Blessing Talk at Exotic

Setting Limits on GMSB Models in the $\gamma\gamma + \not\!\!E_T$ final state with 2 fb^{-1}

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Outline

- Analysis Introduction
- Background Sources and Data Sets
- Background Estimations
- GMSB MC Simulation
- Optimization and Setting Limits
- Conclusion and Plan

Analysis Introduction

Dominant Signal Process and Previous Searches

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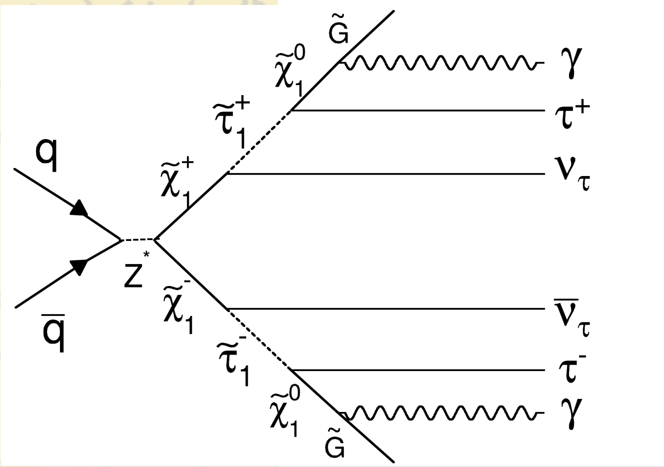
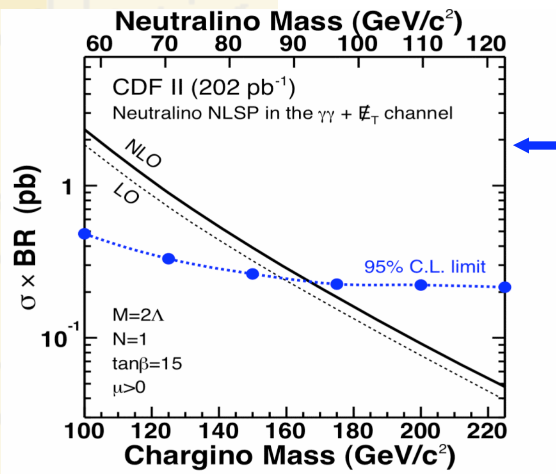


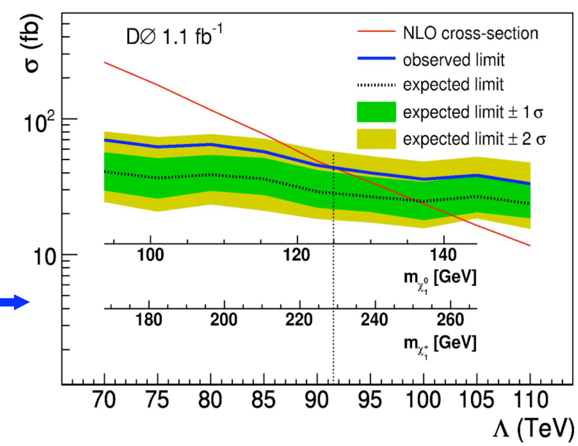
- Looking for $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$
- Both neutralinos decay in the detector $\Rightarrow$ Two photons
- $\gamma\gamma + \not{E}_T$: Optimal for low lifetimes (τ=0 and 1 ns)

D.Toback and P.Wagner, Phys.Rev.D70, 114032 (2004)

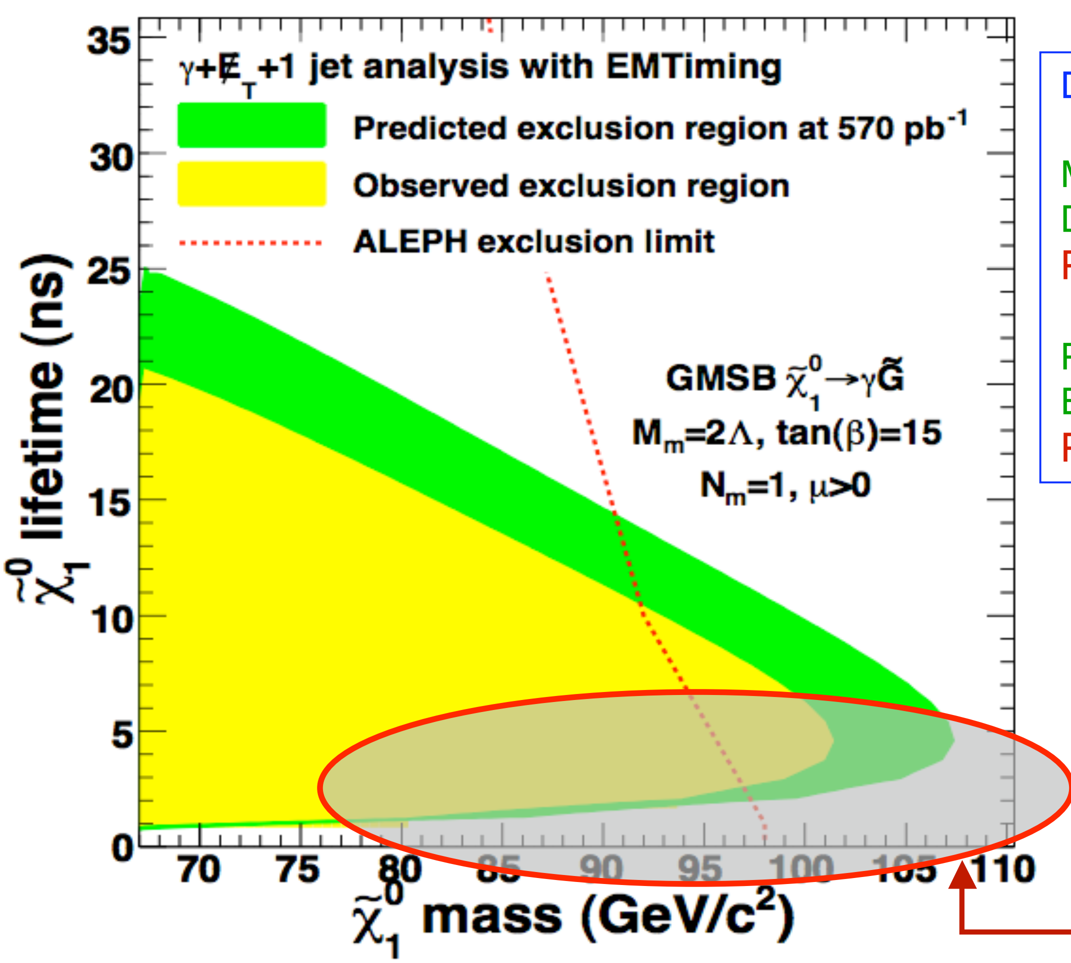


Previous Search at CDF (202 pb^{-1})
Phys.Rev.D71, 031104 (2005)

Recent Search at DØ (1.1 fb^{-1})
Phys.Lett.B659, 856 (2008)



Exclusion Region from the Delayed Photon Search



Delayed Photon Analysis

M.Goncharov, V.Krutelyov, E.Lee, D.Toback and P.Wagner
Phys. Rev. Lett 99, 121801 (2007)

P. Geffert, M.Goncharov, V.Krutelyov, E.Lee, D.Toback and P.Wagner
Phys. Rev. D 78, 032015 (2008)

- Single Delayed Photon : Not sensitive to low lifetimes
- Trying to understand our sensitivity here and for larger masses

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Background Sources and Data Sets

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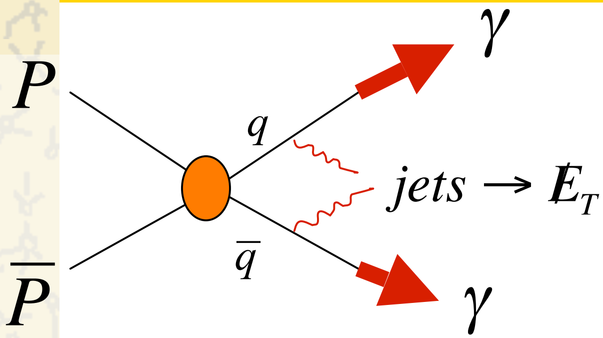
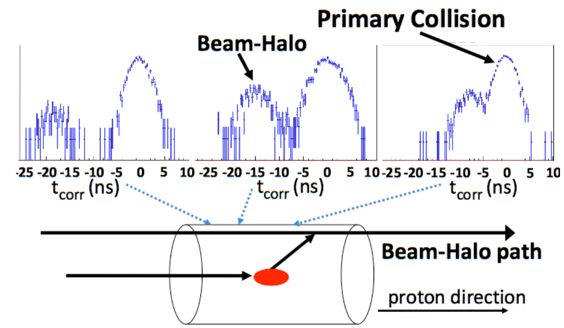
Background Sources



Collision (SM) Background



Non-Collision Background
: Cosmic and Beam Halo

- QCD Events ($\gamma\gamma, \gamma - jet \rightarrow \gamma\gamma_{fake}$ *and* $jet - jet \rightarrow \gamma_{fake}\gamma_{fake}$) with fake $\not{E}_T$ due to energy mis-mearsurement
- EWK Events (mostly eγ or τγ - type events)with real $\not{E}_T$
- Non-Collision Backgrounds (PMT spikes, cosmic rays, beam halo)
- Wrong Vertex Events where one or both photon candidates are coming from the vertex other than the highest ΣP_T vertex, causing large mis-measurement of the $\not{E}_T$
- Triphoton Events with a lost photon that creates the fake $\not{E}_T$

⇒ To reduce these backgrounds, we require di-photon events to pass the global event selection, photon ID, non-collision background removal cuts (CDF note 9184)

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)
- Goodrun list: The good run list v.17 (up to and including period 11)
- Luminosity = 2.03 fb^{-1} with 6% uncertainty
- Code Release: cdfsoft 6.1.4, Stntuple dev_243
- Data Samples : $\gamma\gamma$ sample, $W \to e\nu$ sample (study EWK with real $\not{E}_T$),
  $Z \to e^+e^-$ 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

Standard Central Photon ID Cuts

cuts	Tight cuts
Calorimeter fiduciality	central
Photon E_T	>13 GeV (7 GeV for pre-selection)
CES fiduciality	$\lvert X_{CES}\rvert<21.0$ cm; 9.0 cm$<\lvert Z_{CES}\rvert<230.0$ 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)	$<1.0+0.005*E_T$
2^{nd} 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	$\lvert pmt1-pmt2\rvert/(pmt1+pmt2)<0.65$

Non-Collision Background Removal Cuts

- PMT Spikes (CDF note 7960) removed by requiring:

  i) E_{CEM}>10 GeV and |pmt1-pmt2|/(pmt1+pmt2)<0.65 (removes ~100%)

  ii) E_{HAD}>10 GeV and |pmt1-pmt2|/(pmt1+pmt2)<0.85 (studied by looking on balanced jets)

- Beam Halo(CDF note 7960, 8409) removed by requiring:

  seedWedge>4, NHadPlug>2,

  seedWedgeHadE<0.4+(M.I.*(N_{vx12}-1)+U.E.)*seedWedge

- Cosmics(CDF note 7960) removed by two different category cuts:

  i) Data ("old") before run 190851(no EMTiming system) ⇒ No events with trackless muon stub within 30^{o} around photon direction

  ii) Data ("new") after run 190851(EMTiming system)

  ⇒ $|T_{1,2}| > 4\sigma_T$ where σ_T=1.665 ± 0.007 ns using Z→ee data sample

  ⇒ $|\Delta T=T_1-T_2| > 4\sigma_{\Delta T}$ where $\sigma_{\Delta T}$=1.021 ± 0.007 ns using Z→ee data sample

Diphoton Events after Pre-selection

Requirements	Events passed
Trigger, Goodrun, and Standard Photon ID with E_T>13 GeV	36,802
Phoenix Rejection	33,899
PMT Spikes Rejection	33,796
Vertex Cuts	32,899
Beam Halo Rejection	32,890
Cosmic Rejection (EMTiming cut for Runs after 190851)	32,865
Cosmic Rejection (Muon Stub Cut for Runs before 190851)	32,720
Total Events passed	**32,720**

- 32,720 events pass these pre-selection cuts
- Next we will talk about the backgrounds and the signal
- Then we will talk about the 3 variables and methods we will use to optimize our analysis for GMSB

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Background Estimations

QCD Background with Fake $\not{E}_T$

- Predict a shape of fake $\not{E}_T$ (un-clustered energy and jets) by means of Met Resolution Model (CDF note 9184)
- For un-clustered energy $\not{E}_T$ distributions fitted with double Gaussian parameterized by MC samples (Pythia $\gamma\gamma$, Pythia $Z\to e^+e^-$) and Data ($\gamma\gamma$ control sample, $Z\to e^+e^-$)
  - ⇒ Systematics: Difference between $\gamma\gamma$ control sample and $Z\to ee$ and Uncertainty on evolution of 4 parameters
- For jets obtain jet energy resolution as a function of jet E_T. The jet resolution is parameterized by Gaussian+ Landau fit (Pythia di-jet, Pythia Z/γ^*, Pythia Z+jet and di-jet, Z+jet data)
  - ⇒ Sytematics: Uncertainty on evolution of 5 parameters
- Sum up all of individual $\not{E}_T$ components due to un-clustered energy and each of jets with $E_T^{smear} > 15$ GeV
  - ⇒ Sytematics: 10 individual sources combined in quadrature

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EWK Background with Real $\not{E}_T$

- Process: Boson & Di-Boson production

($W\gamma \to \nu + l + \gamma \to \nu + \gamma(\gamma_{fake}) + \gamma$, $Z\gamma \to ll + \gamma \to \gamma(\gamma_{fake}) + \gamma + X$, $Z \to \mu\mu/\tau\tau \to \gamma\gamma/\gamma_{fake}\,\gamma_{fake}$)

- Signature: ~50% of events have at least one γ faked by electron

  (~60% of $e \to \gamma_{fake}$ are due to Bremsstrahlung)

- Select e+ γ event in data and MC and $\gamma\gamma$+Met in MC

  ⇒ Consider all decay channels of W/Z, scale MC to Data, and account for missing contributions due to γFSR and $\tau \to \gamma$

$$EWK\ Bckg = \frac{DT(e\gamma)}{MC(e\gamma)} MC(\gamma\gamma + \not{E}_T)$$

Non-Collision Background

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- PMT Spikes:

  Very rare and a distinctive signature (remove very efficiently) : Negligible (remaining PMT spike events are zero)

- Beam Halo:

  Estimate how many B.H. remain based on rejection power F_{BH}(~90%) :

  $N_{BH}*(1/F_{BH}-1)*F_{cosmic}$ where F_{cosmic}(~67%) is cosmic rejection power

- Cosmic Rays:

  Determine γγ-like cosmic ray event rate and rejection power for "old" data and then extrapolate these to "new" data

⇒ **More details of these estimations in CDF note 9184**

Wrong Vertex and Triphoton Events

- Wrong Vertex
  - A class of QCD not estimated by Met Model
  - Events where an interaction producing two photon candidates did not give a vertex and overlapped with Min Bias
  - Using PYTHIA diphoton sample where a true diphoton vertex was not matched to any reconstructed vertex for template
  - Normalization is determined from MC and Zero Bias data.

- Triphoton Event with a lost photon
  - Another class of QCD not estimated by Met Model
  - Select triphoton events at HEPG level in MC for template
  - Normalization is given by N_{Data} (tripho)/ N_{MC} (tripho), where all three photons are reconstructed.

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GMSB MC Simulation and Systematic Uncertainties

GMSB MC Simulation

- Use Pythia to generate the GMSB signal and cdfSim(Gen6) to simulate the detector.
- The EMTiming system is simulated. (CDF note 7982)

  http://hepr8.physics.tamu.edu/elee/EmtimeSimul.html

- Generate Neutralino MC samples with the following parameters fixed on the minimal GMSB Snowmass Slope SPS 8 with a neutralino NLSP

$$N = 1, \quad \frac{M_m}{\Lambda} = 2, \quad \tan\beta = 15, \quad \mu > 0$$

- Assuming 18% acceptance error for now - Phys.Rev.D71, 031104 (2005).
- Generate different mass (70 GeV - 150 GeV) and lifetime (0 ns - 2 ns) points.

Systematic Uncertainties

- Selection cut (HAD/EM, χ^2, N3D, track P_T, track Iso, fiducial,conversion): 13%
- PDFs: +1% –5%
- ISR/FSR: 10%
- Q^2: 3%
- MC statistics: 1%
- Luminosity: 6%
- **Total (combined in quadrature): 18%**

R. Culbertson, D. Kim, M. Kim, S. Lee, and D. Toback
Search for Anomalous Production of di-photon MET at CDF and Limits on GMSB Models (CDF/PRD) :Phys.Rev.D71, 031104 (2005), hep-ex/0410053

- New studies have smaller values (not finished yet), but we are using these now to be conservative

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Optimization and Setting Limits

Optimization Strategy and Expected Limits

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- We are going from the pre-sample defined on the earlier pages and then do an optimization
- Pick a GMSB parameter point (mass=140 GeV, lifetime=0 ns) around our limit and find the optimal cuts by calculating the lowest 95% C.L. expected cross section limit. (will check for other masses as a check)
- We use the standard cross section limit calculator taking into account the expected no. of background events, acceptance, luminosity and their errors
- Pick a single set of optimization variable cuts (next slide)
- Map it out as a function of neutralino mass and lifetime.

The Optimization Cuts

- MetSig : get rid of QCD with fake Met
  - GMSB prodcution has mostly real Met
- H_T : get cascade decays from heavy particles
  - In GMSB production heavy gaugino pair-production dominates
  - The gaugino pair decays to high E_T, light final state particles via cascade decays
  - GMSB signal has lots of H_T compared to SM backgrounds
- $\Delta\phi(\gamma_1,\gamma_2)$: get rid of back-to-back photons and wrong vertex
  - EWK backgrounds with large H_T are typically a high E_T photon recoiling against W boson, which is highly boosted ⇒ The two photons in the final state are mostly back-to-back.
  - The high E_T diphoton with large H_T from QCD are mostly back-to-back with fake Met
  - The high E_T diphoton with fake Met for wrong vertex can also be removed

Optimization Results

H_T > 200 GeV
$\Delta\phi(\gamma_1,\gamma_2) < \pi - 0.15$ rad
MetSig > 3

- Example point (100K Events)
  $m(\chi^0_1)$=140 GeV, $\tau(\chi^0_1)$=0 ns
- Acceptance : 9.21±1.66 (%)
- Luminosity Error : 6 %

σ_{exp} = 22.24 fb

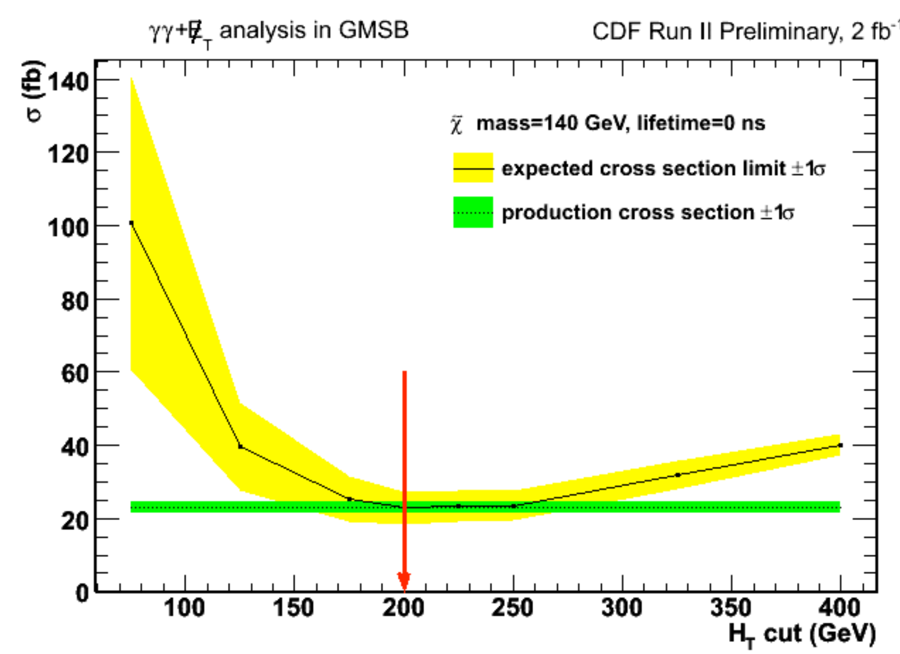
σ_{prod} = 22.97 fb

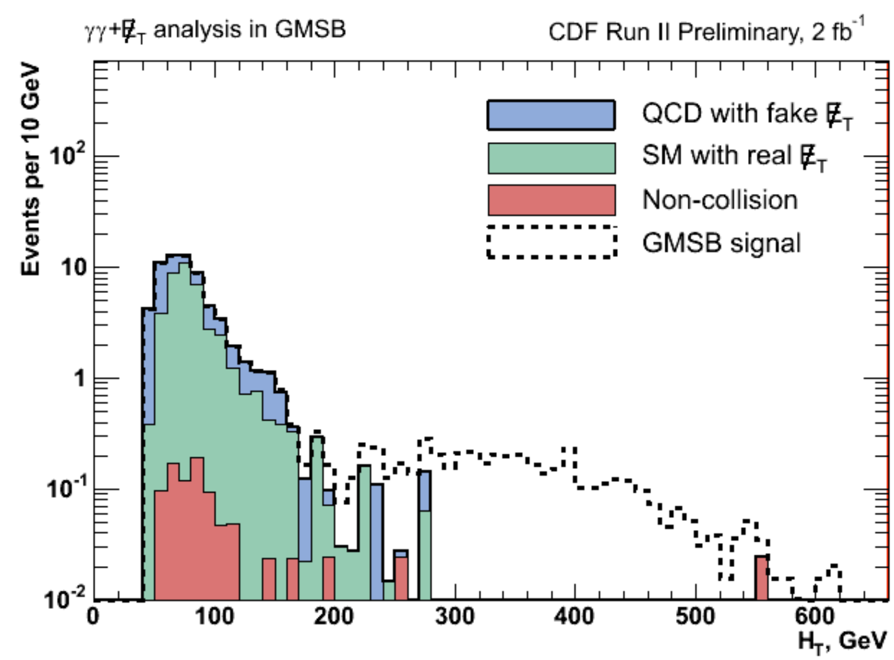
Background Estimations	
EWK	0.39 ± 0.14 ± 0.11
Non-Collision	0.049 ± 0.042 ± 0.028
Tri-Pho	0.00 ± 0.180 ± 0.035
Wrong Vertex	0.00 ± 0.081 ± 0.008
QCD	0.1 ± 0.1 ± 0.0
Total	0.62 ± 0.26 ± 0.12

The Plots to be Pre-Blessed

All Plots from here on out to be blessed

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





- **While varying a cut all other variables held at optimal cuts**
- **N-1 plot for background distributions along with GMSB MC signal shows good separation**

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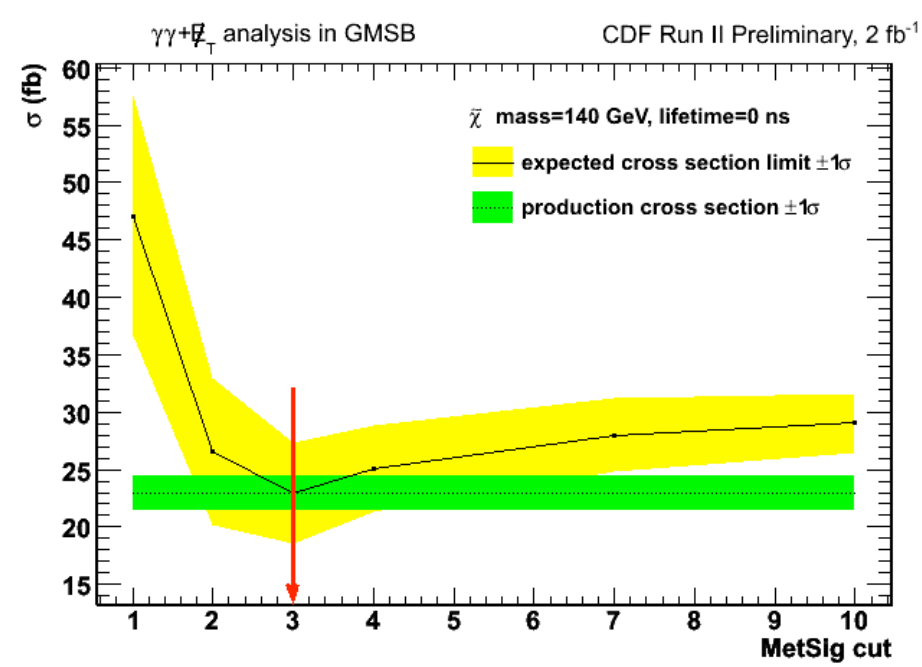
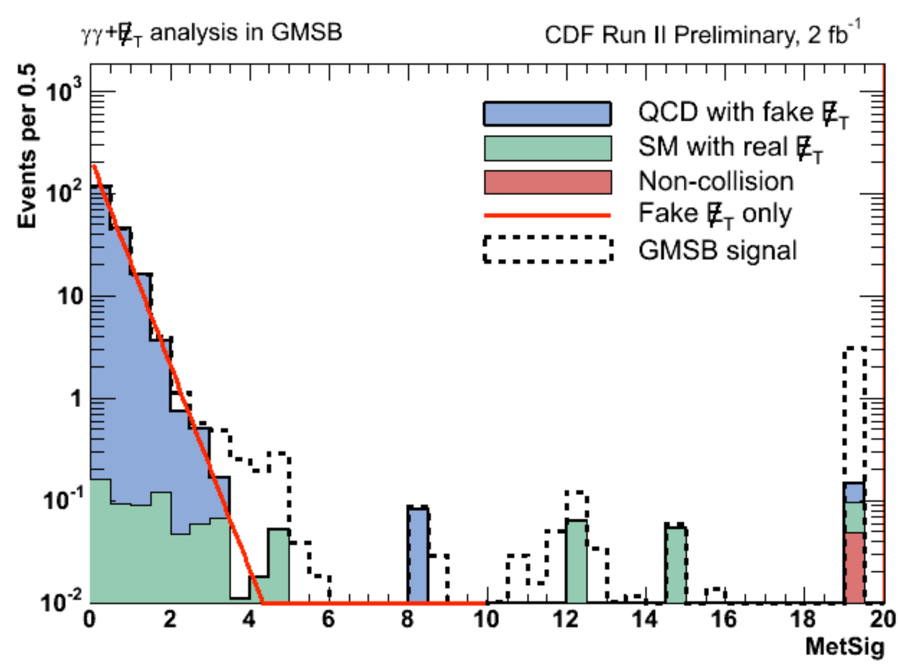
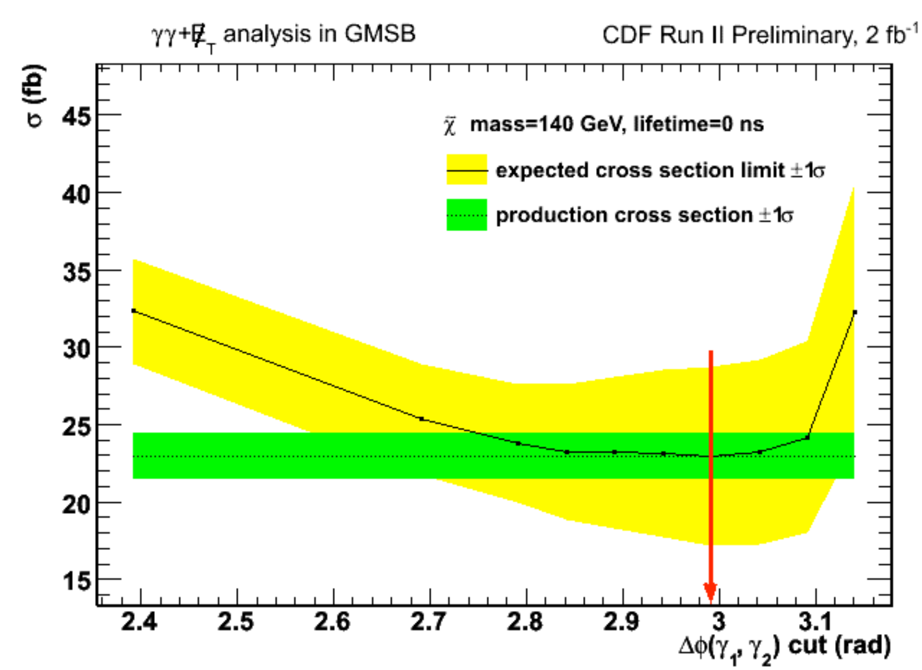
95% C.L. Expected Cross Section Limit and N-1 Plot: MetSig

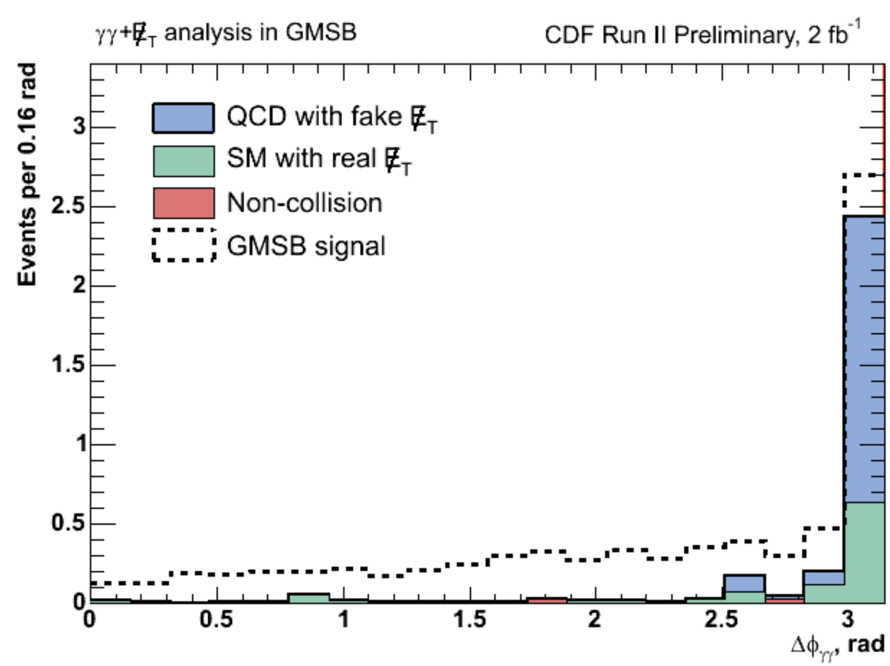




- **While varying a cut all other variables held at optimal cuts**
- **N-1 plot for background distributions along with GMSB MC signal shows good separation**

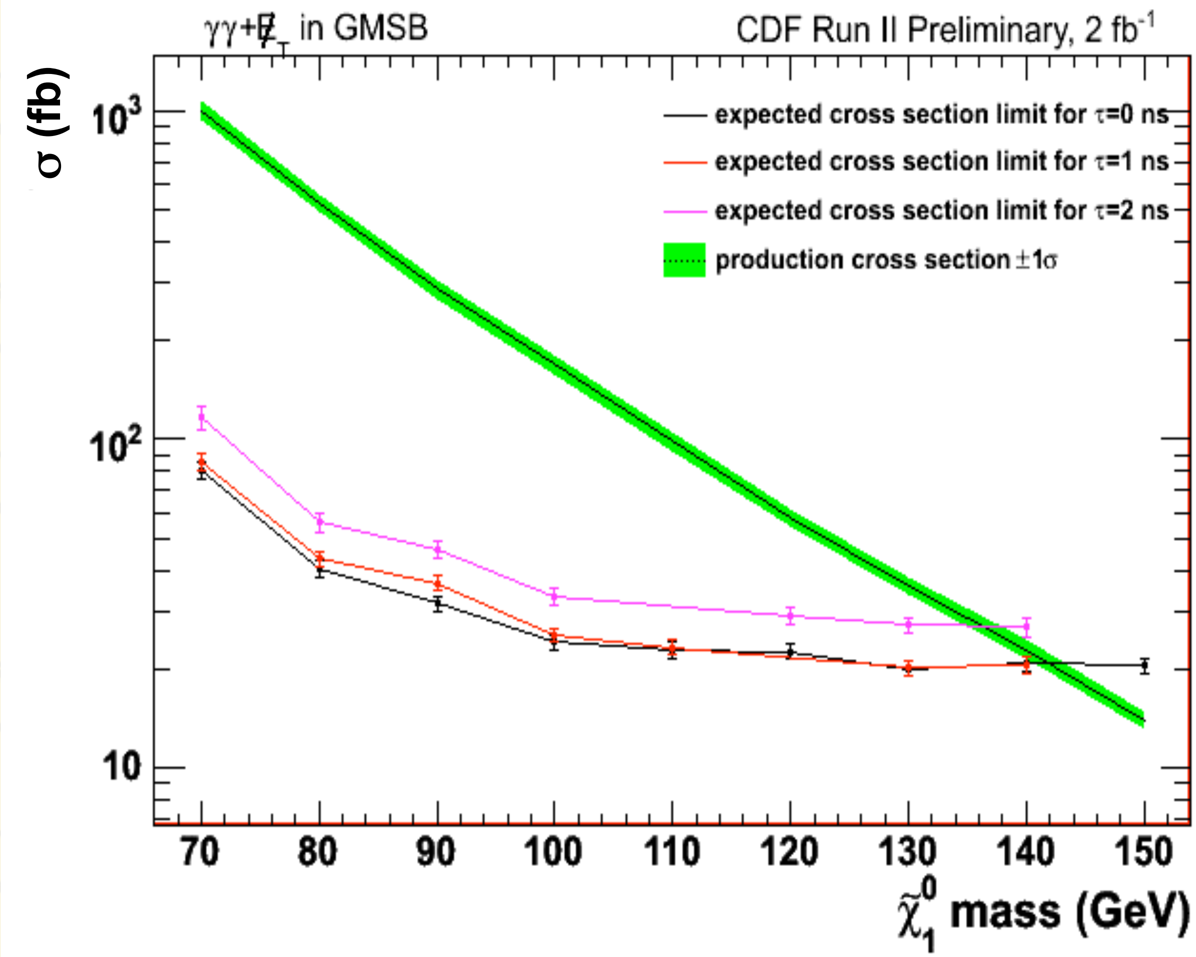
95% C.L. Expected Cross Section Limit and N-1 Plot: $\Delta\phi(\gamma_1,\gamma_2)$





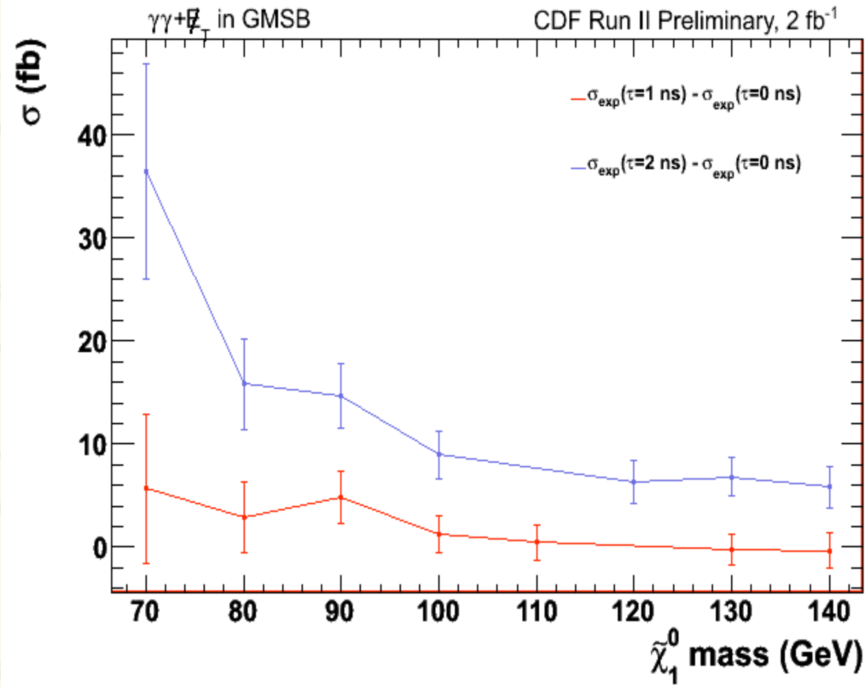
- **While varying a cut all other variables held at optimal cuts**
- **N-1 plot for background distributions along with GMSB MC signal shows good separation**

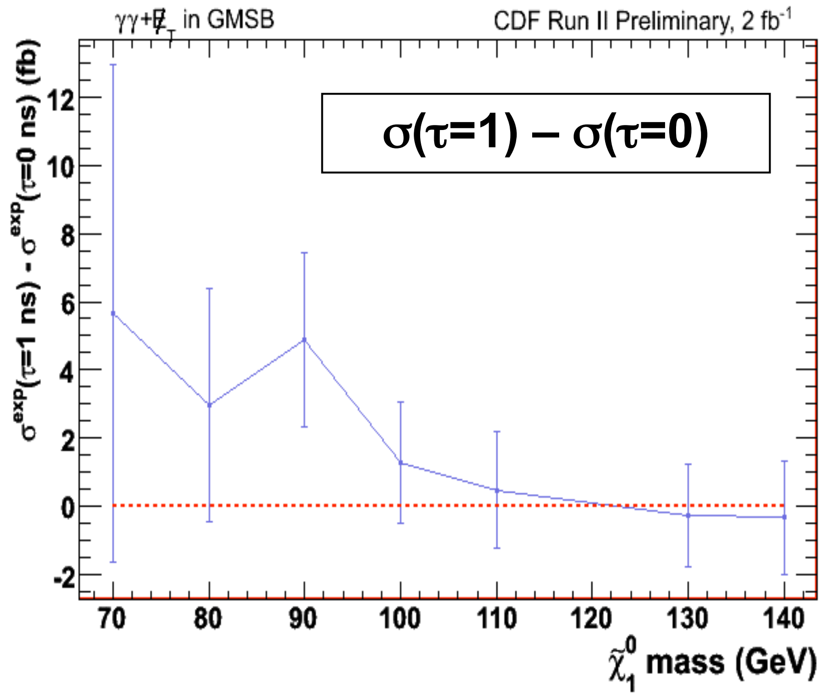
Lifetime Studies on GMSB



- No difference between τ=0 and 1 ns
- τ=2 ns: not the same shape as τ=0 ns, but close
- Eventually we will parameterize the limits vs. mass and lifetime.

Lifetime Studies on GMSB -cont.

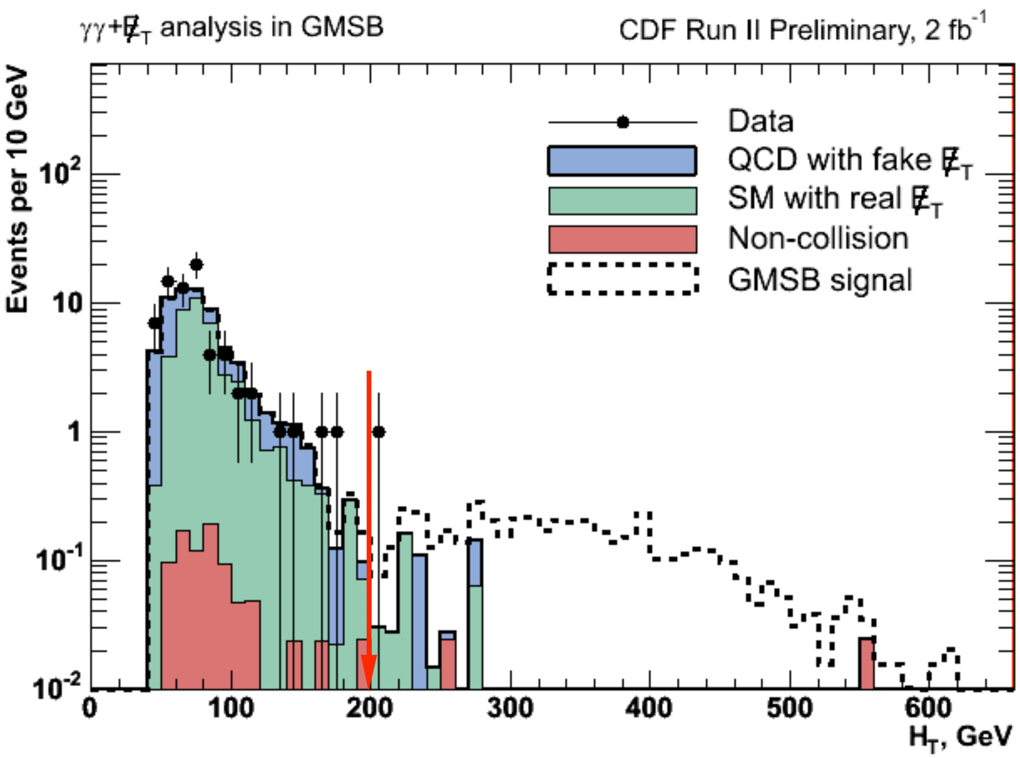




- **Limits at τ =1 ns are identical to τ=0 ns within errors**
- **For low lifetimes (2 ns) shape has largely the same mass dependence until low masses. (More neutralinos leaving the detector because of long lifetime)**

N-1 Plots

We open the box: 1 event observed



- For a distribution all other variables held at optimal cuts
- Everything is well modeled

The table to be pre-blessed

Background Estimations	
EWK	0.39 ± 0.14 ± 0.11
Non-Collision	0.049 ± 0.042 ± 0.028
Tri-Pho	0.00 ± 0.180 ± 0.035
Wrong Vertex	0.00 ± 0.081 ± 0.008
QCD	0.1 ± 0.1 ± 0.0
Total	0.62 ± 0.26 ± 0.12
Data	1

We have looked at this event and there is no evidence it is from GMSB

More N-1 Plots

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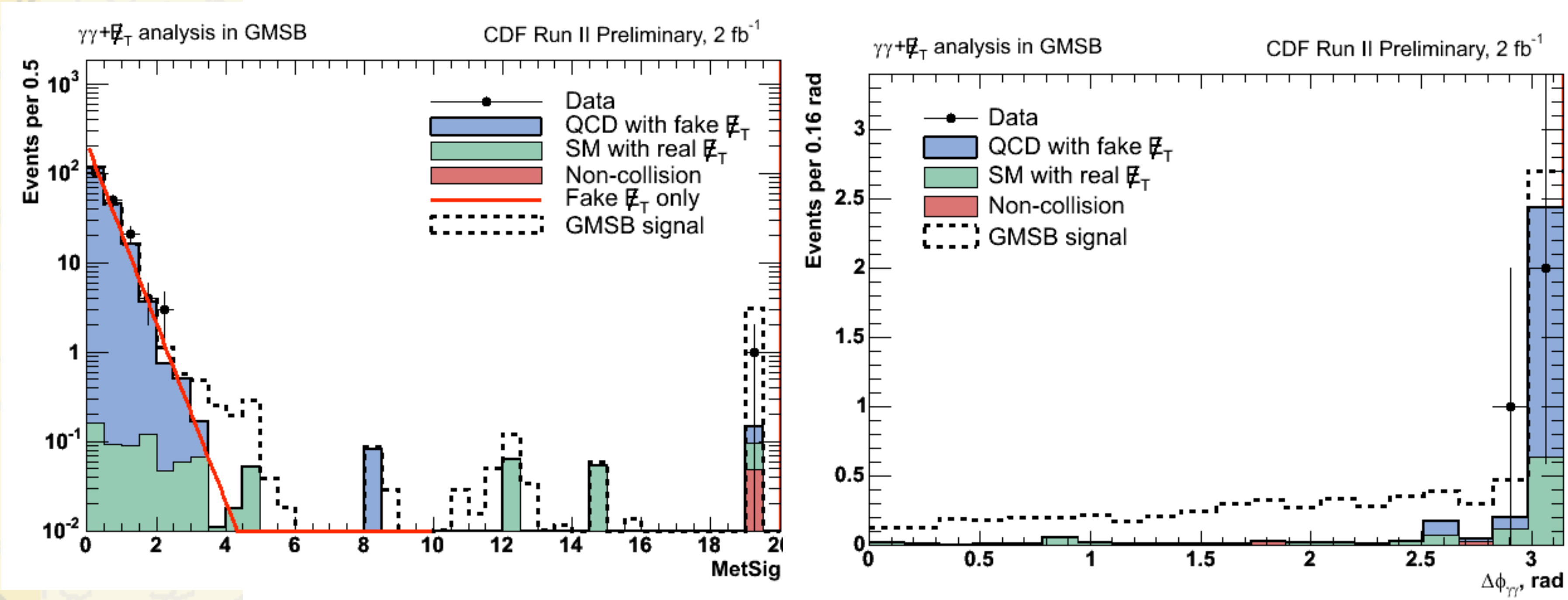
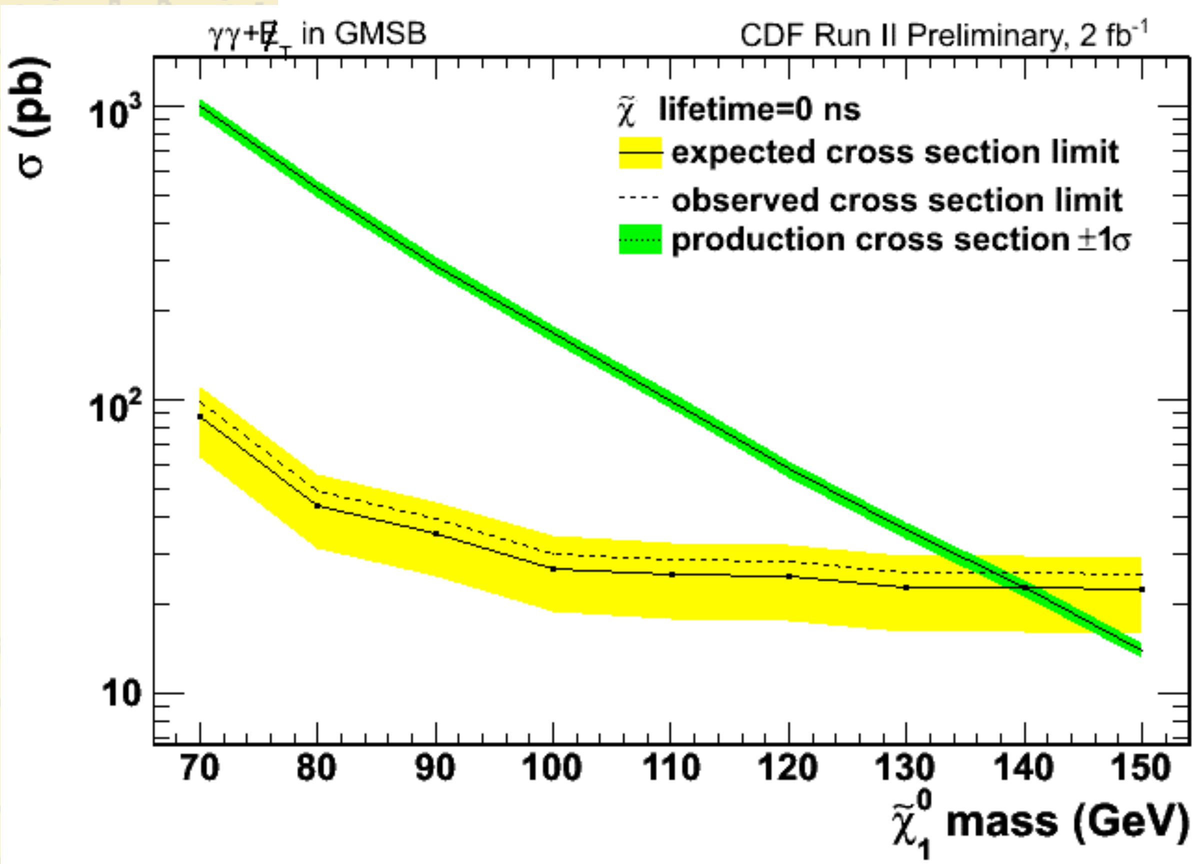


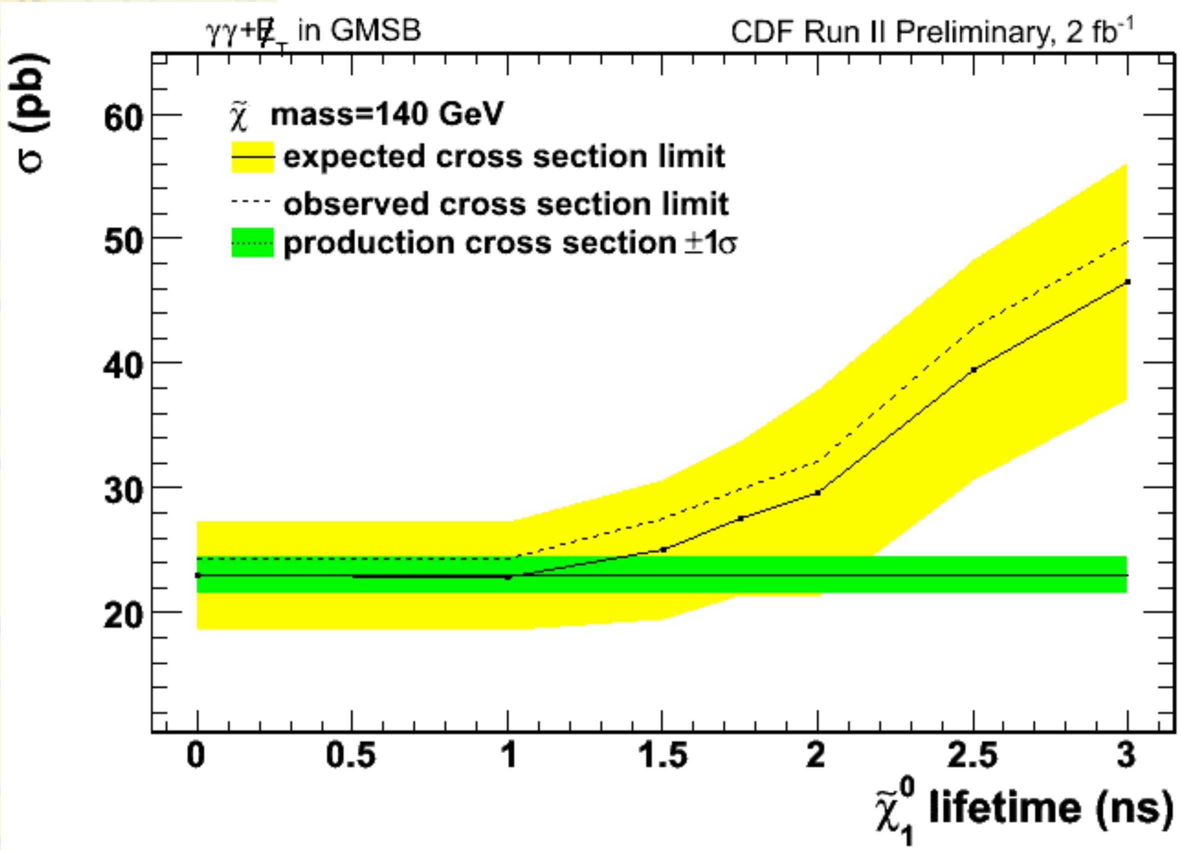
- For a distribution all other variables held at optimal cuts

Cross Section Limits vs. Neutralino mass for τ = 0 ns



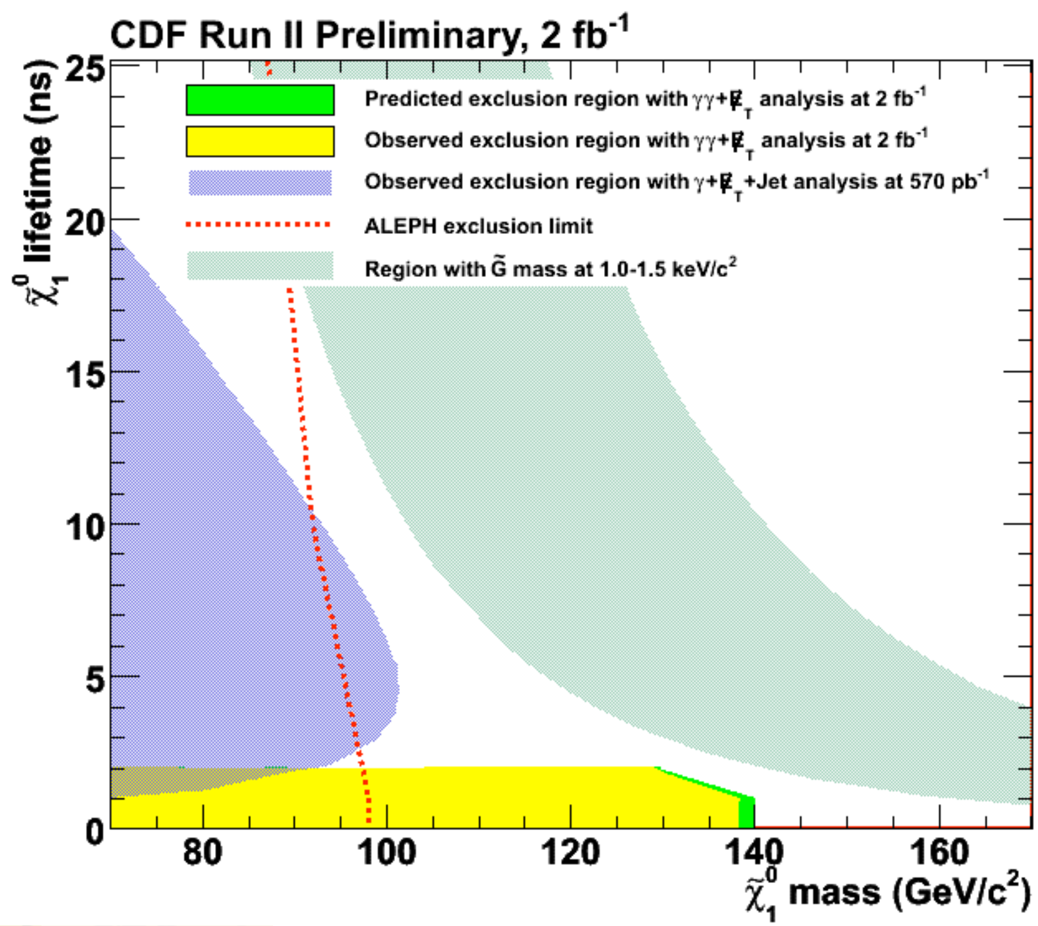
- Using the same set of optimal cuts:
  - Ht > 200 GeV
  - $\Delta\phi(\gamma_1,\gamma_2) < \pi - 0.15$ rad
  - MetSig >3
- Expected (Observed) neutralino mass limit 140 GeV (138 GeV) for t=0 ns

Cross Section Limits vs. Neutralino lifetime for m = 140 GeV



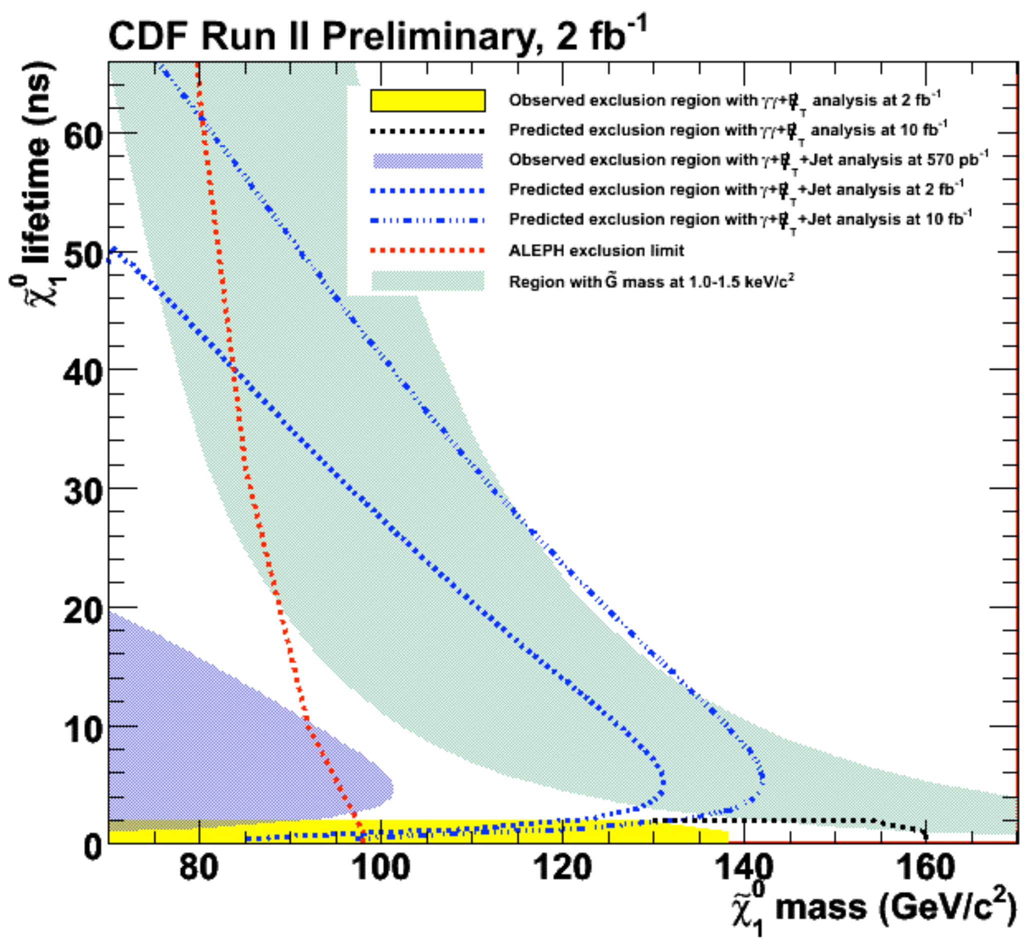
- Using the same set of optimal cuts:
  - Ht > 200 GeV
  - $\Delta\phi(\gamma_1,\gamma_2) < \pi - 0.15$ rad
  - MetSig >3
- Exclude neutralino lifetime up to
  ~1 ns for m=140 GeV

Exclusion Region



- Exclude up to ~ 138 GeV at 0 and 1 ns. (Beyond DØ Limit = 125 GeV)
- New Limits extend the sensitivity in both mass and lifetime. (goes above the Delayed Photon Analysis)
- We are nearing the cosmology favored region (blue band)
- We stop artificially at 2 ns for now

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

Conclusion and Plan

- Done with Optimization:
  Ht > 200 GeV, $\Delta\phi(\gamma_1, \gamma_2) < \pi - 0.1$, Metsig > 3
- Exclude neuralino mass 138 GeV for lifetime=0, 1 ns.
- Next generation delayed photon analysis is coming soon - sensitive to higher lifetimes (above ~ 2 ns).
- Finishing studies to reduce the systematic errors. Nearly finished.
- Add more data up to 3 fb^{-1} for paper publishing

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Back Up Slides

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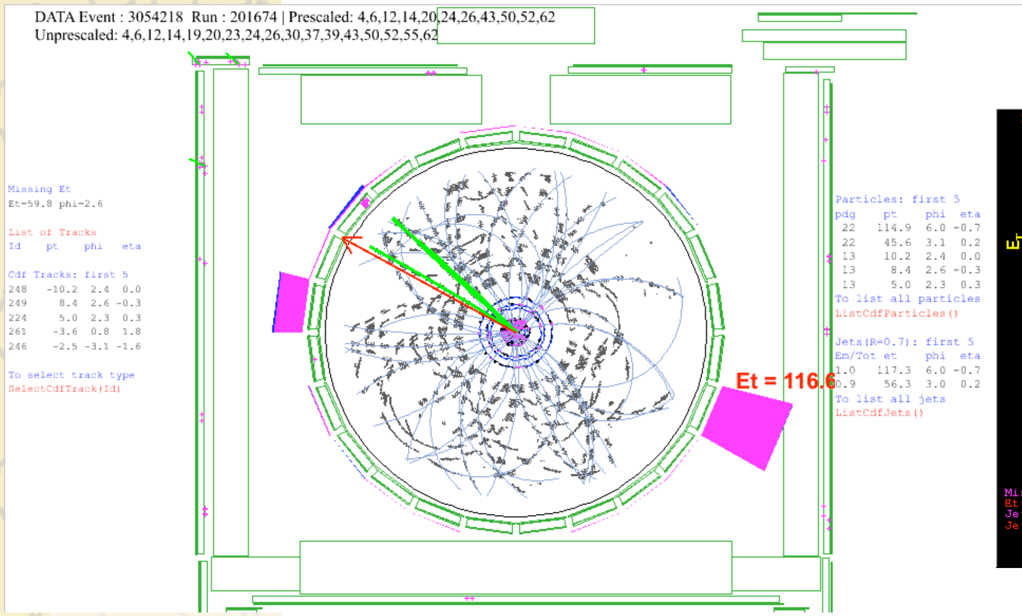
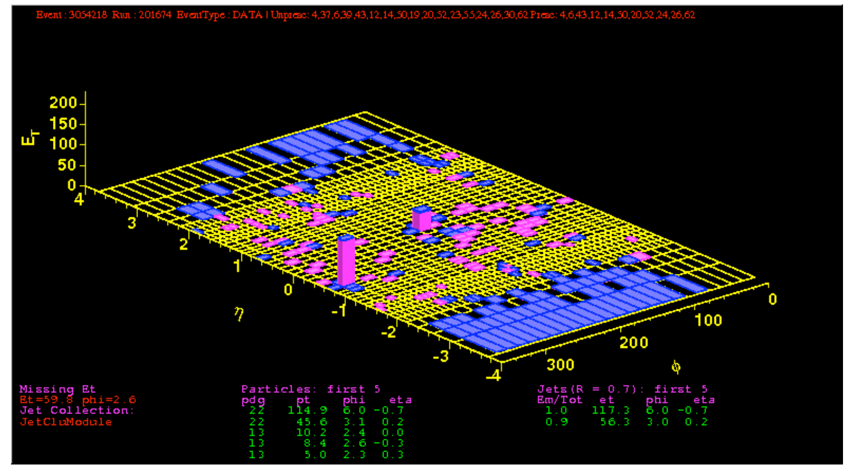
The Event We Observed

Run=201674 Event=3054218





- $E_T(\gamma_1)$=106.5 GeV, $\phi(\gamma_1)$=5.95, $\eta_{Det}(\gamma_1)$=-0.68, CESX=-11.85 CESZ=-135.5, CESStrip=0.52, CESWire=1.16
- $E_T(\gamma_2)$=46.02 GeV, $\phi(\gamma_2)$=3.06, $\eta_{Det}(\gamma_2)$=0.23, CESX=-10.48, CESZ=43.72, CESStrip=-99, CESWire=-99
- $\not{E}_T$ =54.98 GeV, $\phi(\not{E}_T)$=2.60, MetSig=19
- N_{vx}=2, $N_{jet}(E_T > 15\text{ GeV})$=0