ Invariant Mass

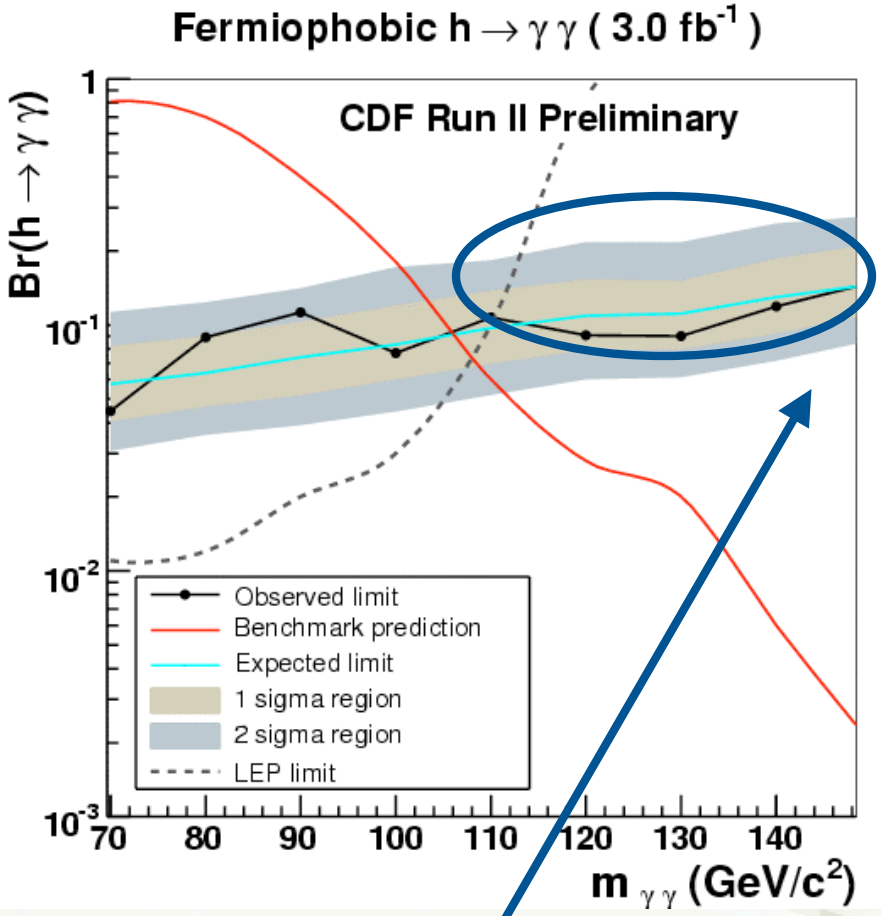




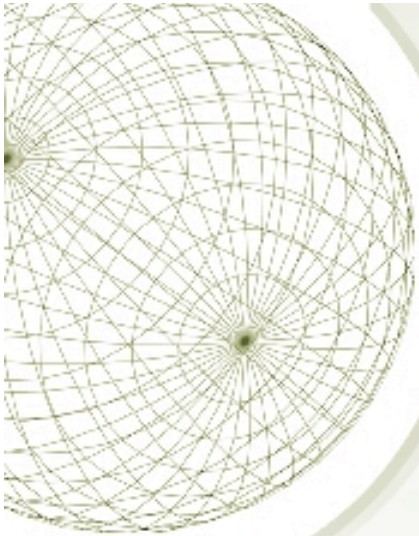
- Signal signature
  - H→$\gamma\gamma$ appears as a very narrow peak in $m_{\gamma\gamma}$ distribution
  - 3% resolution for $m_{\gamma\gamma}$=110 GeV
- $m_{\gamma\gamma}$ distribution in data
  - No narrow peaks observed
  - Fit $m_{\gamma\gamma}$ with smooth functions

Limits on Fermiophobic Higgs





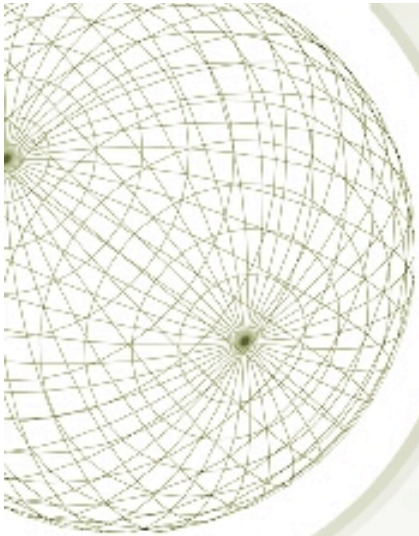
- 95% C.L. mass limit: m_{FH}>106 GeV (LEP 109.7 GeV)
- More sensitive to high mass region than LEP



Conclusions

Summary

- No anomalous excess of events are observed with up to 3 fb^{-1}
- Exclude neutralino mass up to 149 GeV in GMSB model using $\gamma\gamma$+ME_T
- Exclude Fermiophobic Higgs mass up to 106 GeV
- Hopefully CDF will find New Exotic Physics using Photons in the near future



BackUp

$\not\!\!E_T$ Resolution Model

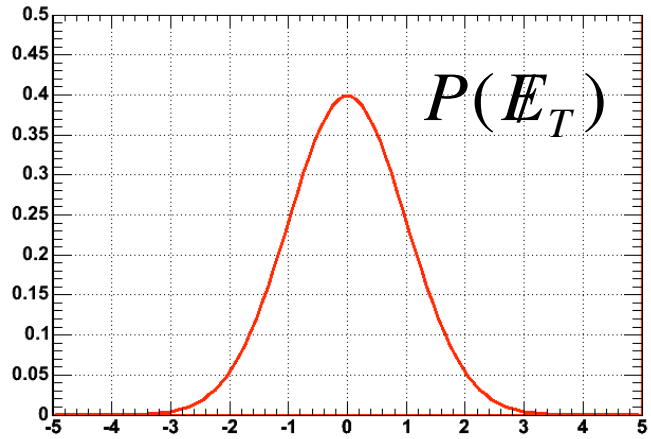
- Missing Transverse Energy ($\not\!\!E_T$): Transverse momentum of particles that escape a detector $\Rightarrow$ real $\not\!\!E_T$
- Detectors not perfect: fake $\not\!\!E_T$ can arise due to energy measurement fluctuations
- $\not\!\!E_T$ Resolution Model (*Met Model*) is designed to predict a shape of fake $\not\!\!E_T$ and calculate its significance
- Assumption: fake $\not\!\!E_T$ is only from fluctuations in energy measurements of jets and unclustered energy (e.g. multiple interactions)

$\not\!\!E_T$-significance

- Conventional definition: $\not\!\!E_T$ - significance = $\dfrac{\not\!\!E_T}{\Sigma E_T}$

- New definition:

$$\not\!\!E_T \text{ - significance} = -\log_{10} P(\not\!\!E_T^{fluc} \geq \not\!\!E_T^{meas})$$



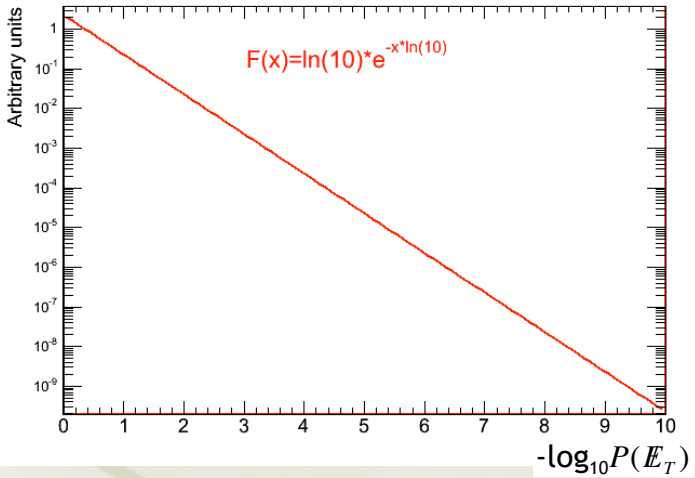
- Produce $P(\not\!\!E_T)$ of all possible values of the fake $\not\!\!E_T$ by smearing jets and unclustered energy

- For 10,000 events

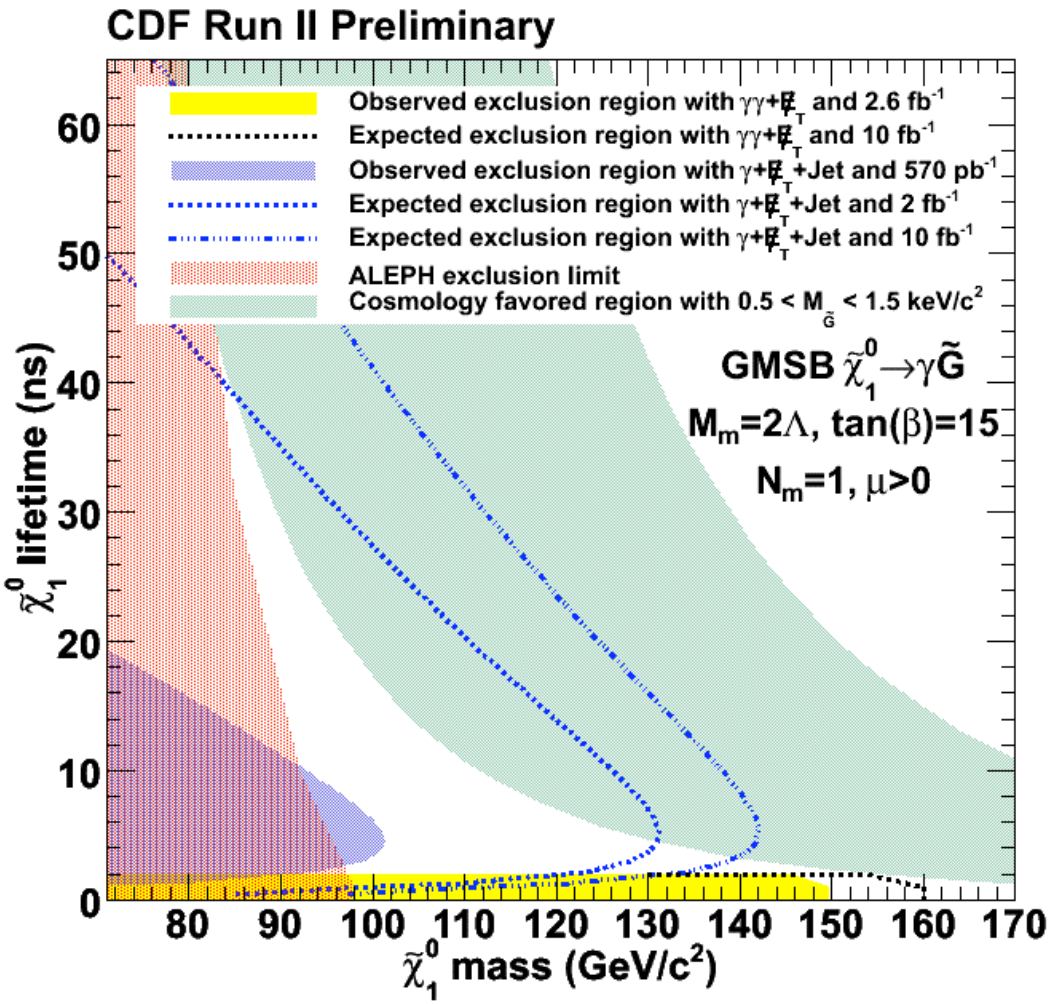
$\not\!\!E_T$ - significance cut > 1 : ~ 1,000 events pass

$\not\!\!E_T$ - significance cut > 2 : ~ 100 events pass

$\not\!\!E_T$ - significance cut > 3 : ~ 10 events pass

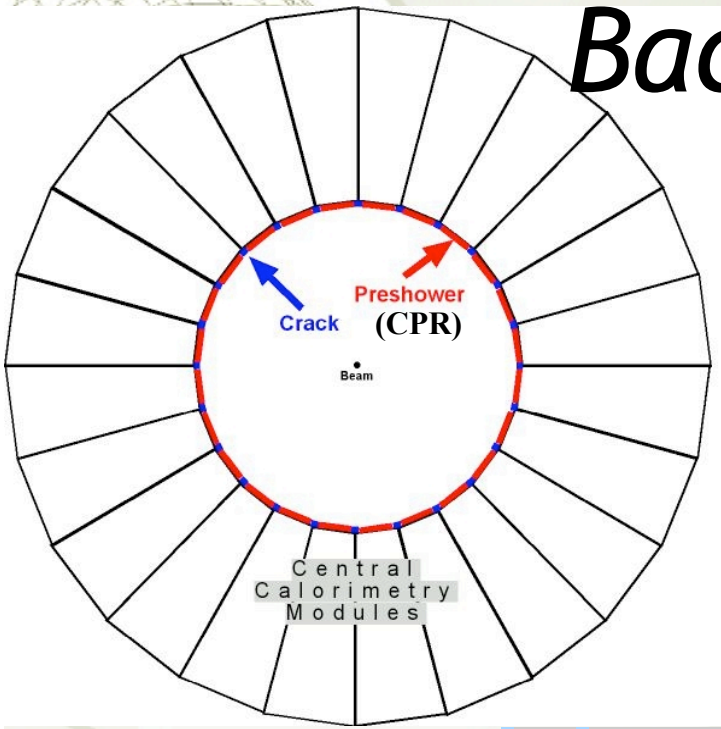


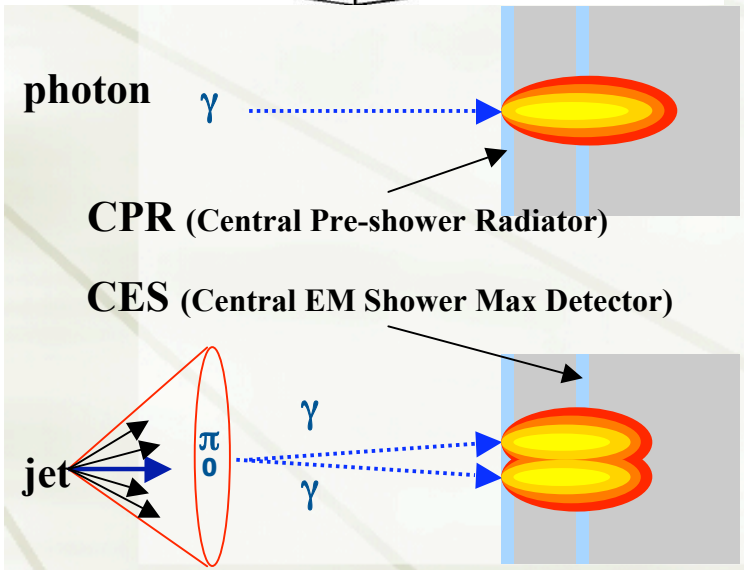
Prospects for the Future



- For high luminosity we calculate the cross section limits assuming:
  - all backgrounds scale linearly with luminosity
  - their uncertainty fractions remain constant
- $\gamma\gamma+\not\!\!E_T$: will extend mass limits up to 160 GeV with 10 fb^{-1}
- The next generation delayed photon analysis will cover up high lifetime region

Background: γ_{fake}, γ+b_{fake}



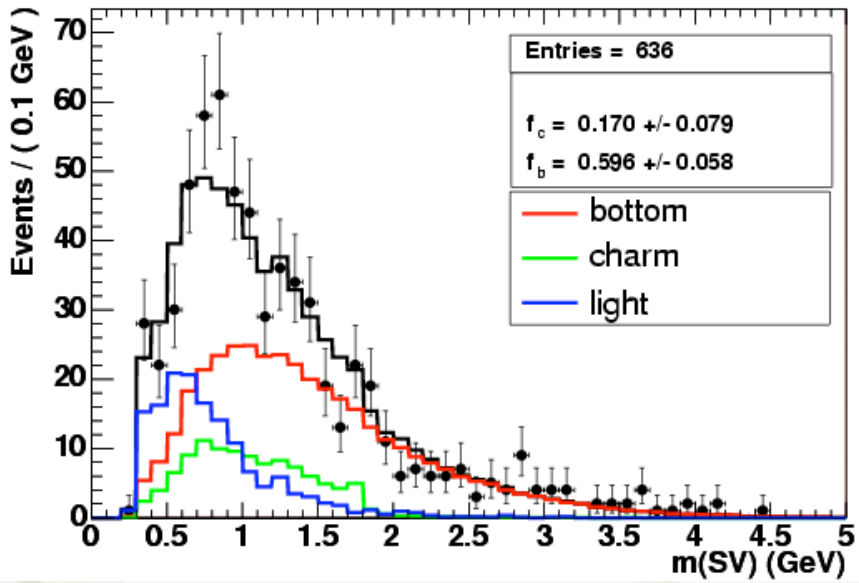


- Use the CES/CPR method: Discriminate between real single γ and $\gamma\gamma$ from π^0 decay
- For E_T<35 GeV use CES
  - used to measure shower shape
- For E_T>35 GeV use CPR
  - used to count photon conversion

Background with fake γ: apply reverse CES/CPR method

Background with real γ, fake b: apply CES/CPR and a j mis-b-tag probability, before b-tagging

Backgrounds: γb, γc



- γb, γc backgrounds
- Use Heavy Flavor Normalization
- MadGraph+PYTHIA γb, γc
- Fit SECVTX mass of tagged jets

- γb normalization
  - Find b fraction, adjusting b fractions in fake γ sample weighted by CES/CPR method
  - Apply MC efficiency to signal region
- γc normalization
  - Do not have a realistic enough MC efficiency
  - Simply fit the SECVTX mass in the signal region