Search for Supersymmetry Using Diphoton Events in Proton-Antiproton Collision at a Center of Mass Energy of 1.96 TeV

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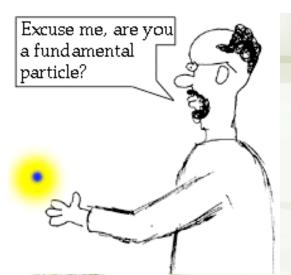
Outline

Motivation

Tools

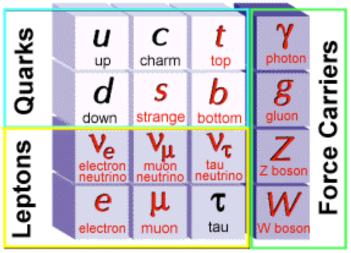Analysis

Conclusion

Motivation

The Standard Model

The Fundamental Question:
What is the world made of?

✦ The SM provides a remarkably successful description of the properties of fundamental particles based on symmetry principle.

- Fermions (matters, spin 1/2)
- Bosons (force carriers, spin 1)
- Particle masses acquired by Higgs boson (not found yet)

✦ But incomplete… e.g. hierarchy (naturalness) problem

Excuse me, are you a fundamental particle?
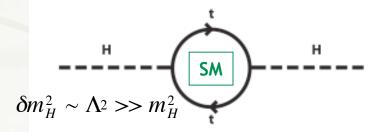
Elementary Particles

Quarks

u	c	t
up	charm	top
d	s	b
down	strange	bottom

Leptons

ν_e	ν_μ	ν_τ
electron neutrino	muon neutrino	tau neutrino
e	μ	τ
electron	muon	tau

Force Carriers

γ photon
g gluon
Z Z boson
W W boson

I   II   III
Three Families of Matter

Hierarchy Problem in SM

✦ Electromagnetic and weak forces are successfully unified at ~10^2 GeV scale: Electroweak theory (EWK)

✦ Want to unify EWK and strong force: Grand Unified Theory (GUT)

✦ The GUT scale (Λ) is believed to be 10^{16} GeV while Higgs mass should be EWK scale ~10^2 GeV - Difficulties arise in the SM: HIERARCHY problem

✦ Higgs mass driven by the GUT scale is unstable (divergent)

✦ Supersymmetry is designed to solve this problem
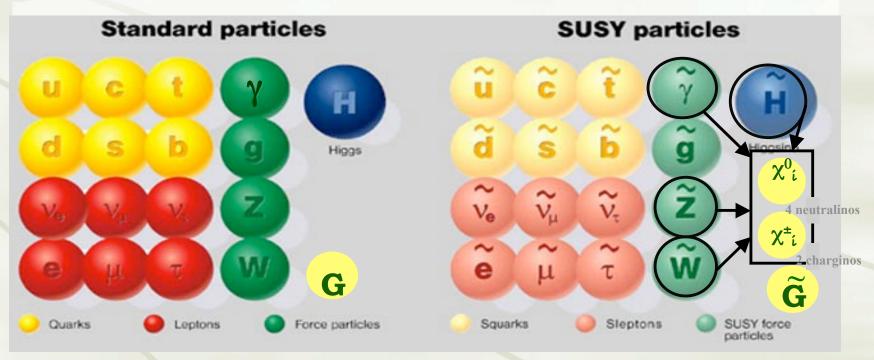
$$\delta m_H^2 \sim \Lambda^2 >> m_H^2$$

$$\delta m_H^2 \sim O(\frac{\alpha}{\pi})(m_B^2 - m_F^2) \sim TeV^2$$

Supersymmetry

- A solution to the problem: suggest a symmetry between fermions and bosons, supersymmtry, at few TeV scale
- Protect the Higgs mass from the divergence
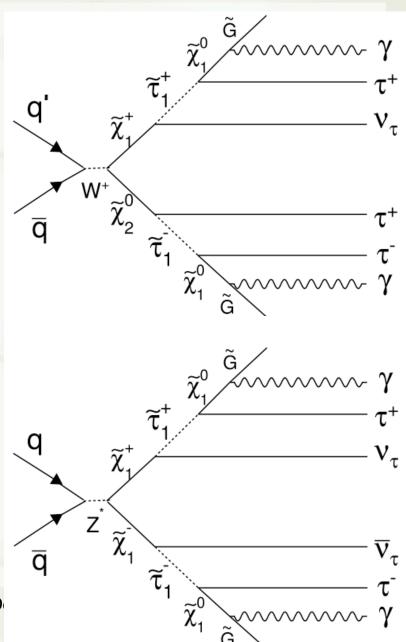- SUSY particles not observed yet - they must be heavier and SUSY must be broken

GMSB Models

- ✦ In Gauge Mediated SUSY Breaking (GMSB) Models SUSY is broken at low energy scale (TeV), with breaking transmitted by SM gauge interactions
- ✦ GMSB is quite predictive in the SUSY mass spectrum and has distinctive phenomenological features - collider experiments can put these predictions fully to test
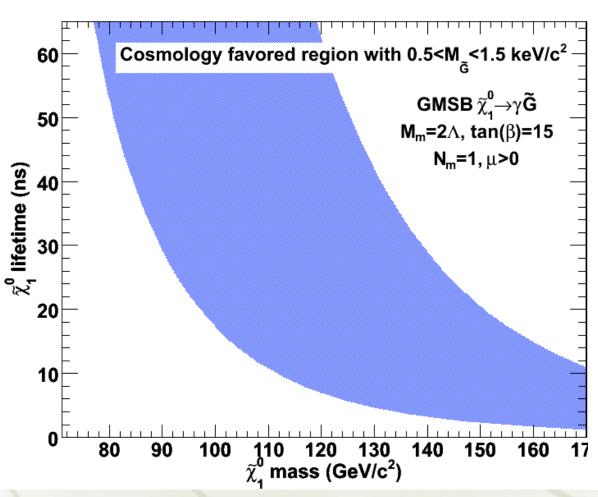
GMSB Neutralino

- For simple case GMSB predicts the lightest Neutralino ($\tilde{\chi}_1^0$) to be the Next-to-Lightest SUSY Particle with the Gravitino ($\tilde{G}$) as the Lightest SUSY Particle

- For much of the parameter space the Neutralino decays via $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$

- The final state high energy photons can be produced at collider experiments

- $\tilde{\chi}_1^0$ can travel macroscopic distance (meters) with nanosecond lifetimes

Cosmology Favored Region
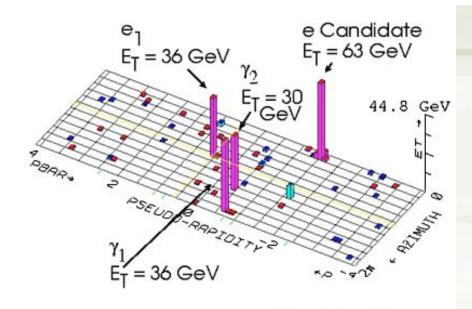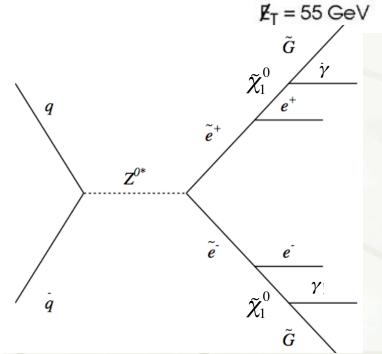

Cosmology favored region with $0.5 < M_{\tilde{G}} < 1.5$ keV/c^2

GMSB $\tilde{\chi}_1^0 \to \gamma \tilde{G}$

$M_m = 2\Lambda$, $\tan(\beta) = 15$

$N_m = 1$, $\mu > 0$

- Cosmological constraints ($m_{Grav} \sim 1$ keV) relate mass and lifetime of $\tilde{\chi}_1^0$: small lifetimes (several ns) are favored for large masses (~100 GeV)

- $0.5 < m_{Grav} < 1.5$ keV

- $\tilde{G}$ can be a warm dark matter candidate in this region

Unusual Event: SUSY?

+ In late 1990's
  an unusual $ee\gamma\gamma\not{E}_T$
  candidate event was
  observed at the CDF
  detector in Fermilab

+ SM prediction:
  ~10^{-6} events
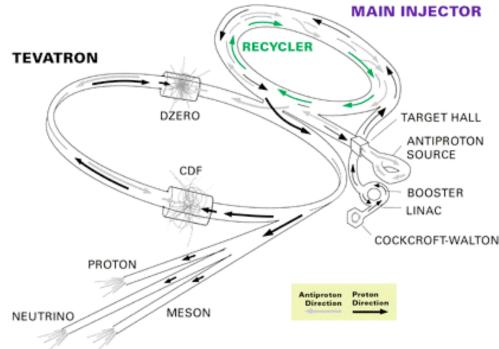
+ Is this GMSB-SUSY?

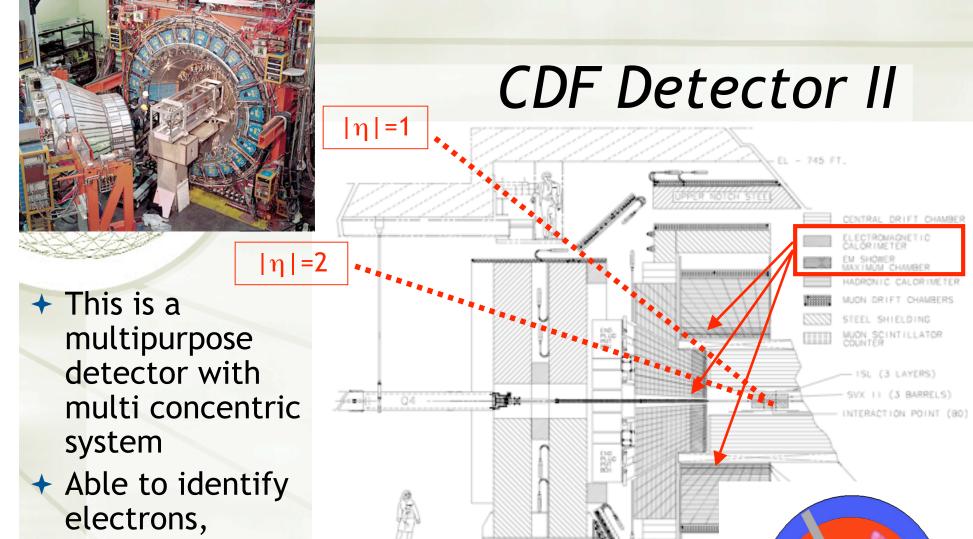# *Tools*

Particle Collider

One way to search for the Neutralinos is to use particle colliders like the Tevatron at Fermilab

- Energy frontier for now : 1.96 TeV
- A beam crossing every 396 ns
- ~ 60 mb inelastic cross section: 6 trillion collisions per 100 pb^{-1}
- Total integrated luminosity ~7 fb^{-1} delivered up to now
- 2.6 fb^{-1} for our analysis

FERMILAB'S ACCELERATOR CHAIN

MAIN INJECTOR

RECYCLER

TEVATRON

DZERO

CDF

TARGET HALL

ANTIPROTON SOURCE

BOOSTER

LINAC

COCKCROFT-WALTON

PROTON

NEUTRINO

MESON

Antiproton Direction   Proton Direction

Fermilab 00-635

CDF Detector II

$|\eta|=1$

$|\eta|=2$

$\eta = -\ln[\tan(\theta/2)]$

CENTRAL DRIFT CHAMBER
ELECTROMAGNETIC CALORIMETER
EM SHOWER MAXIMUM CHAMBER
HADRONIC CALORIMETER
MUON DRIFT CHAMBERS
STEEL SHIELDING
MUON SCINTILLATOR COUNTER

EL - 745 FT.

UPPER NOTCH STEEL

ISL (3 LAYERS)
SVX II (3 BARRELS)
INTERACTION POINT (BO)

Q4

0 1m 2m 3m 4m 5m
0 2 4 6 8 10 12 14 16 ft.

✦ This is a multipurpose detector with multi concentric system

✦ Able to identify electrons, muons, taus, jets, photons, b's and $\not{E}_T$

τ
(also e, μ)
e
μ

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Dissertation Defense
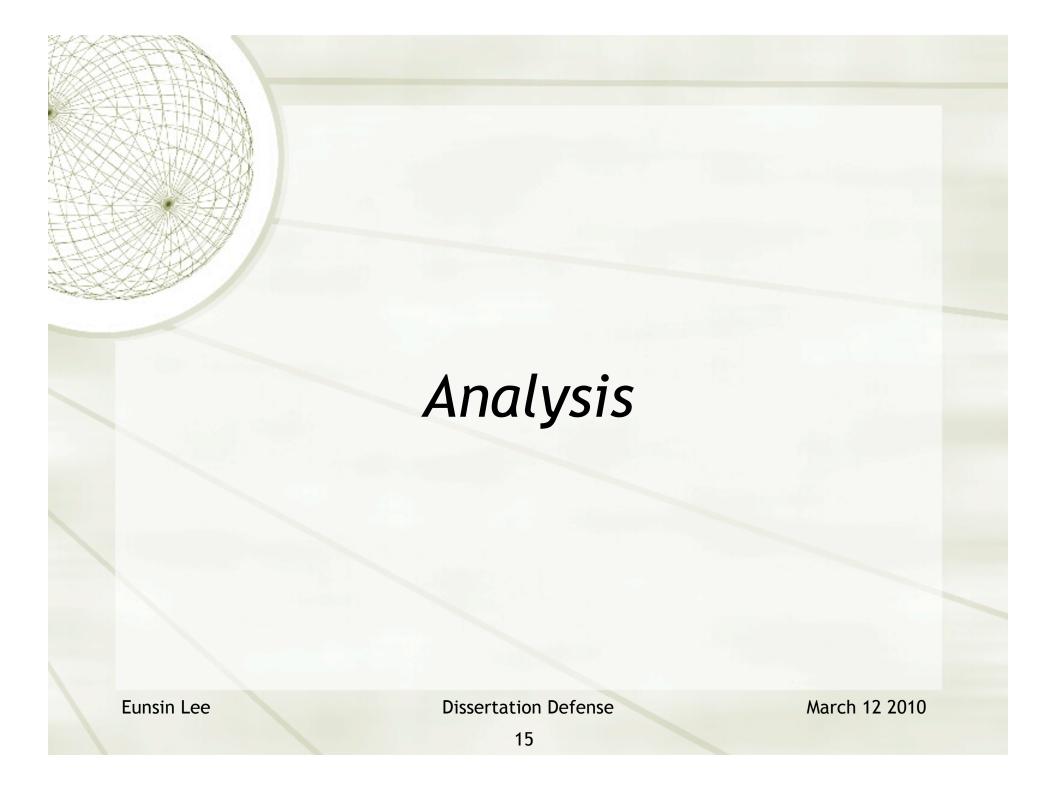
13
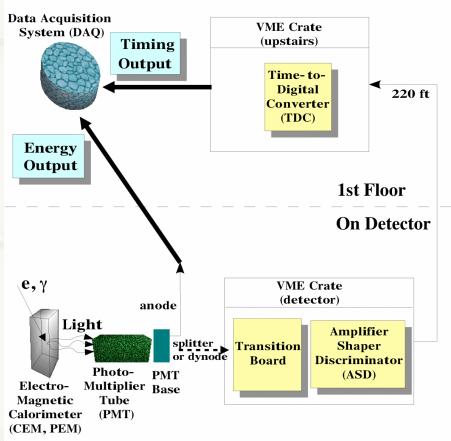
The EMTiming System

+ Provides time of arrival of photons at calorimeter

+ Includes both CEM and PEM ($|\eta| < 2.0$)

+ Became fully operational starting in Dec 2004

+ Timing resolution: ~0.5 ns

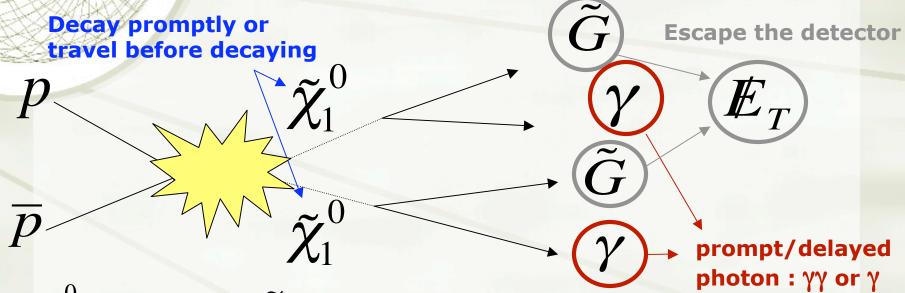+ 100% efficient for photons with $E_T > 3$ GeV

CDF EM Timing Project

Data Acquisition System (DAQ)

Timing Output

Energy Output

VME Crate (upstairs)

Time-to-Digital Converter (TDC)

220 ft

1st Floor

On Detector

e, γ

Light

anode

splitter or dynode

VME Crate (detector)

Transition Board

Amplifier Shaper Discriminator (ASD)

Electro-Magnetic Calorimeter (CEM, PEM)

Photo-Multiplier Tube (PMT)

PMT Base

Analysis

GMSB Event Signature

★ In the Tevatron ($p\bar{p}$ collision) gaugino pair-production dominates

★ The gaugino pair decays produce a pair of $\tilde{\chi}_1^0$'s

Decay promptly or travel before decaying

Escape the detector

p

$\tilde{\chi}_1^0$

$\bar{p}$

$\tilde{\chi}_1^0$

$\tilde{G}$

γ

$\not{E}_T$

$\tilde{G}$

γ

prompt/delayed photon : γγ or γ

★ $\tilde{\chi}_1^0$ decays into $\tilde{G}$, that gives rise to missing transverse energy ($\not{E}_T$), and a photon

★ Both or either $\tilde{\chi}_1^0$ can decay in the detector
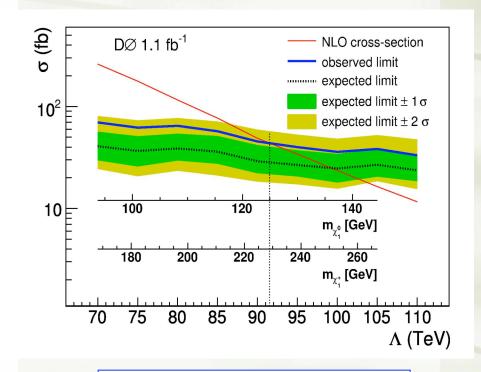
$$\gamma\,\gamma + \not{E}_T \text{ or } \gamma + \not{E}_T$$
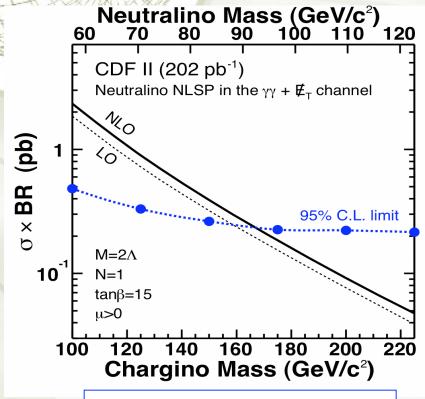
Previous Diphoton Searches

$\gamma\gamma + \not{E}_T$ searches : sensitive to low lifetimes (τ < 2 ns)

(only prompt photons : τ << 1 ns)

CDF (0.2 fb⁻¹)
Phys.Rev.D71, 031104 (2005)
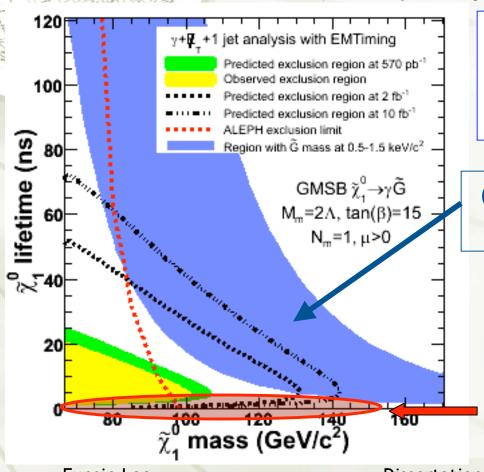
DØ (1.1 fb⁻¹)
Phys.Lett.B659, 856 (2008)

Single Delayed Photon Search

$\gamma + E_T + jet$: sensitive to high lifetimes

(delayed photons : $\tau > 2$ ns)

Cosmology Favored Region
(shown in previous slide)

Our new search is first $\gamma\gamma$
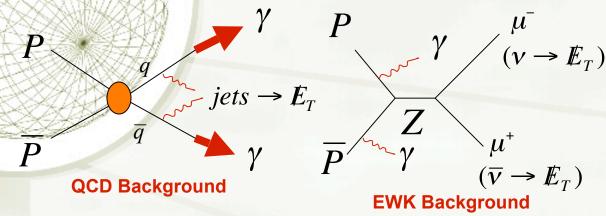search for non-zero low
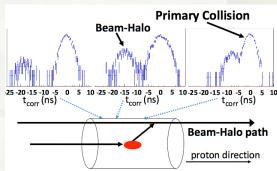lifetime region (τ<2 ns):

Trying to understand here

Analysis Overview

✦ An *a priori* analysis where we look at all events that have two photons, regardless of what else is in the sample (inclusive diphoton sample)

✦ Estimate the backgrounds for this sample as a function of various cuts

✦ Optimize with background predictions and signal acceptance

✦ Open the box

Backgrounds

P

γ

q

$jets \to \not{E}_T$

$\bar{q}$

γ

$\bar{P}$

QCD Background

P

γ

μ^-

$(\nu \to \not{E}_T)$

Z

$\bar{P}$

γ

μ^+

$(\bar{\nu} \to \not{E}_T)$

EWK Background

Primary Collision

Beam-Halo

t_{corr} (ns)

Beam-Halo path

proton direction

Non-Collision Background
: Cosmic and Beam Halo

✦ QCD Events ($\gamma\gamma, \gamma - jet \to \gamma\gamma_{fake}$ and $jet - jet \to \gamma_{fake}\gamma_{fake}$) with fake $\not{E}_T$ due to energy mis-mearsurement and event reconstruction pathologies such as wrong vertex and tri-photon events

✦ EWK Events (*W*'s and *Z*'s) with real $\not{E}_T$

✦ Non-Collision Backgrounds
   (cosmic rays and beam halo)

More on each later!

Dataset and Event Selection

- Luminosity = 2.6 fb^{-1}
- Photon of $E_T > 13$ GeV, $|\eta| < 1.1$
- Standard Photon ID requirements
- $N_{vx} \geq 1$, Highest ΣP_T Vertex, $|Z_{vx}| < 60$ cm
- Cosmic rays and Beam related background removal requirements

What's new?

- ✦ New METMODEL to improve QCD rejection
- ✦ The EMTiming system to reject cosmics and beam related backgrounds
- ✦ Simplify and re-optimize the analysis due to more direct ways of rejecting backgrounds
- ✦ Use 13 times more data ($0.2 \text{ fb}^{-1} \Rightarrow 2.6 \text{ fb}^{-1}$)
- ✦ Estimate the sensitivity to non-zero lifetimes

  (The EMTiming Simulation in GMSB signal MC)

$\not{E}_T$ Resolution Model
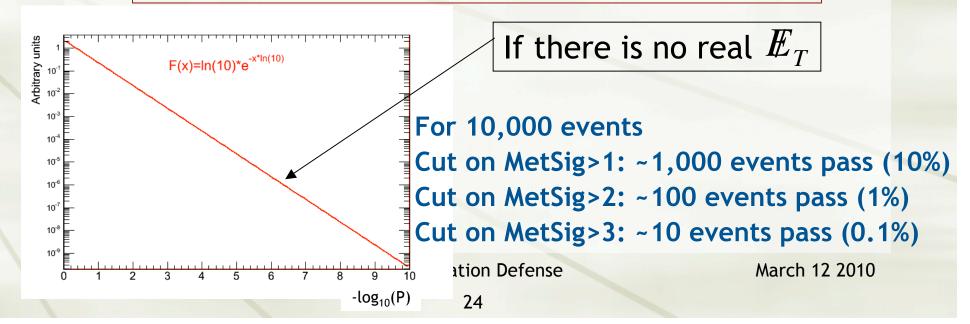
- Missing Transverse Energy ($\not{E}_T$): Transverse momentum of particles that escape a detector $\Rightarrow$ real $\not{E}_T$

- Detectors not perfect: fake $\not{E}_T$ can arise due to energy measurement fluctuations

- $\not{E}_T$ Resolution Model (*METMODEL*) is designed to measure the significance of the $\not{E}_T$ and predict the expected $\not{E}_T$ significance distribution for a sample of events

$\displaystyle{\not{E}}_T$-significance

- METMODEL runs large number of pseudo experiments to produce $P(\not{E}_T)$ of all possible values of the fake $\not{E}_T$ by smearing clustered (jets) and unclustered energy
- Want to know how significant measured $\not{E}_T$ is
- New definition:

$$\not{E}_T - \text{significance} = -\log_{10}P(\not{E}_T^{\,fluc} \geq \not{E}_T^{\,meas})$$

$F(x)=\ln(10)*e^{-x*\ln(10)}$

Arbitrary units

$-\log_{10}(P)$

If there is no real $\not{E}_T$

For 10,000 events
Cut on MetSig>1: ~1,000 events pass (10%)
Cut on MetSig>2: ~100 events pass (1%)
Cut on MetSig>3: ~10 events pass (0.1%)
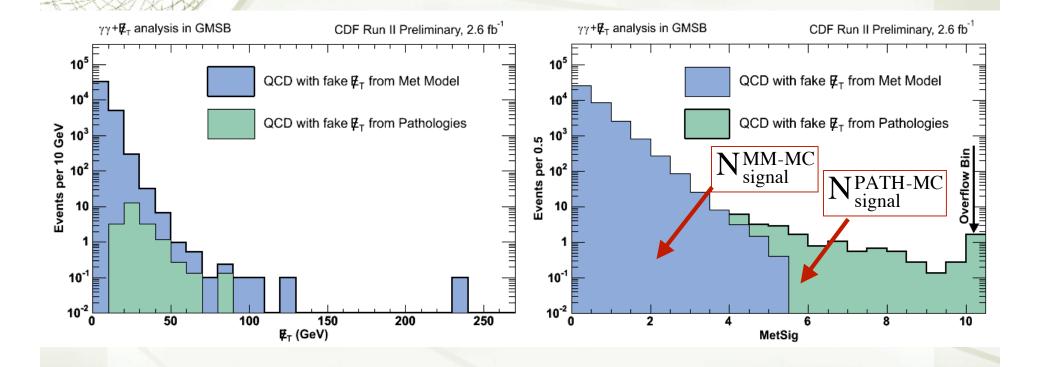
QCD Backgrounds with Fake $\displaystyle{\not{E}_T}$

* $\gamma\,\gamma$, γ jet $\rightarrow \gamma\,\gamma_{fake}$, jet jet $\rightarrow \gamma_{fake}\,\gamma_{fake}$

* Energy Measurement Fluctuations

  - Measure the significance of the $\not{E}_T$ and predict the expected significance distribution for a sample of events by means of METMODEL

* Large Fake $\not{E}_T$ from event reconstruction pathologies such as tri-photon events where a photon is lost

  - Normalize diphoton MC sample to the inclusive diphoton sample, taking into account jet backgrounds

* Total QCD Prediction: $$N_{signal}^{QCD} = N_{signal}^{MetModel} + N_{signal}^{PATH}$$

Total QCD Backgrounds
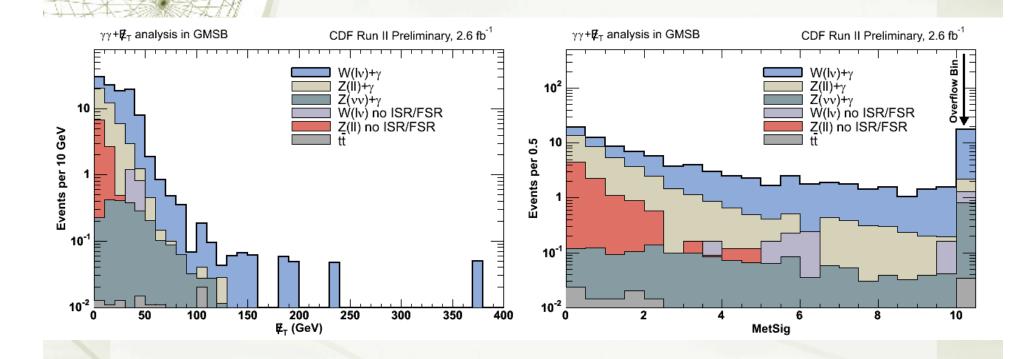
EWK Backgrounds with Real $\not{E}_T$

★ W's and Z's with real $\not{E}_T$ in Leptonic Channels :
1) $W\gamma\gamma$ and $Z\gamma\gamma$
2) $W\gamma\gamma_{fake}$ and $Z\gamma\gamma_{fake}$
3) $W\gamma_{fake}\gamma_{fake}$ and $Z\gamma_{fake}\gamma_{fake}$

★ Using MC samples with production cross section, normalize to $e\gamma$ data

$$N_{signal}^{EWK} = \sum_{i=\,sources} N_{signal,i}^{EWK-MC} \cdot SF_i \frac{\text{Data}(e\gamma)}{\text{MC}(e\gamma)}$$

where $SF_i = \dfrac{\sigma_i \cdot k_i \cdot \mathcal{L}}{N_{sample,i}^{EWK}}$ is scale factors to get proper ration of each EWK background for $\gamma\gamma + \not{E}_T$

EWK Backgrounds Distributions
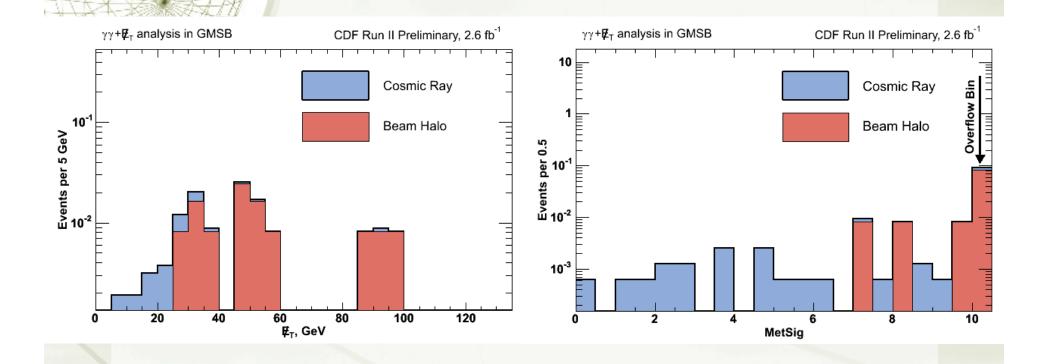
Non-Collision Backgrounds

✦ Beam Halo (BH): Estimate based on the number of identified BH events

   - Distinctive energy deposition pattern of BH muons traveling along the beam pipe

✦ Cosmic Rays: Use the EMTiming system

   - not correlated in time with collisions and their timing distribution roughly flat

   These non-collision backgrounds are almost negligible compared to QCD and EWK backgrounds
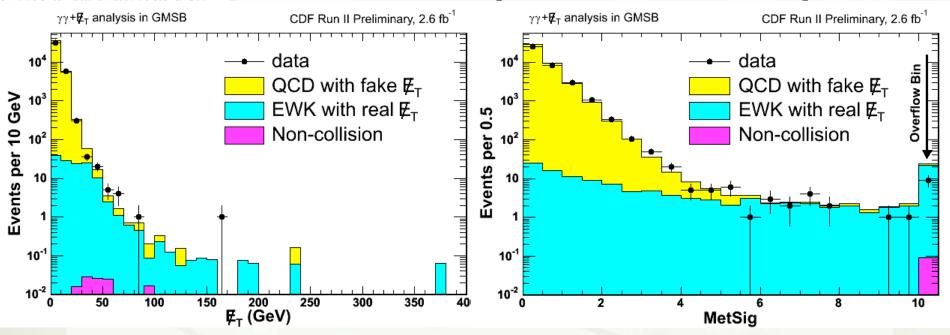
Non-Collision Background Distributions

Backgrounds for the inclusive diphoton sample

- ✦ A total of 38,053 events pass the inclusive diphoton selection requirements
- ✦ Backgrounds are well modeled
- ✦ $\not{E}_T$ – significance shows a good separation between QCD with fake $\not{E}_T$ and EWK with real $\not{E}_T$

GMSB MC Simulation

- Use MC simulation to produce the GMSB signal with detector simulation

- The EMTiming system is also simulated to search for neutralino's non-zero lifetime region

- Generate 133K events for different mass (70 GeV - 150 GeV) and lifetime (0 ns - 2 ns) points

Optimization Strategy

- Take the inclusive diphoton sample and then do an optimization
- Pick a GMSB parameter point (mass=140 GeV, lifetime<<1 ns)
- Find the optimal cuts by calculating the lowest 95% C.L. expected cross section limit
- Pick a single set of optimization variable cuts (next slide)
- Map out the sensitivity as a function of neutralino mass and lifetime

Optimization Cuts

✦ MetSig

  - Get rid of QCD with fake $\not{E}_T$

✦ H_T (Scalar sum of E_T for photon, jet and $\not{E}_T$)

  - GMSB signal gets cascade decays from heavy gaugino pairs so GMSB has large H_T compared to SM

✦ $\Delta\phi(\gamma_1,\gamma_2)$

  - Get rid of back-to-back photons and wrong vertex (EWK backgrounds with large H_T have a high E_T photon recoiling against $W{\rightarrow}e\nu$ and QCD with large H_T have high E_T back-to-back diphotons or wrong vertex)

Optimization Results

$$H_T > 200 \text{ GeV}$$
$$\Delta\phi(\gamma_1, \gamma_2) < \pi - 0.35 \text{ rad}$$
$$\text{MetSig} > 3$$

✦ Example point:
  $m(\chi^0_1) = 140$ GeV, $\tau(\chi^0_1) \ll 1$ ns
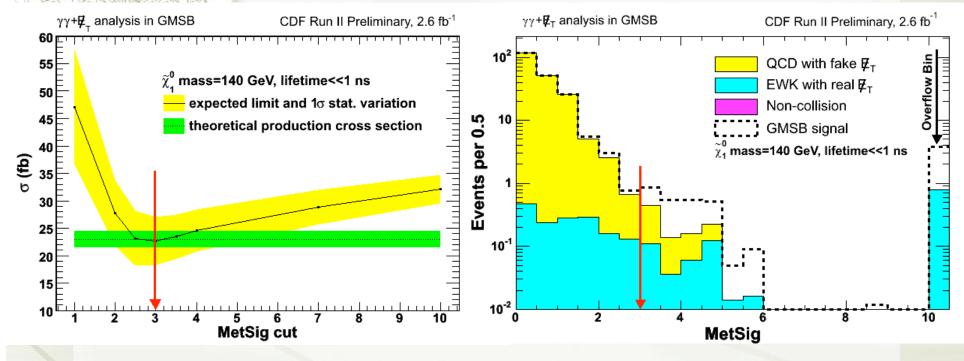
✦ Acceptance: 7.80 ± 0.54 (%)

✦ Luminosity: 2.6 ± 0.2 fb^{-1}

σ_{exp} = **22.62 fb**

σ_{prd} = **22.97 fb**

Background Estimations	
EWK	$0.92 \pm 0.21 \pm 0.30$
QCD	$0.46 \pm 0.22 \pm 0.10$
Non-Collision	$0.001 + 0.008 - 0.001$
Total	$1.38 \pm 0.30 \pm 0.32$
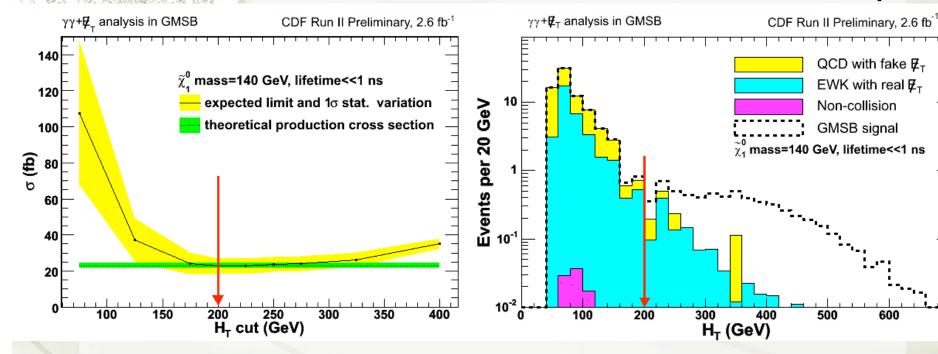
95% C.L. Cross Section Limits and N-1 Plot: MetSig
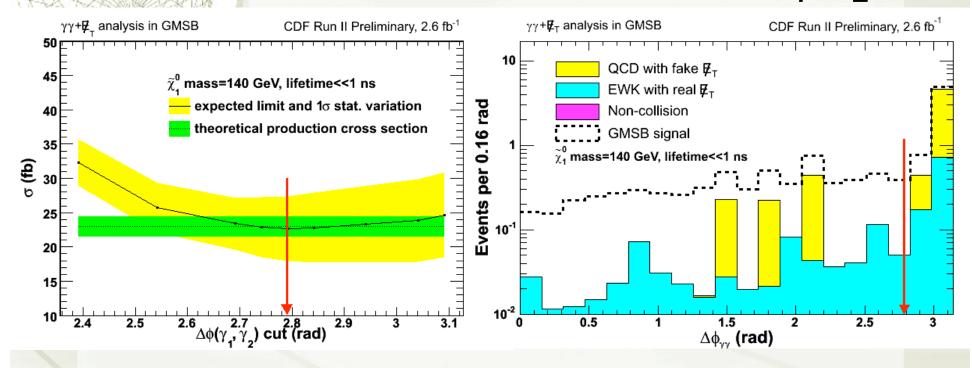

- ✦ While varying a cut all others held at optimal cuts: Minimal at Metsig=3

- ✦ N-1 Plot for background distributions along with GMSB signal: Good separation!

95% C.L. Cross Section Limits and N-1 Plot: H_T

$\gamma\gamma + \not{E}_T$ analysis in GMSB — CDF Run II Preliminary, 2.6 fb^{-1}

$\tilde{\chi}_1^0$ mass=140 GeV, lifetime<<1 ns
- expected limit and 1σ stat. variation
- theoretical production cross section

σ (fb) vs H_T cut (GeV)

$\gamma\gamma + \not{E}_T$ analysis in GMSB — CDF Run II Preliminary, 2.6 fb^{-1}

- QCD with fake $\not{E}_T$
- EWK with real $\not{E}_T$
- Non-collision
- GMSB signal
- $\tilde{\chi}_1^0$ mass=140 GeV, lifetime<<1 ns

Events per 20 GeV vs H_T (GeV)

✦ While varying a cut all others held at optimal cuts : Minimal at H_T=200 GeV

✦ N-1 Plot for background distributions along with GMSB signal: Good separation!

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95% C.L. Cross Section Limits and N-1 Plot: $\Delta\phi(\gamma_1,\gamma_2)$
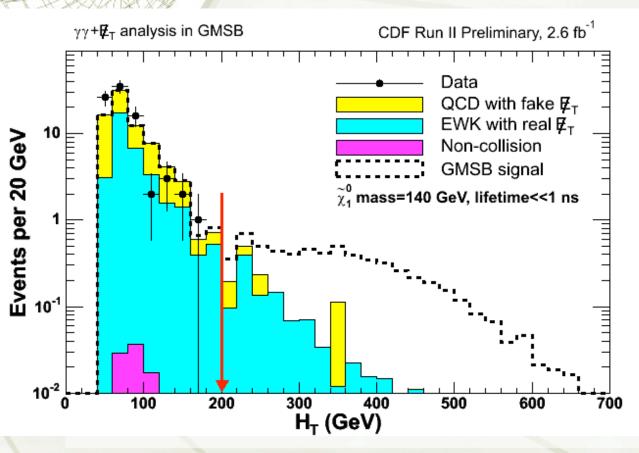
- ✦ While varying a cut all others held at optimal cuts : Minimal at $\Delta\phi(\gamma_1,\gamma_2)=\pi$-0.35 rad

- ✦ N-1 Plot for background distributions along with GMSB signal: Good separation!

Data and N-1 Plot: H_T

We open the box: 0 events observed

$\gamma\gamma + \not{E}_T$ analysis in GMSB — CDF Run II Preliminary, 2.6 fb^{-1}

Legend:
- Data
- QCD with fake $\not{E}_T$
- EWK with real $\not{E}_T$
- Non-collision
- GMSB signal

$\tilde{\chi}_1^0$ mass=140 GeV, lifetime<<1 ns

Events per 20 GeV vs H_T (GeV)
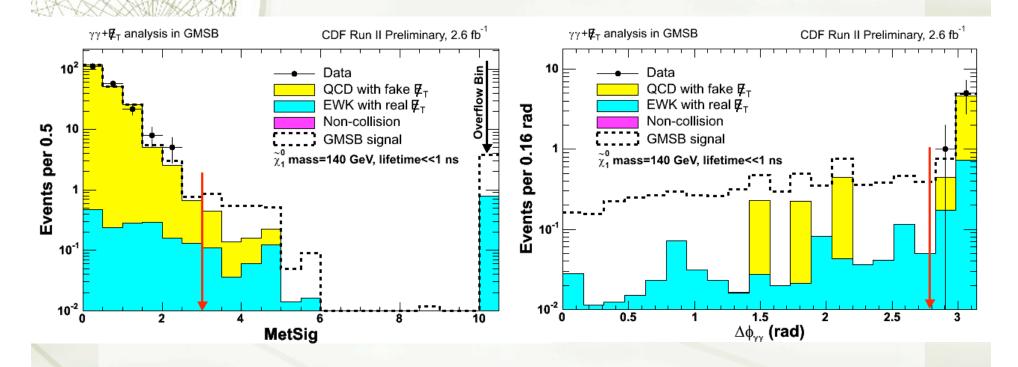
- ✦ For a distribution all other variables held at optimal cuts
- ✦ Everything is well modeled

Other N-1 Plots with Data
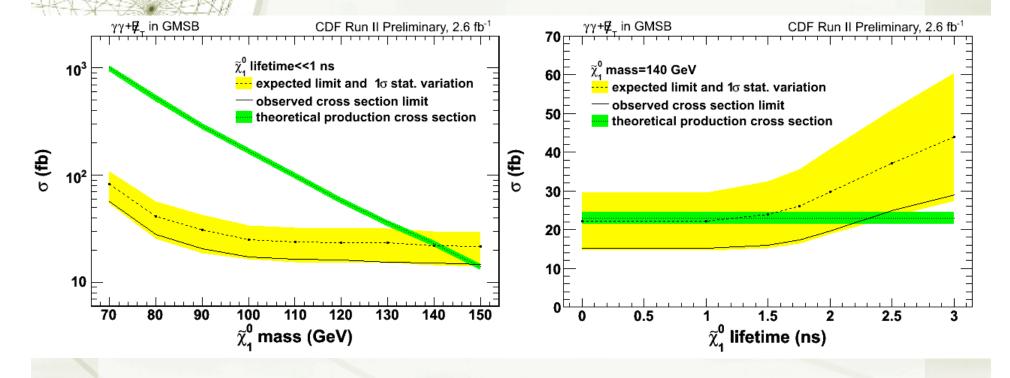
- For a distribution all other variables held at optimal cuts
- Again everything is well modeled

Cross Section Limits vs. Neutralino mass and lifetime
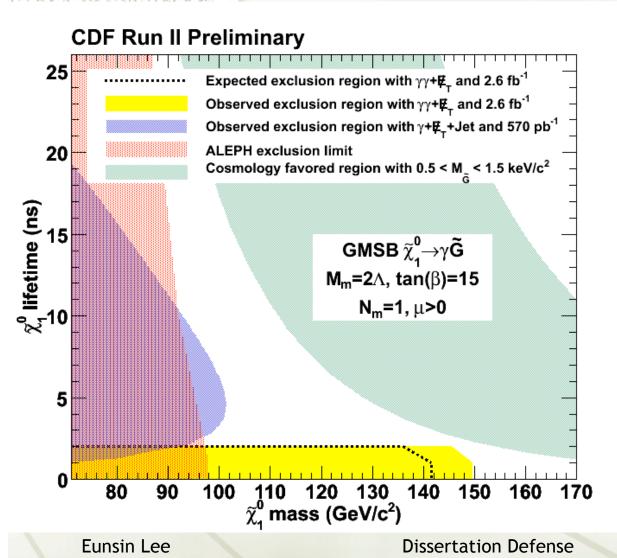
- ✦ **Using the optimal cuts:** $H_T > 200$ GeV $\Delta\phi(\gamma_1,\gamma_2) < \pi-0.35$ rad MetSig >3
- ✦ Expected (Observed) neutralino mass limit 141 GeV (149 GeV) for $\tau<<1$ ns

Exclusion Region

CDF Run II Preliminary
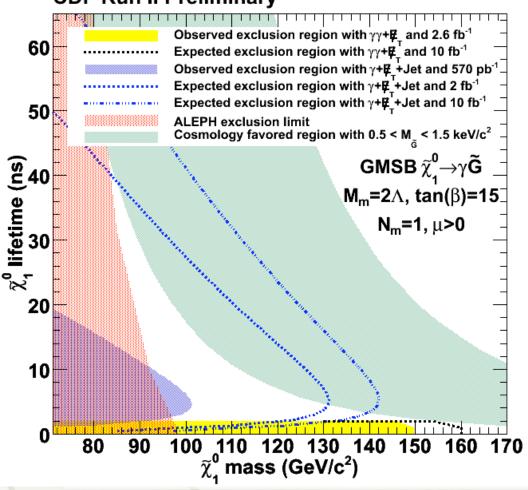
- ✦ Exclude up to ~ 149 GeV for τ < 2 ns (World-Best Limit)

- ✦ New Limits extend the sensitivity in both mass and lifetime. (goes above the Delayed Photon Analysis)

- ✦ We are nearing the cosmology favored region (green band)

Prospects for the Future

CDF Run II Preliminary

- ✦ 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

Conclusion

Summary

- First $\gamma\gamma$ search for neutralinos with non-zero lifetimes
- World's most sensitive search for low lifetime GMSB in $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$
- Observed 0 events consistent with 1.4 ±0.4 of background predictions
- Exclude neutralino mass up to 149 GeV for lifetime < 2 ns
- Published in Phys. Rev. Lett. 104, 011801 (2010)

Back Up

More on GMSB

- ✦ A minimal GMSB has only 6 "free" parameters while Minimal SUSY Model has 105 free parameters

- ✦ Intrinsically suppress flavor-changing neutral currents (FCNC), which is experimentally not observed

- ✦ Consistent with cosmological constraints as all SUSY particles produced in early universe decay to the $\tilde{G}$ Lightest SUSY Particle (LSP) which can be a warm dark matter candidate - More on this later

GMSB and Cosmology

✦ GMSB with non-zero $\tilde{\chi}_1^0$ lifetime and ~1 keV mass $\tilde{G}$ is favored as they are consistent with astronomical observations and early universe inflation model

✦ If $\tilde{G}$'s too light (< 1 keV) these will not contribute significantly to the total mass density of the universe - cosmic microwave background inconsistent with observation, may need another source of dark matter

✦ If $\tilde{G}$'s too heavy (> 1 keV) their density can cause the universe to "overclose"

✦ This cosmology constraints (m_{Grav}~1 keV) relate mass and lifetime of $\tilde{\chi}_1^0$

- small lifetimes (several ns) are favored for large masses (~100 GeV)
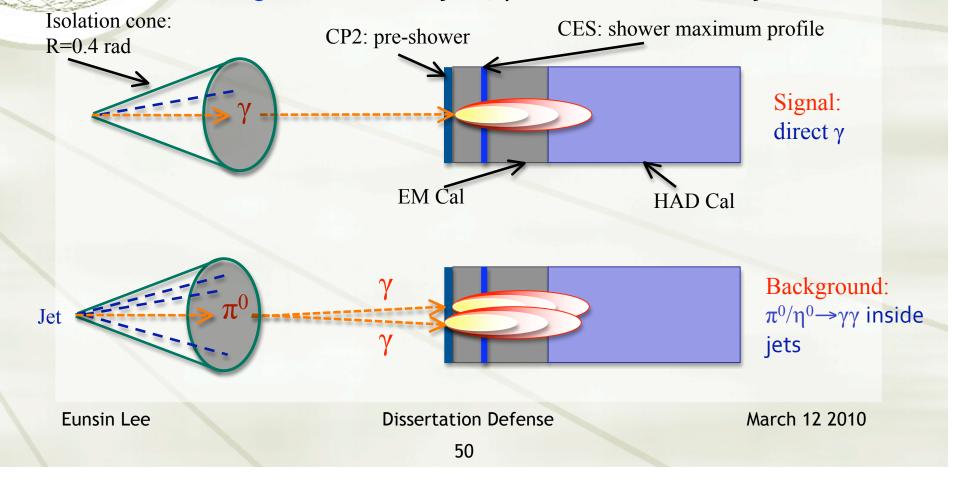
Good Runs, Triggers, Data Sets and Pre-Selection Cuts

- Data Stntuples: cdfpstn: cdipa(d,h,i,j) , cdfpstn: bhelb(d,h,i,j)
- Triggers : DIPHOTON_12 (iso), DIPHOTON_18 (no iso),
  PHO_50 (no iso), PHO_70 (no HadEm)
- Goodrun list: The good run list v.23 (up to and including period 17)
- Luminosity = 2.59 fb^{-1} with 6% uncertainty
- Code Release: cdfsoft 6.1.4, Stntuple dev_243
- Data Samples : $\gamma\gamma$ sample, W→eν sample (study EWK with real $\not{E}_T$),
  Z→e$^+$e$^-$ sample (study QCD with fake $\not{E}_T$)
- Pre-Selection Cuts:
  - $N_{vx12} \geq 1$, Highest ΣP_T Vertex, $|Z_{vx}| < 60$ cm
  - Two Central Photons ($E_T > 13$ GeV)
  - Standard Photon ID cuts and Phoenix rejection cut
  - PMT Spikes, Cosmics and Beam Halo removal cuts
  - Vertex Swap Procedure and Met Cleanup cuts

Concept of Photon ID

✦ Photon signature

✦ "Compact" EM cluster: shower contained in EM CAL

✦ No electric charge: no track (unlike electron)

✦ No color charge: unlike π^0 in jets, photon is isolated object

Isolation cone:
R=0.4 rad

CP2: pre-shower

CES: shower maximum profile

γ

Signal:
direct γ

EM Cal

HAD Cal

Jet

π^0

γ

γ

Background:
$\pi^0/\eta^0 \rightarrow \gamma\gamma$ inside
jets

Eunsin Lee

Dissertation Defense

March 12 2010

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Standard Central Photon ID Cuts
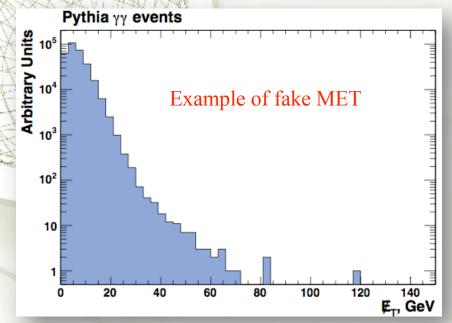
cuts	Tight cuts
Calorimeter fiduciality	central
Photon E_T	>13 GeV (7 GeV for pre-selection)
CES fiduciality	$\|X_{CES}\|<21.0$ cm; 9.0 cm$<\|Z_{CES}\|<230.0$ cm
Average CES χ^2	<20
Had/Em	$<0.055+0.00045*E_T$
Corrected CalISO	$<2.0+0.02(E_T-20)$ or $<0.1*E_T$ if $E_T<20.0$ GeV
TrkISO	$<2.0+0.005*E_T$
N3D	N3D=0,1
Trk P_T (if N3D=1)	$<1.0+0.005*E_T$
2nd CES (wire or strip)	$<0.14*E_T$ if $E_T<18$ GeV or $<2.4+0.01*E_T$ if $E_T>18$ GeV
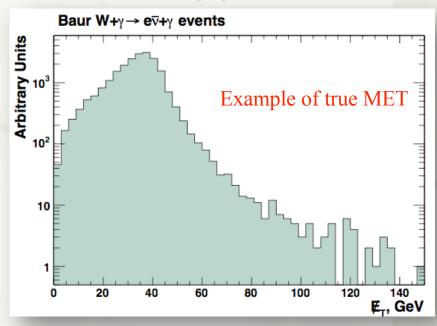
Phoenix rejection	No photons matched to phoenix track
PMT spike rejection	|pmt1-pmt2|/(pmt1+pmt2)<0.65

Fake MET Problem in γγ+MET

Pythia γγ events — Example of fake MET

Baur W+γ → eν̄+γ events — Example of true MET
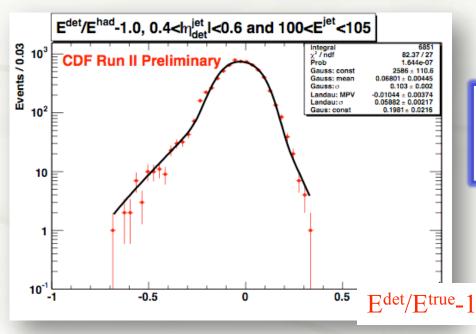
- ✦ MET distribution in γγ events is dominated by regular "QCD" events with fake MET

- ✦ MC is not reliable in modeling multi-jet events:
  - ✦ not accurate description of fake MET

- ✦ How do you distinguish events with true & fake MET?

Met Resolution Model

Example of jet energy resolution

$E^{det}/E^{true}-1$

Mis-measurements in jet energy are leading source of fake MET

Obtain jet energy resolution as function of E^{jet} & η

- ✦ Predicting fake MET
  - ✦ Smear jets & soft particles in $\gamma\gamma$ events according to energy resolution

- ✦ Select events with true MET
  - ✦ Use MET-significance to select with true MET
  - ✦ Calculate MET-significance based on event configuration & known energy resolution
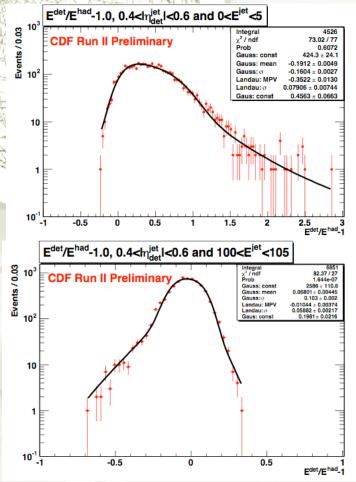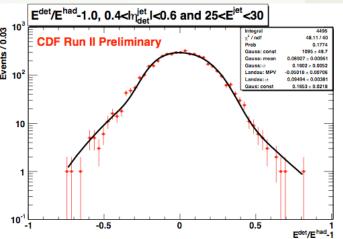
J.E.R.- Key Part of METMODEL
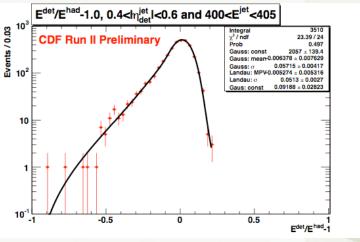
Gauss+Landau fits JER well at any E_{jet} and η

$$\frac{C*G(y) + L(y)}{1+C},$$

$$where \ y = \frac{-x}{1+x},$$

$$x = \frac{E^{had}}{E^{det}} - 1$$
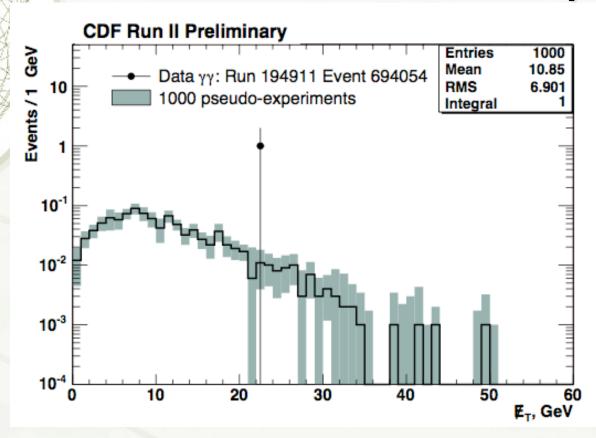
✓ Smooth parameterization of JER as a function of E_{jet} in bins of η_{det} (bin size of 0.2)

Met Model Example-1

CDF Run II Preliminary

Data γγ: Run 194911 Event 694054
1000 pseudo-experiments

Entries 1000
Mean 10.85
RMS 6.901
Integral 1

Events / 1 GeV

$\not{E}_T$, GeV
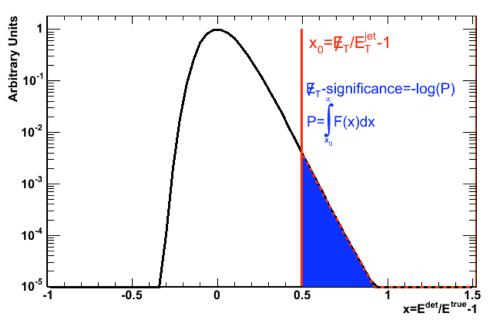
✦ Met Model gives a PDF of possible MET values due to energy mis-measurements (also available in XY)

   ✦ This is done by smearing un-clustered and each jet energy according to their resolution

METMODEL & Significance

- ✦ Takes into account individual jet resolution
- ✦ Accounts for relative direction of MET and jet
- ✦ Eliminates need for $\Delta\varphi$ (MET-jet) cuts
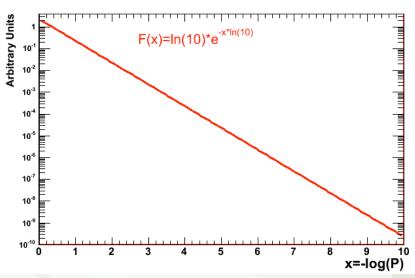
New MET-sig=-log(P) for fake MET:
Simple shape for any distribution F(x)
For 10,000 events:
Cut on Sig>1 $\Rightarrow$ ~1,000 events pass
Cut on Sig>2 $\Rightarrow$ ~100 events pass
Cut on Sig>3 $\Rightarrow$ ~10 events pass
Cut on Sig>4 $\Rightarrow$ ~1 event pass
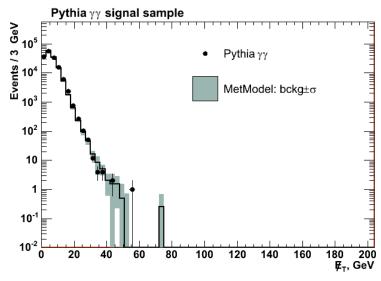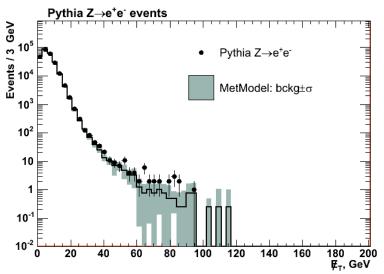
$F(x) = \ln(10) \cdot e^{-x \cdot \ln(10)}$

How Well METMODEL Works

Pythia γγ signal sample

Pythia Z→e⁺e⁻ events

Baur Wγ→ eν̄+γ signal sample
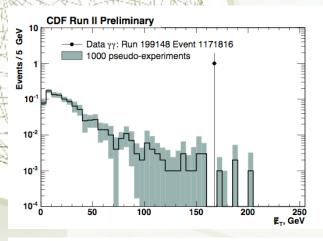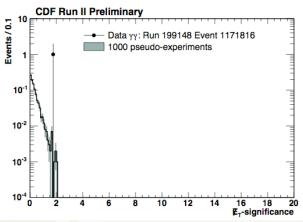
- ✦ Met Model successfully describes MET in Pythia $\gamma\gamma$ and Z events where there is no real MET
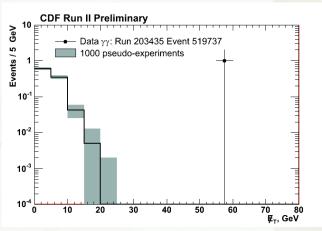
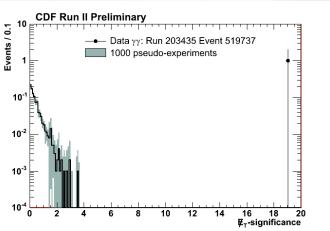- ✦ Just as expected, it doesn't describe MET in Baur Wγ events with real MET
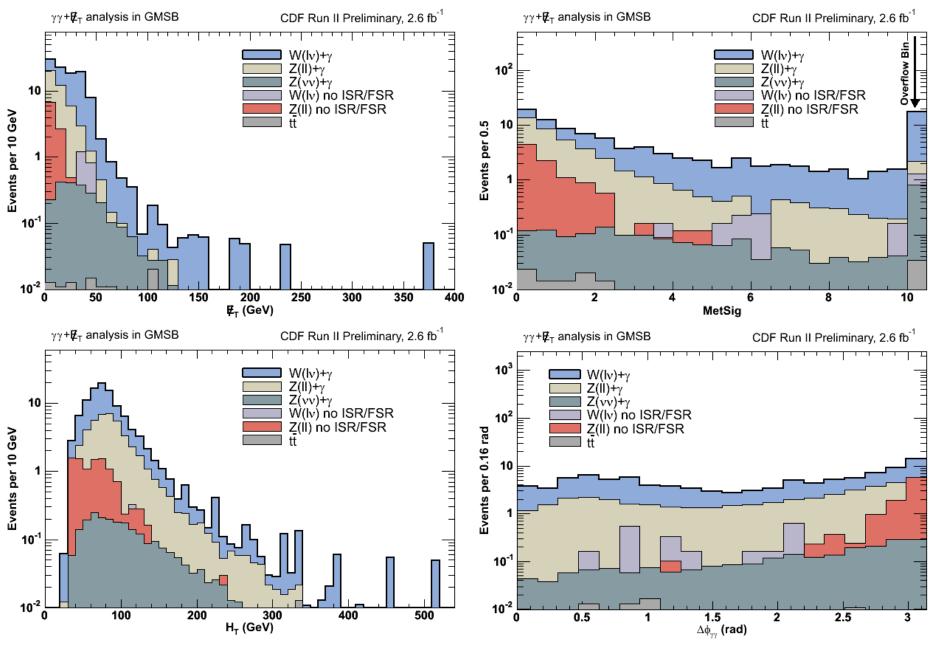
"New" MET Significance

- **"Old" Metsig**
  - Sig=MET/$\sum$E
- **Event-1**
  - largest MET
  - MET=165.1 GeV
  - METsig
    - METMODEL: 1.76
    - "Old" Metsig: 7.65
- **Event-2**
  - MET=57.1 GeV
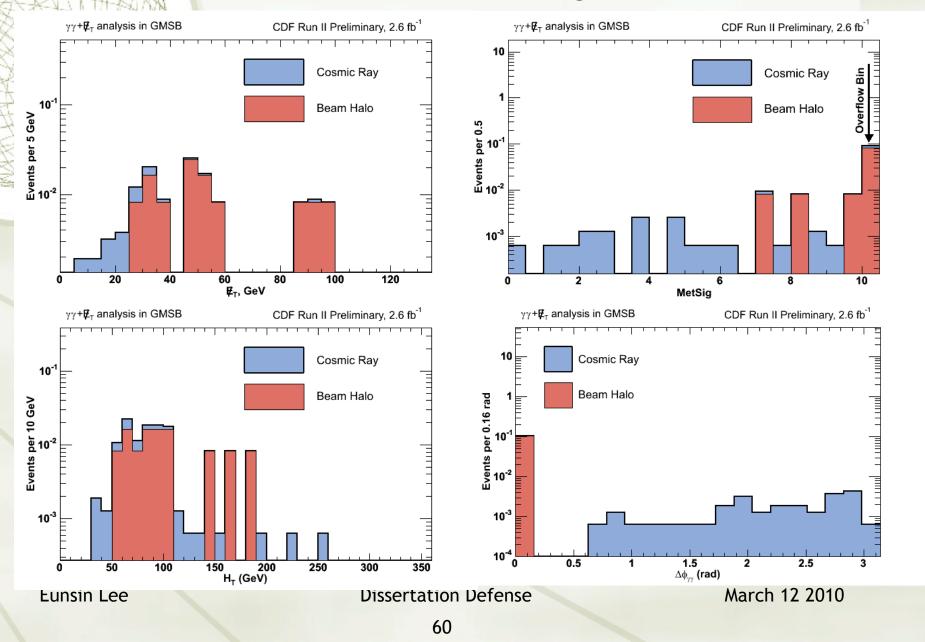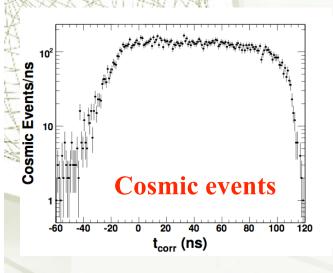 - METsig
    - METMODEL: >18.0
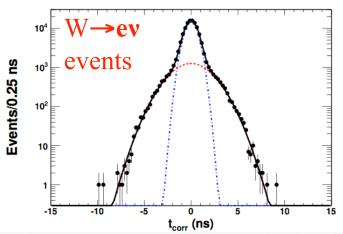   - "Old" Metsig: 5.45

EWK Backgrounds Distributions

Non-Collision Background Distributions

Cosmics & EMTiming

Cosmic events

W→eν events

EM timing resolution:

True vertex: $\sigma \sim 0.7$ ns
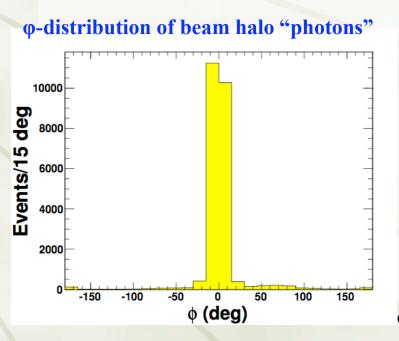
Wrong vertex: $\sigma \sim 1.9$ ns

★ Cosmics
  ✦ Significant background for γ+MET and "delayed" photon searches
  ✦ Arrives independently of collision time
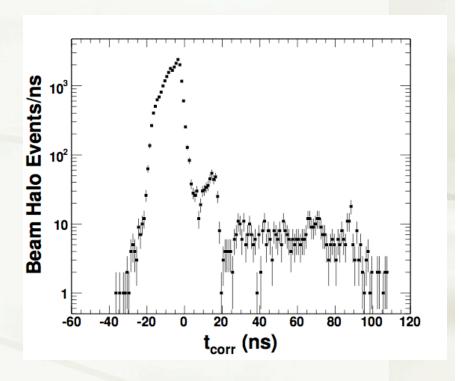 o Use W→eν events to study EM timing in true collision events

Beam Halo

φ-distribution of beam halo "photons"

✦ Beam Halo rejection

  ✦ Topological cuts and EM timing

Diphoton Events after Pre-selection

Requirements	Events passed
Trigger, Goodrun, and Standard Photon ID with $E_T>13$ GeV	45,275
Phoenix Rejection	41,418
PMT Spikes Rejection	41,412
Vertex requirements	41,402
E_T(swap)>13 GeV after vertex swap	39,719
Beam Halo Rejection	39,713
Cosmic Rejection	39,663
Met Cleanup Cuts	38,053

✦ 38,053 events pass these pre-selection cuts

Uncertainties (bkg)

✦ QCD with fake MET

    - METMODEL: syst. from METMODEL parameterizations

                   stat. from pseudo-experiment (dominant)

    - PATHOLOGIES: syst. from SF, MC-data differences in METMODEL paramterization, JES

                     stat. from MC (dominant)

✦ EWK with real MET

  - stat. from MC

  - MC-to-data normalization uncertainies (dominant): include stat. from $e\gamma$ data and MC, syst. from differences in MC modeling (E/p)

✦ Non-collision

  - dominant in stat.

Systematic Uncertainties (signal)

- ✦ Acceptance
  - Diphoton ID and Isolation: 5.4%
  - ISR/FSR: 4.0%
  - JES: 1.5%
  - MetSig parameterization: 0.7%
  - PDFs: 0.6%
- ✦ Cross Section
  - PDFs: 7.5%
  - Q^2: 2.6%
- ✦ **Total (combined in quadrature): 10.6%**