Gauge Mediated SUSY and The Higgs at the Tevatron

$h^0 \to \tilde{\chi}_0^1 \tilde{\chi}_0^1$

David Toback

Texas A&M University

CIPANP, June 2012

Outline

- Introduction and Overview
- Gauge Mediated SUSY and the Higgs Sector
- Phenomenology Analysis
- Results
- Conclusions

Prospects of Searches for Neutral, Long-Lived Particles that Decay to Photons using Timing at CDF
D.T. and P. Wagner
Phys.Rev.D70, 114032 (2004)

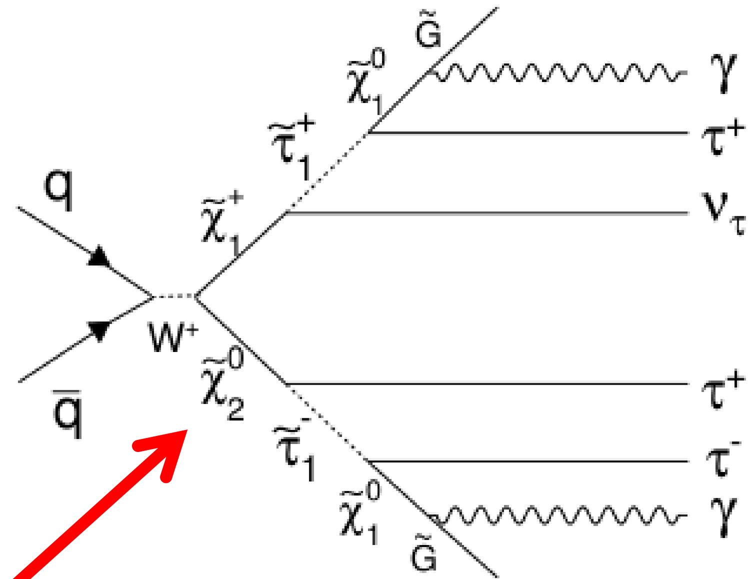
Higgs Boson Decays to Neutralinos in Low-Scale Gauge Mediation
D. Morrissey, D. Poland, and J. Mason
Phys.Rev.D80, 115015 (2009)

Prospects of Searches for Gauge Mediated Supersymmetry with $h^0 \to \tilde{\chi}_0^1 \tilde{\chi}_0^1$ Production in the Time-Delayed γ+Met final state at the Tevatron
J. Mason and D. T
Physics Letters B702, 377 (2011)

New work done with Ziqing Hong

Gauge Mediated SUSY and the Higgs Sector

- Compelling reasons to search for both the Higgs and Low-Scale Supersymmetry
- Many mechanisms of SUSY breaking, will focus on Gauge Mediation (GMSB)
  - Light Gravitino ($\tilde{G}$) and $\tilde{\chi}_0^1 \to \gamma\tilde{G}$ final states

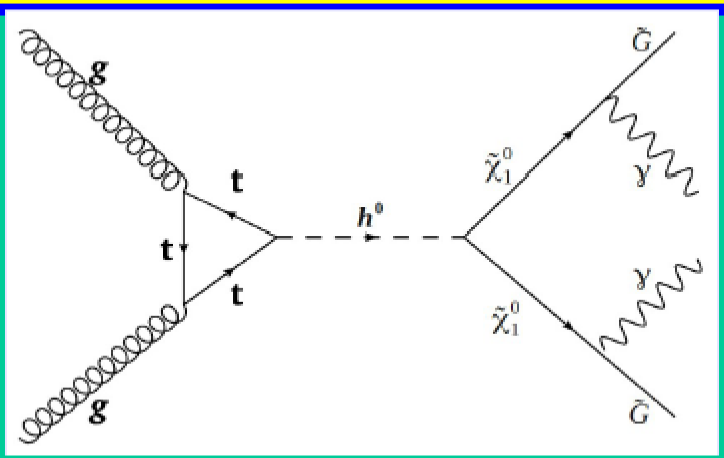


- Most searches at Colliders (LEP, Tevatron and LHC) focused on Minimal models, like SPS-8*: $\tilde{\chi}$ pairs or $\tilde{q}/\tilde{g}$ production
- Typically search for γγ+Met or delayed photons
- No evidence so far

*B.C. Allanach, *et al.*, Eur. Phys. J. C 25, 113 (2002)

Light Neutralino and Gravitino Model

- *What if we don't live in a minimal world?*
- An important and uncovered region of parameter space is where all sparticles except the $\tilde{\chi}_0^1$ and $\tilde{G}$ and are kinematically inaccessible at colliders
- No direct sparticle production at LEP, Tevatron or LHC
  → Evades current bounds



The only sparticles produced would be through a Higgs decay… assuming reasonable values of the mass of the Higgs and $\tilde{\chi}_0^1$

Higgs Production and SUSY Decay

- Basically, three things matter:
  - Mass of the Higgs → Production cross section (will assume only h^0 for simplicity)
  - Mass and couplings of the $\tilde{\chi}_0^1$ → Branching ratio $(h^0 \rightarrow \tilde{\chi}_0^1 \tilde{\chi}_0^1)$
  - Other couplings in the model → Lifetime of the $\tilde{\chi}_0^1$, $\tau_{\tilde{\chi}_0^1}$ (*decay in the detector?*)
- This is a new final state topology that needs to be studied: Exclusive production
  - Many searches for $\gamma\gamma$+Met, but we need a new search for $\tau_{\tilde{\chi}_0^1}$ >1 ns

Model Parameters

M_1

M_2

$\tan\beta$

μ

M_{h^0} and $M_{\tilde{\chi}_1^0}$ as free parameters, but focus on

120 GeV/c^2 < M_{h^0} < 160 GeV/c^2

30 GeV/c^2 < $M_{\tilde{\chi}_1^0}$ < 80 GeV/c^2

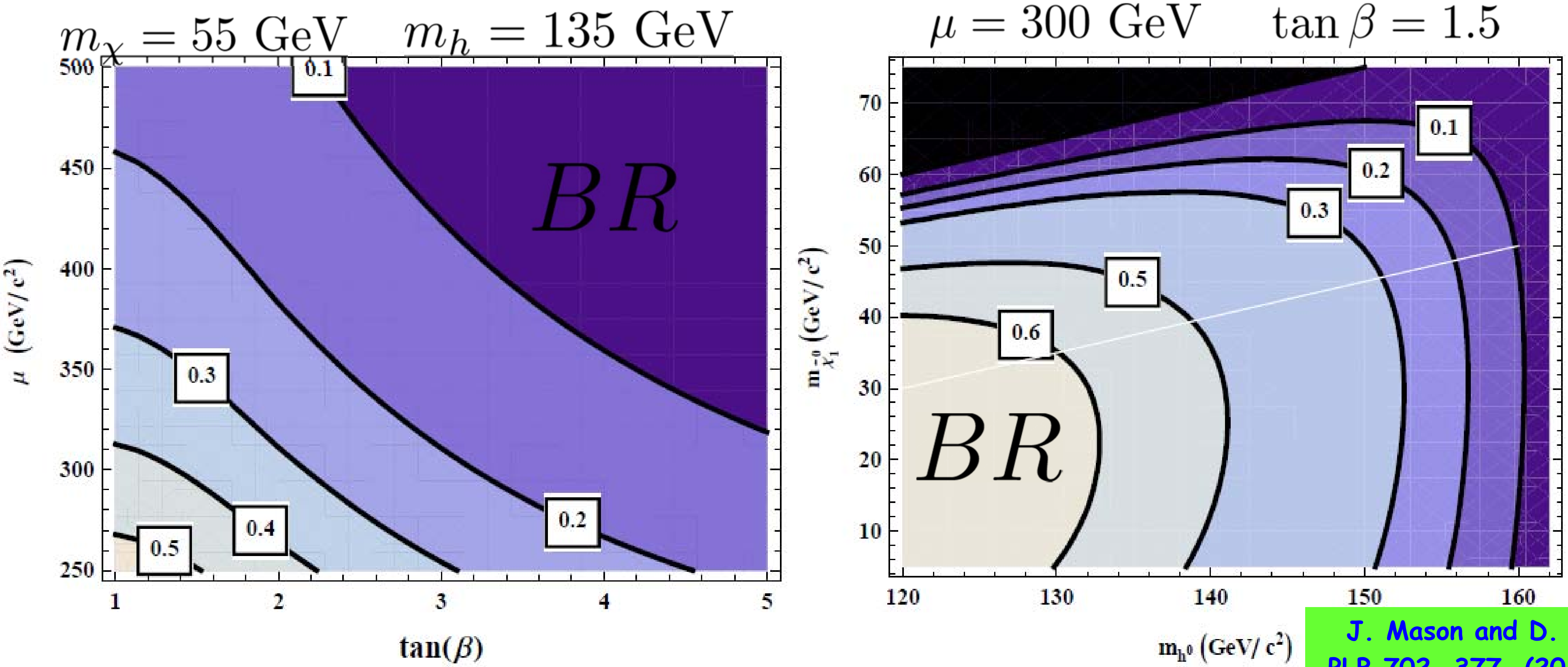
$\sigma(h^0) \sim 1$ pb in this mass regime

$\tau_{\tilde{\chi}_0^1}$ as a free parameter, but focus on

1 ns < $\tau_{\tilde{\chi}_0^1}$ < 20 ns

Can have a Branching Fraction $BR(h^0 \to \tilde{\chi}_0^1 \tilde{\chi}_0^1)$ > 50%

Contours of constant BR



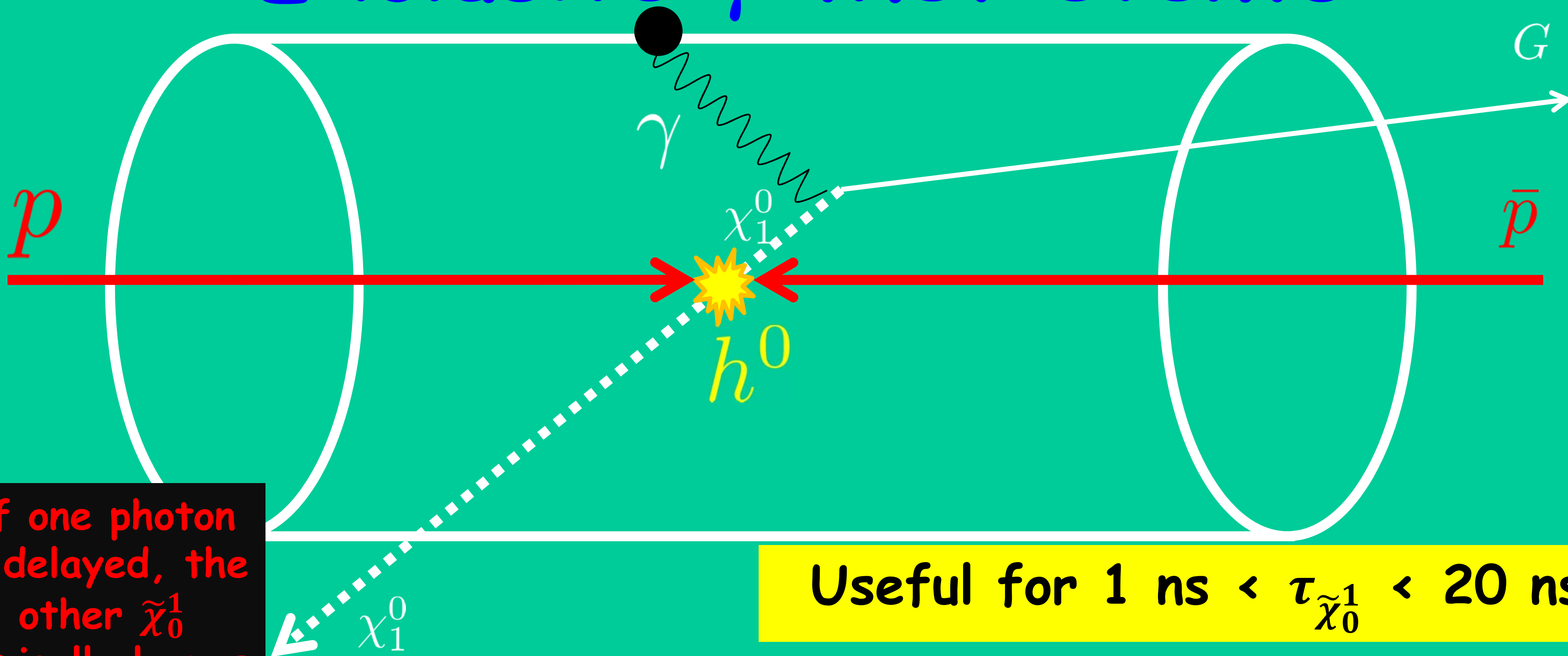
J. Mason and D. T
PLB 702, 377 (2011)

Can think of Branching Fraction as a free parameter that varies from

0% < $BR(h^0 \to \tilde{\chi}_0^1 \tilde{\chi}_0^1)$ < 70%

Smoking Gun Final State Signature

Look for a "Delayed" Photon in Exclusive γ+Met events



If one photon is delayed, the other $\tilde{\chi}_0^1$ typically leaves the detector

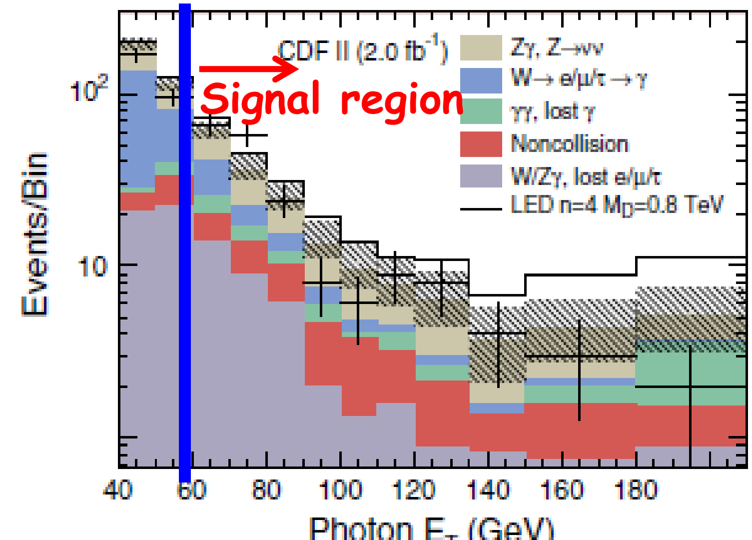
Useful for 1 ns < $\tau_{\tilde{\chi}_0^1}$ < 20 ns

D.T. and P. Wagner PRD 70, 114032 (2004)
CDF Timing: NIM A563, 543 (2006)
CDF Delayed Photon Searches:
PRL 99 121801 (2007)
PRD 78 032015 (2008)

Photons from these decays arrive at the calorimeter late compared to expectations from prompt photons ("delayed photons").

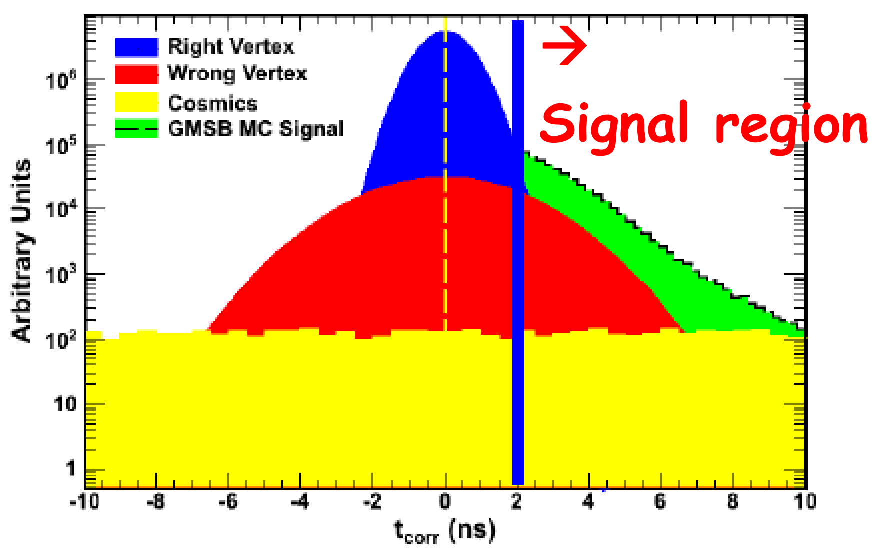
Phenomenology for Exclusive γ+Met

- Assume $10 fb^{-1}$ of Tevatron data
- Use CDF Timing system and Monophoton Search as "Basis of Estimate" for SM rates
  - Large E_T, large Met and large time
- Dominant backgrounds
  1. SM collision where the wrong vertex was reconstructed
  2. Cosmic Rays
- Estimate sensitivity using the "expected 95% C.L. Upper cross section limits"
- Assume 30% uncertainty on the background and 20% uncertainty on the signal acceptance



Photons with $|\eta|<1.1$, $E_T>50$ GeV, MET>50 GeV, jet veto

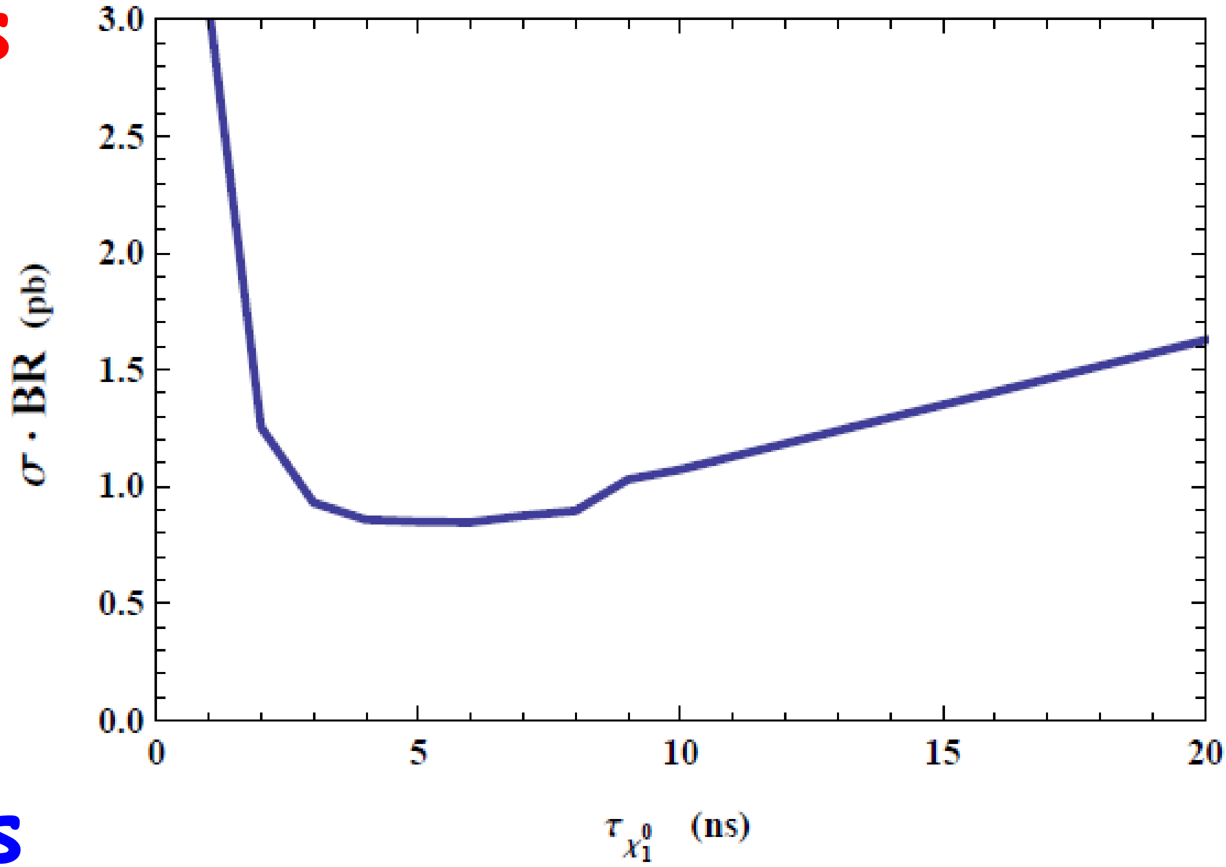
CDF PRL 101.181602 (2008)



Expected Sensitivity as a Function of Neutralino Lifetime

Minimizes at ~5 ns because

1. Need a long enough lifetime to get a delay for the photon
2. If the lifetime gets too large, both neutralinos leave before decaying



Example limit with

M_{h^0}=135 GeV/c^2

$M_{\tilde{\chi}_1^0}$=55 GeV/c^2

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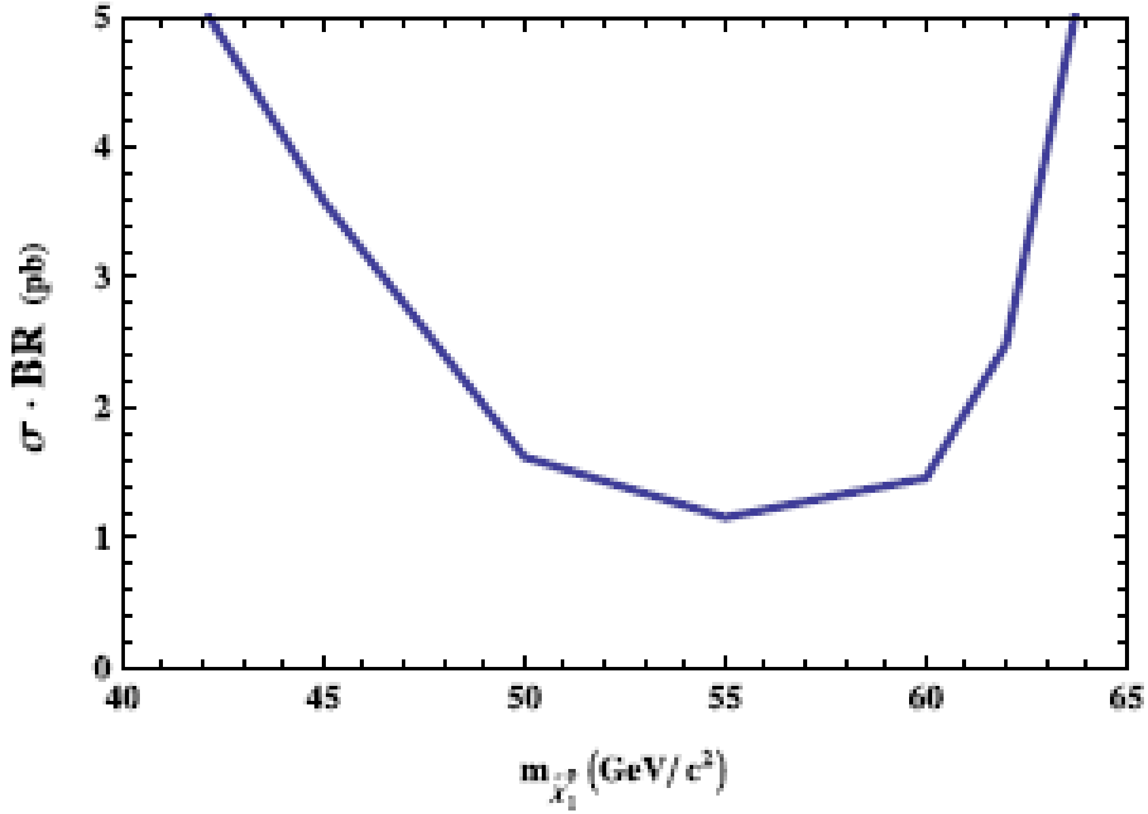
Kinematics and Sensitivity

- The Higgs - $\tilde{\chi}_0^1$ mass difference also determines the sensitivity
- If the $\tilde{\chi}_0^1$ is very boosted it doesn't give a delayed photon
- If the $\tilde{\chi}_0^1$ is too massive don't get a photon that is energetic enough to pass kinematic threshold

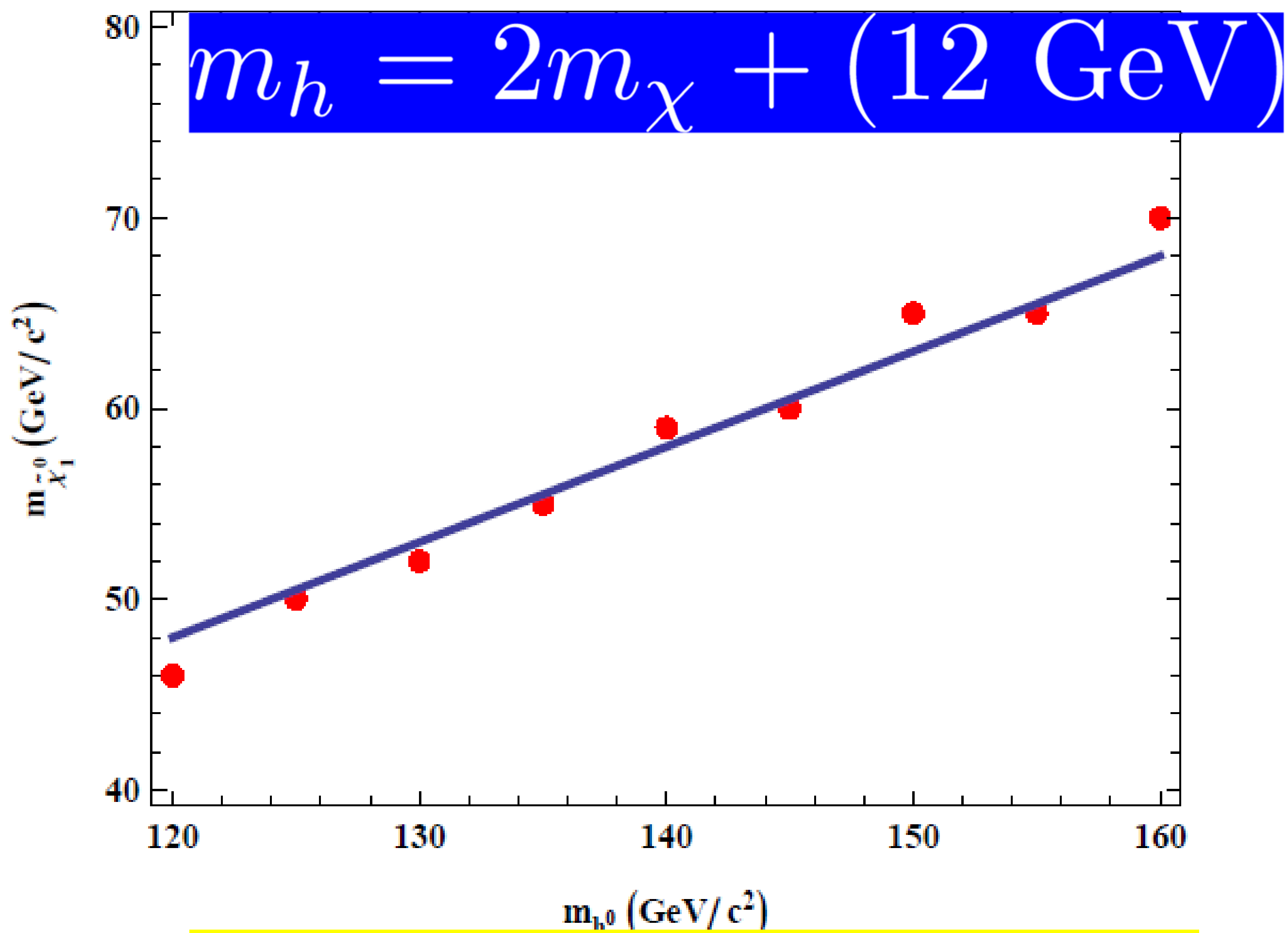


M_{h^0}=135 GeV/c^2

$\tau_{\tilde{\chi}_1^0}$=5 ns

The Higgs-$\tilde{\chi}_0^1$ mass difference that we are most sensitive to

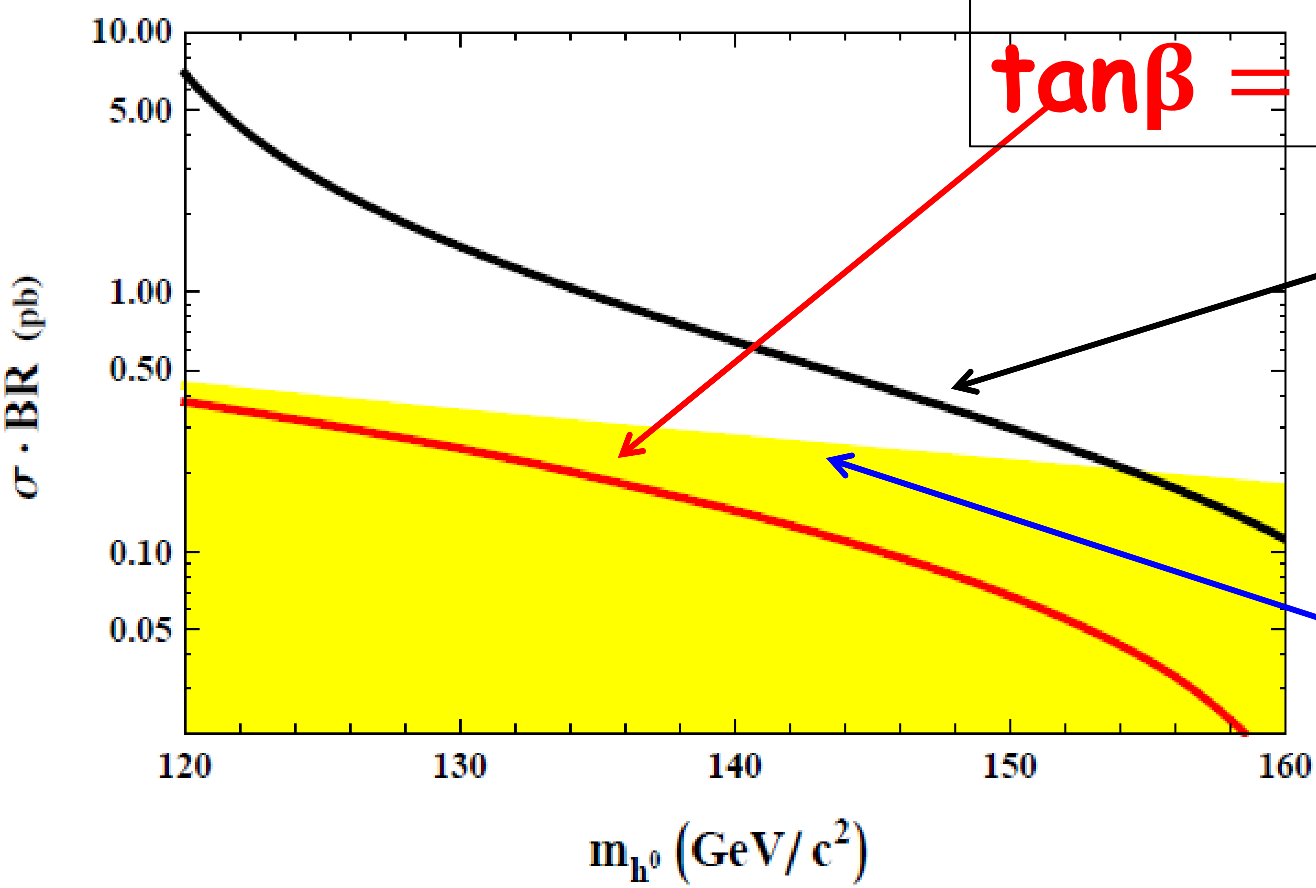
- Higher Higgs masses produce better acceptance
- Also, shifts the optimal $\tilde{\chi}_0^1$ mass
- Rises roughly linearly



$\tau_{\tilde{\chi}_1^0}$=5 ns

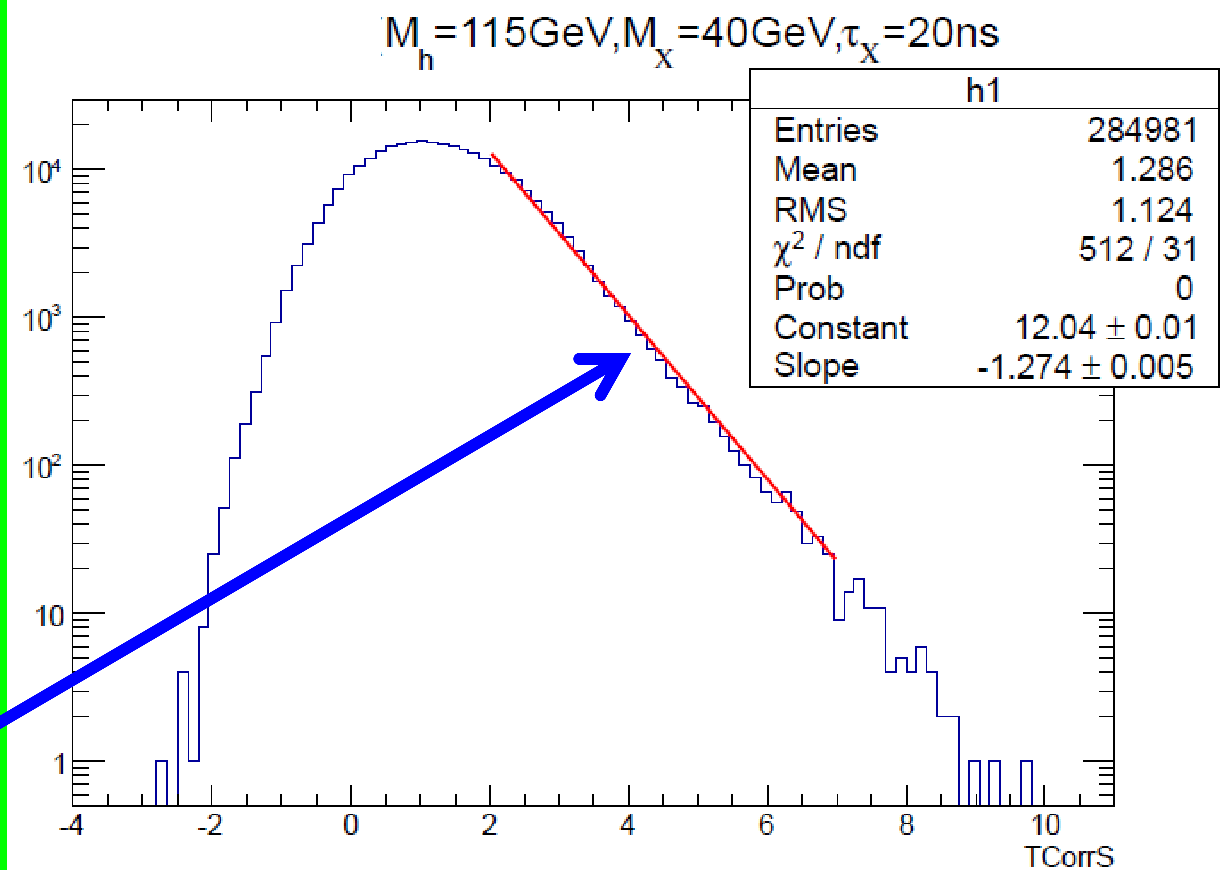
Sensitivity at the Tevatron?

Even with this simple analysis we are often with a factor of two of having sensitivity



Measure any parameters?

- *If there were an observation, could we measure any of the parameters?*
- **Measure cross section and slope of the timing distribution**



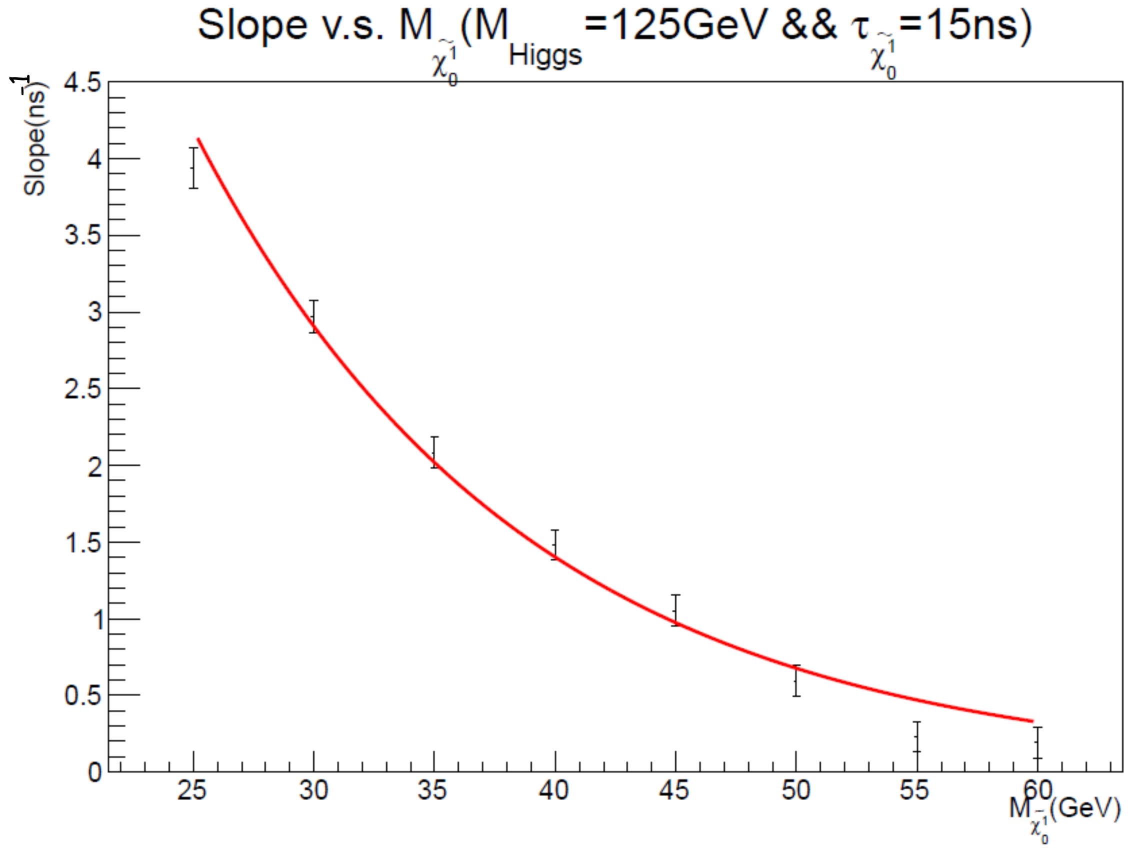
Measure the slope using the functional form

$$\text{Function} = e^{-(t_{corr} * Slope)}$$

New work with Ziqing Hong

Slope is most sensitive to $M_{\tilde{\chi}_1^0}$

- The Higgs - $\tilde{\chi}_1^0$ Mass difference determines the boost → slope
- For $M_{\tilde{\chi}_1^0}$=40 GeV get a slope of 1.5ns^{-1}

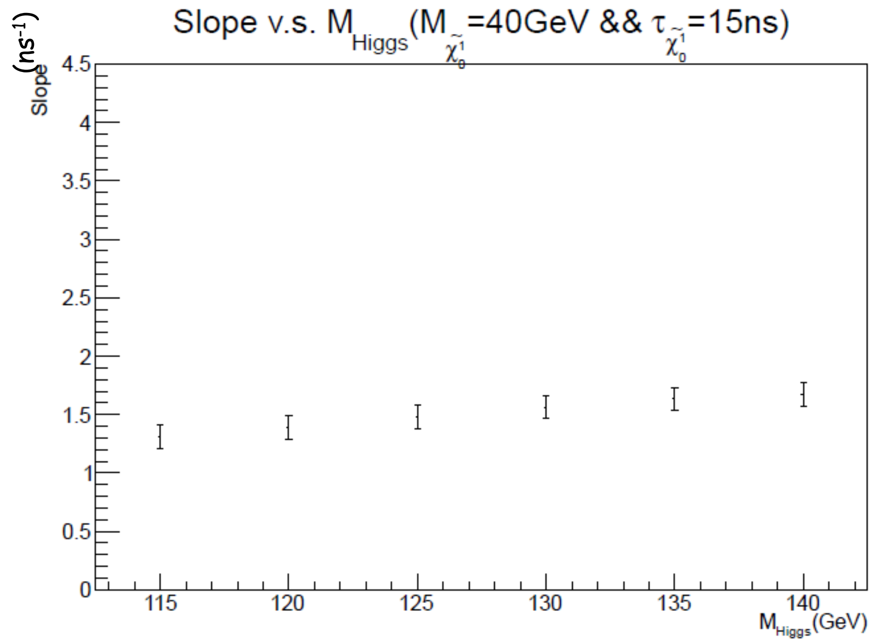


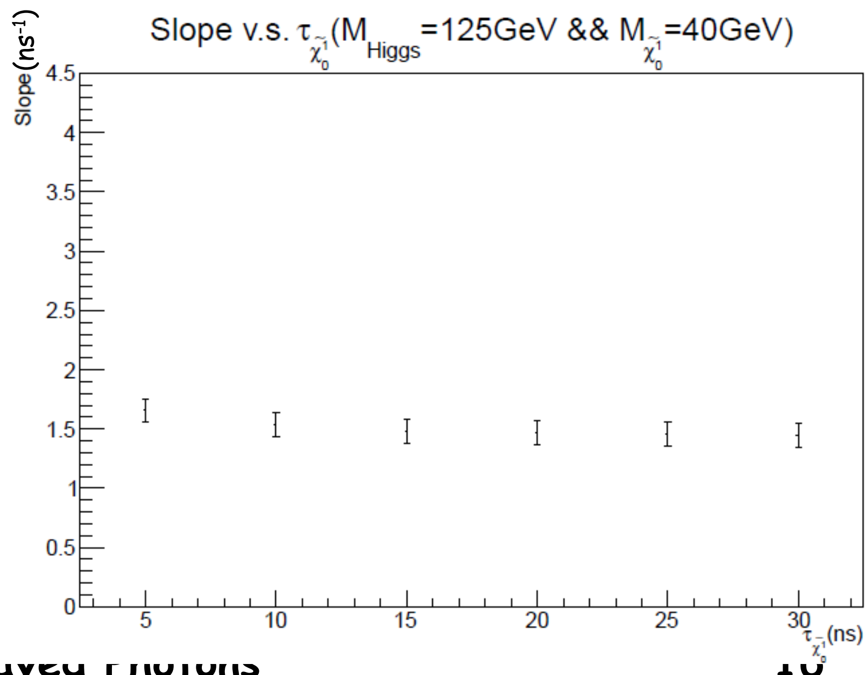
M_{h^0}=125 GeV/c^2

$\tau_{\tilde{\chi}_1^0}$=15 ns

Higgs and Lifetime have Small Impact

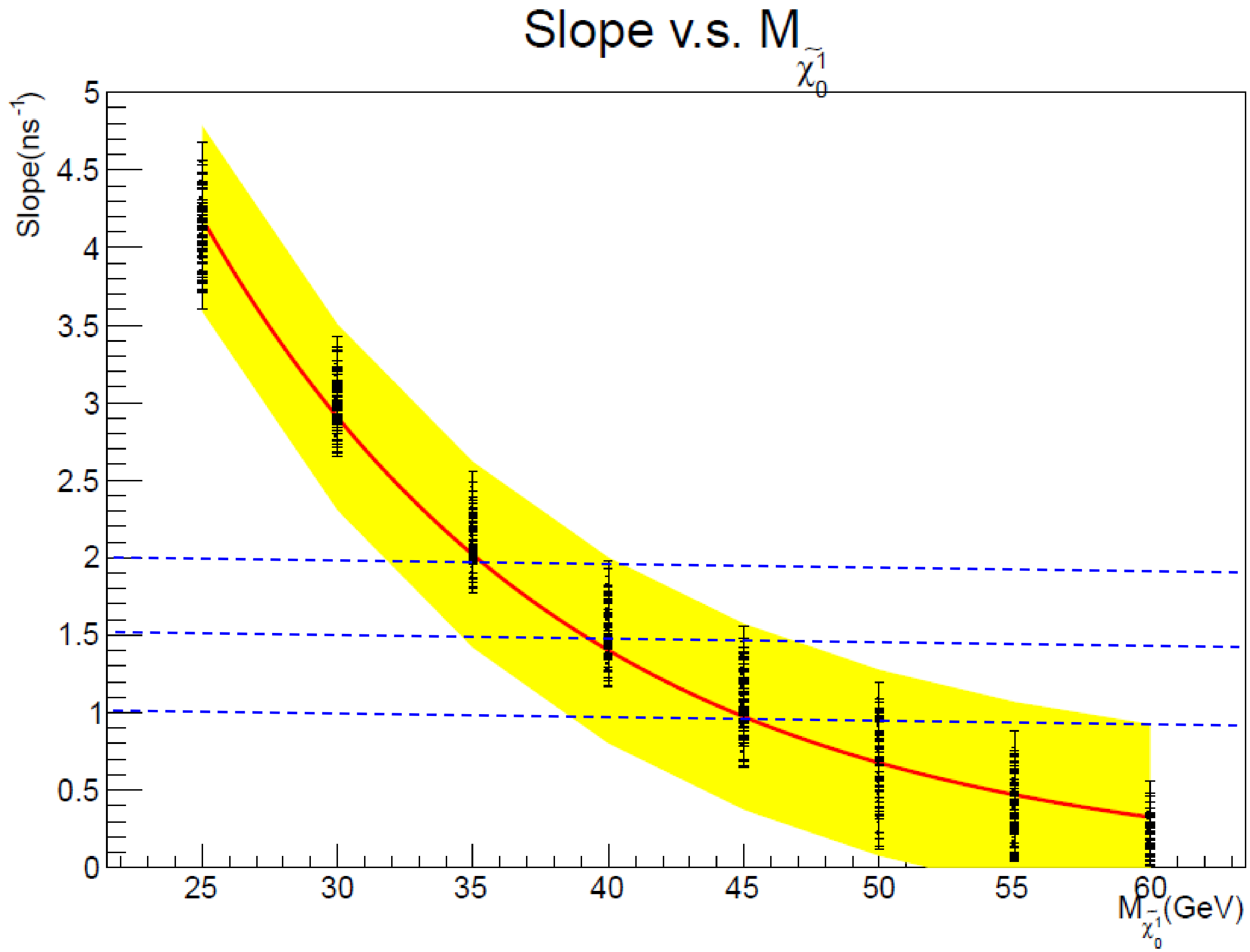
- Around this baseline value the slope changes less than a nanosecond in our range of interest
- Good news: Doesn't affect our $M_{\tilde{\chi}_1^0}$ measurement much
- Bad news: Have no sensitivity to measure $\tilde{\chi}_1^0$ lifetime or Higgs mass





Measure $M_{\tilde{\chi}_0^1}$

- If we measured a slope of 1.5±0.5 ns^{-1} we could determine the mass to be 40^{+20}_{-10} GeV
- *Combine with cross section measurement to get Higgs mass and/or lifetime? Reduce errors?*



115 GeV < M_{h^0} <140 GeV

5ns < $\tau_{\tilde{\chi}_1^0}$ <30ns

Conclusions: $h^0 \rightarrow \tilde{\chi}_0^1 \tilde{\chi}_0^1$ Search

- Proposed a new search for $h^0 \rightarrow \tilde{\chi}_0^1 \tilde{\chi}_0^1$ in the exclusive $\gamma_{Delayed}$ + Met final state
  - Sensitivity studies for LHC in progress
- Exciting possibility of discovering Higgs and SUSY at the same time with the full Run II dataset
- Optimal sensitivity when $\tau_{\tilde{\chi}_1^0}$=5 ns and when the mass of the $\tilde{\chi}_0^1$ is slightly less than half the mass of the h^0
- May even have the potential of measuring some of the parameters of the new physics

Backups

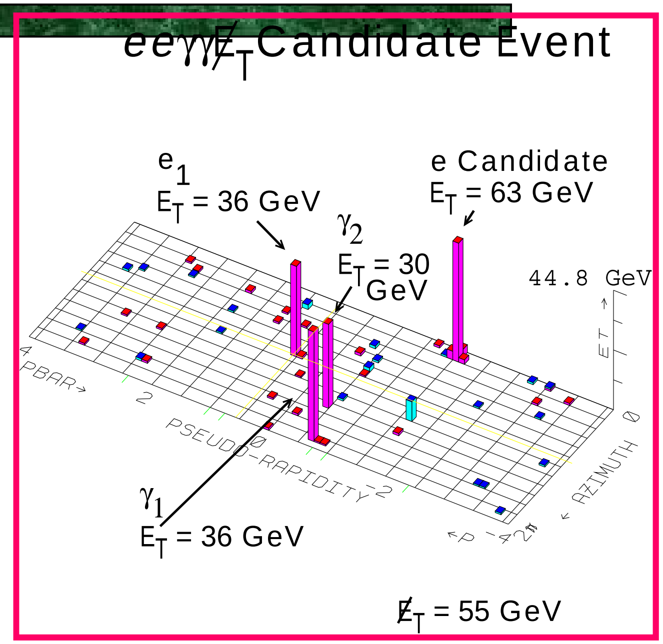
Abstract

We propose a search for direct production and decay of the lightest supersymmetric Higgs boson to two neutralinos in gauge mediated models at the Fermilab Tevatron. We focus on the final state where each neutralino decays to photon and light gravitino with a lifetime of order *O(ns)*. In the detector this will show up as a photon with a time-delayed signature and missing *ET*. We estimate that using the photon timing system at CDF, and the full 10 fb^{-1} data sample, that the sensitivity can be within a factor of three in some regions of parameter space for direct production of the Higgs.

Gauge-Mediated SUSY Breaking Models

$\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ models provide a warm dark matter candidate Consistent with Astronomical observations and models of inflation

More natural solution for FCNC problems than mSUGRA



CDF Run I $ee\gamma\gamma$+Met candidate event

Early Universe

$\tilde{\chi}_1^0$

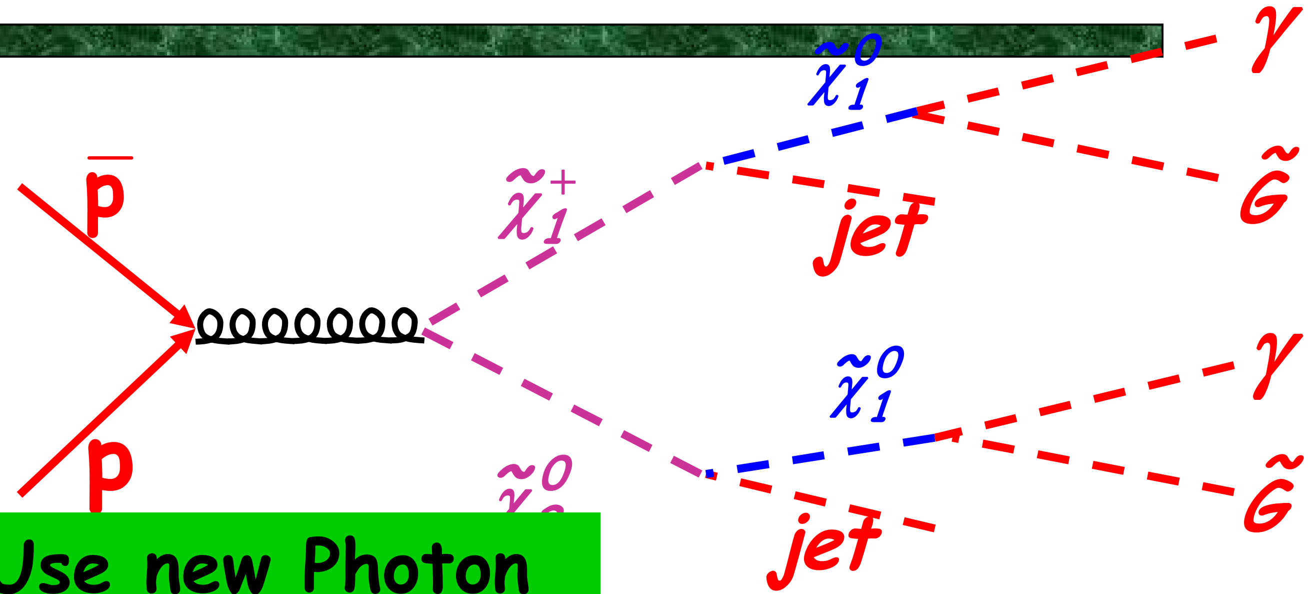
Nanosecond lifetimes

Later Universe

$\tilde{G}$

Warm Dark Matter

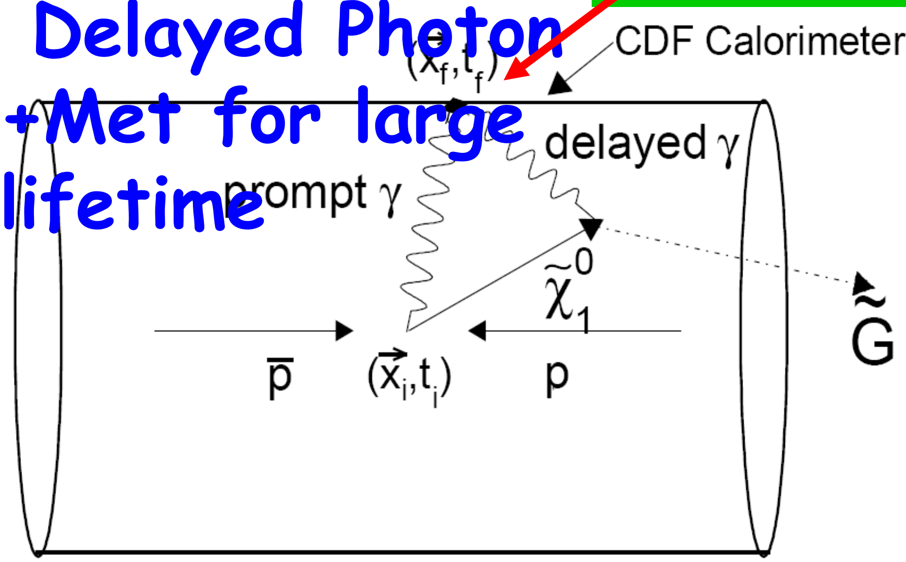
High and Low Lifetime Searches

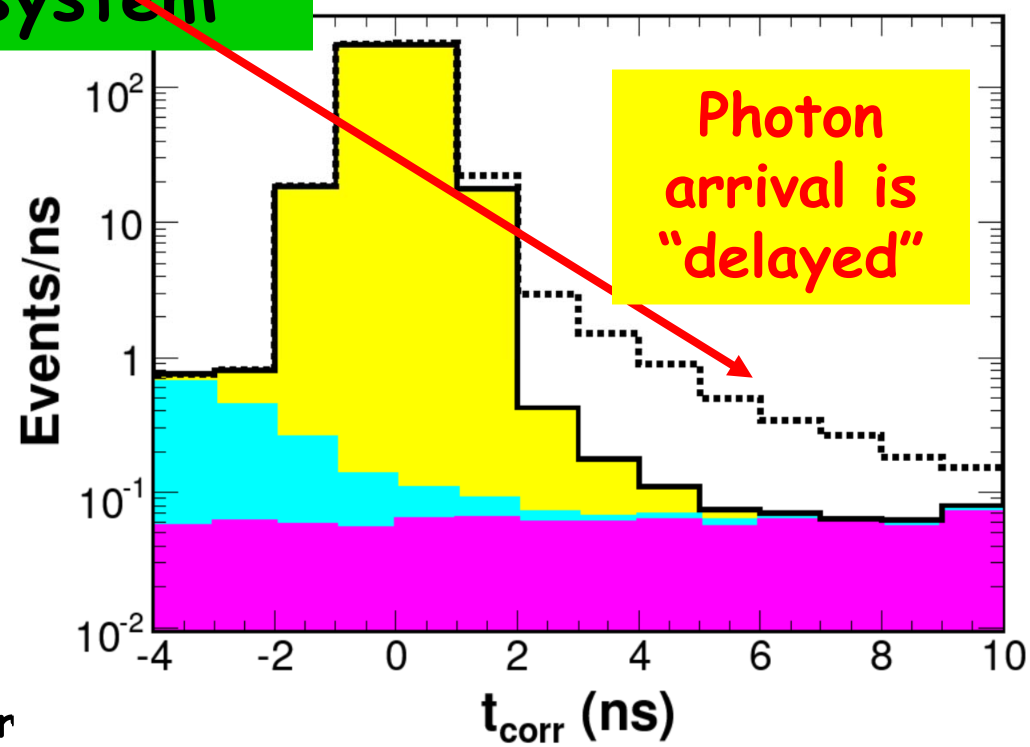


The lifetime and associated particle production dictate different final states

- $\gamma\gamma$+Met for small lifetime
- Delayed Photon +Met for large lifetime

Use new Photon Timing system

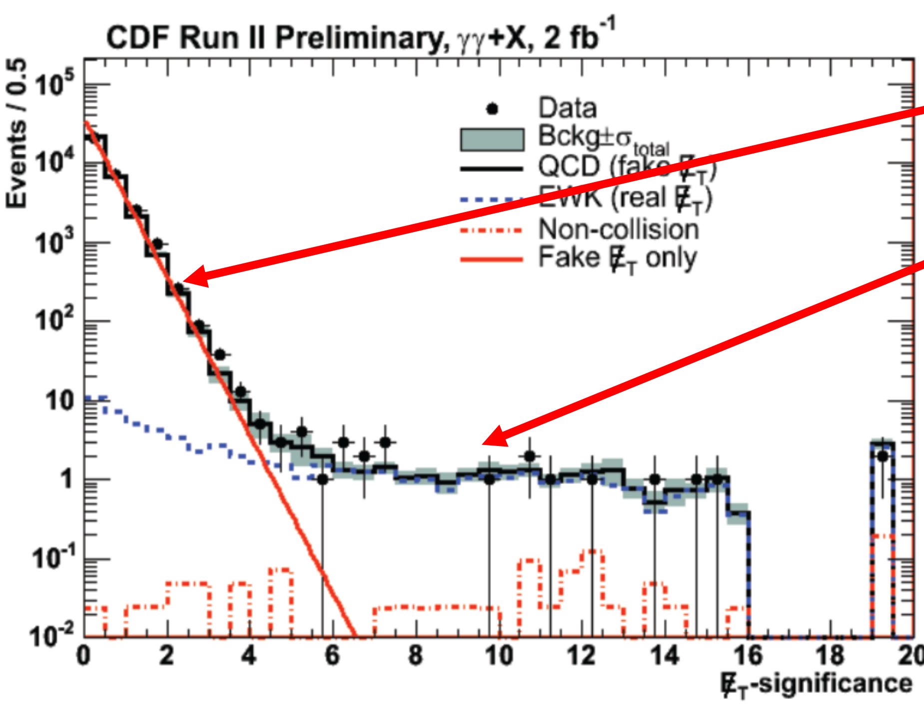




γγ+Met

New model independent search in γγ+Met

New tool: Sophisticated mechanism to measure the significance of the Met measurement



Can straightforwardly separate QCD backgrounds with no intrinsic Met from EWK that does

No evidence for new physics

Next move to set limits on GMSB models

arXiv: 0910.5170 (submitted to PRD)

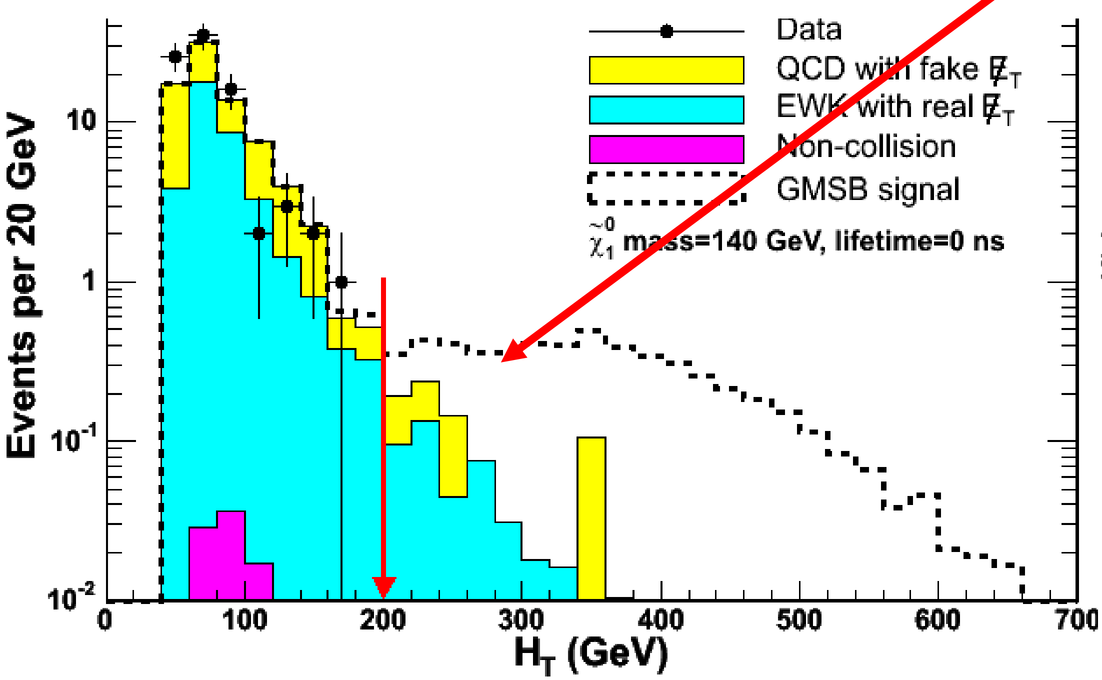
Low lifetime Neutralinos

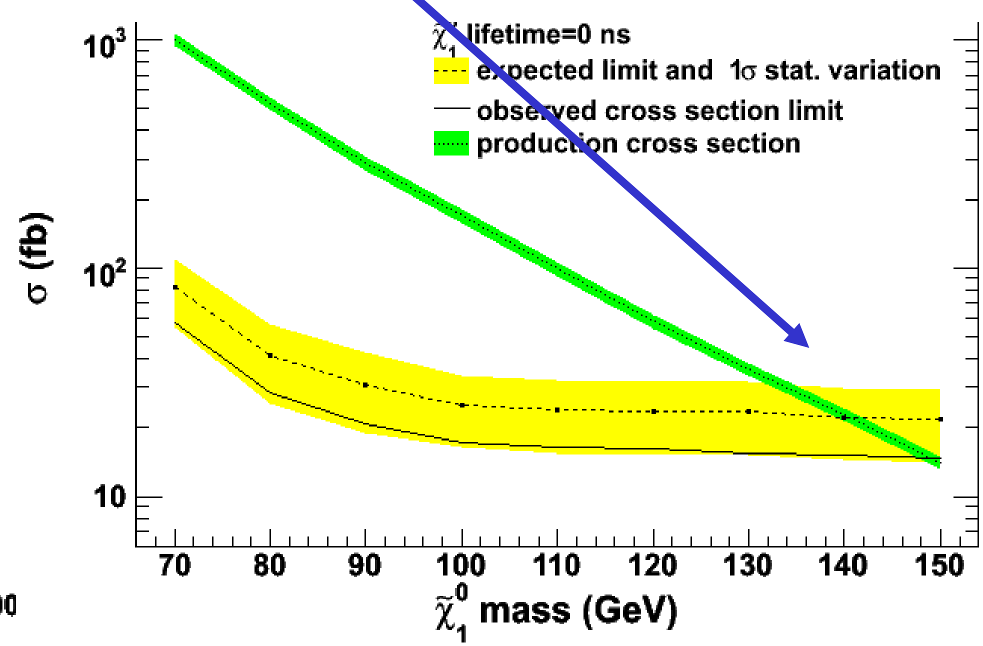
Optimize the $\gamma\gamma$+Met analysis for a lifetime« 1 ns :

Significant Met and Large “other energy”

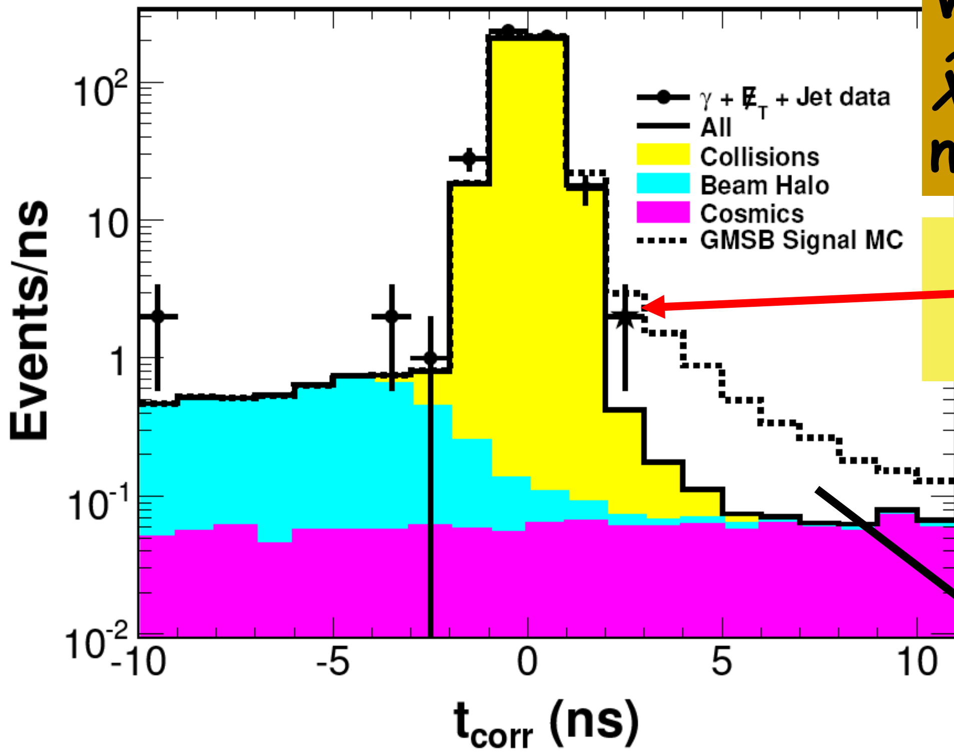
No evidence for new physics

PRL 104, 011801 (2010)





Nanosecond Neutralino Lifetime Searches

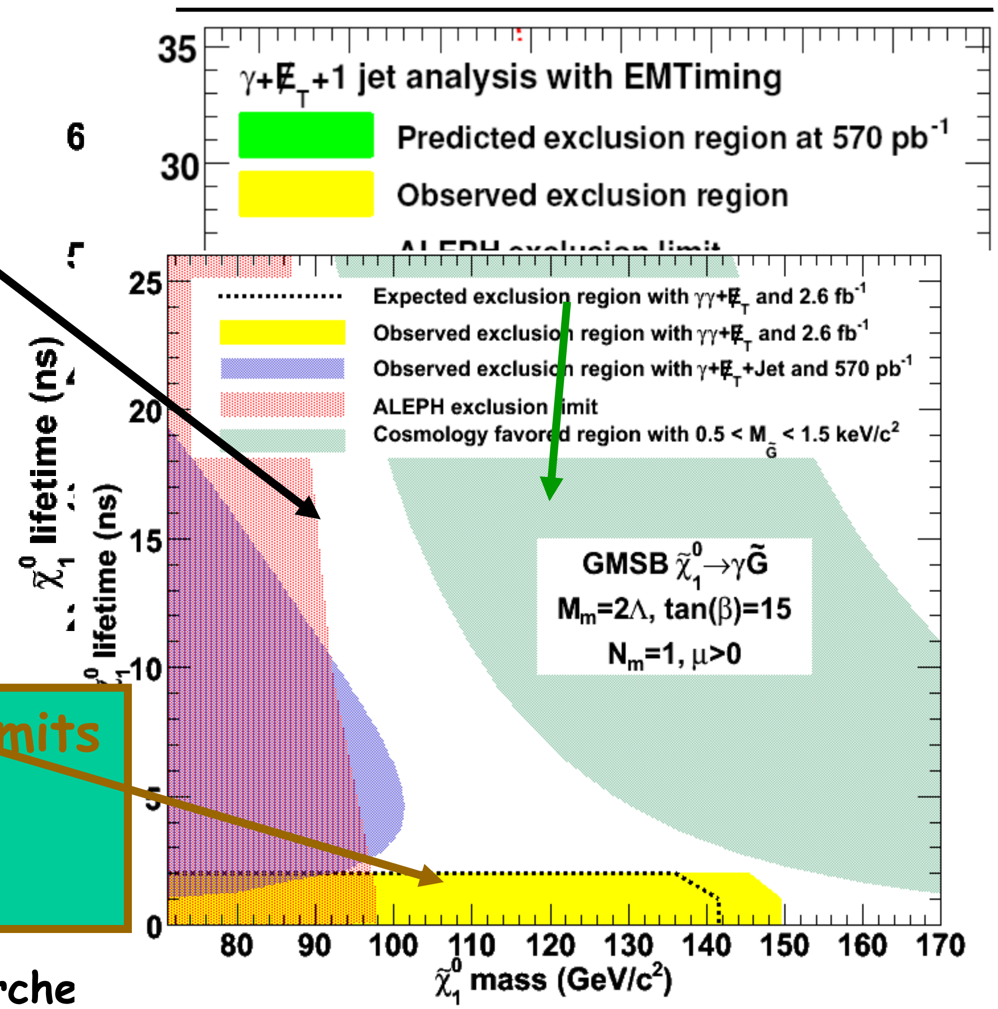


Warm dark matter models of GMSB with $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ favor keV $\tilde{G}$ masses and nanosecond $\tilde{\chi}_1^0$ lifetimes

Measure the time of arrival of photons in γ+Met+Jet events

CDF, PRL 99, 121801 (2007)

CDF, PRD 78, 032015 (2008)



Combine $\gamma\gamma$+Met and Delayed Photon Limits

Set limits for zero and

Non-zero lifetimes

The Lightest Neutralino

The soft parameters mix interaction Eigenstates.

[redacted]

$$\begin{pmatrix} M_1 & 0 & -m_Z s_\beta s_W & m_Z c_\beta s_W \\ 0 & M_2 & m_Z c_W s_\beta & -m_Z c_\beta c_W \\ -m_Z s_\beta s_W & m_Z c_\beta s_W & 0 & -\mu \\ m_Z c_\beta s_W & -m_Z c_\beta c_W & -\mu & 0 \end{pmatrix} \begin{pmatrix} \lambda' \\ \lambda^3 \\ \psi^2_{H_u} \\ \psi^1_{H_d} \end{pmatrix}$$

$$\tilde{\chi}^0_4, \ \tilde{\chi}^0_3, \ \tilde{\chi}^0_2, \ \tilde{\chi}^0_1$$

lightest Neutralino

Recall the Neutralino Mass matrix

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z s_\beta s_W & m_Z c_\beta s_W \\ 0 & M_2 & m_Z c_W s_\beta & -m_Z c_\beta c_W \\ -m_Z s_\beta s_W & m_Z c_\beta s_W & 0 & -\mu \\ m_Z c_\beta s_W & -m_Z c_\beta c_W & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} \lambda' \\ \lambda^3 \\ \psi^2_{H_u} \\ \psi^1_{H_d} \end{pmatrix}$$

$$M_2,\ \mu \gg M_1$$

$$g_{Z^0 \chi^0_1 \chi^0_1} \sim \epsilon^2$$

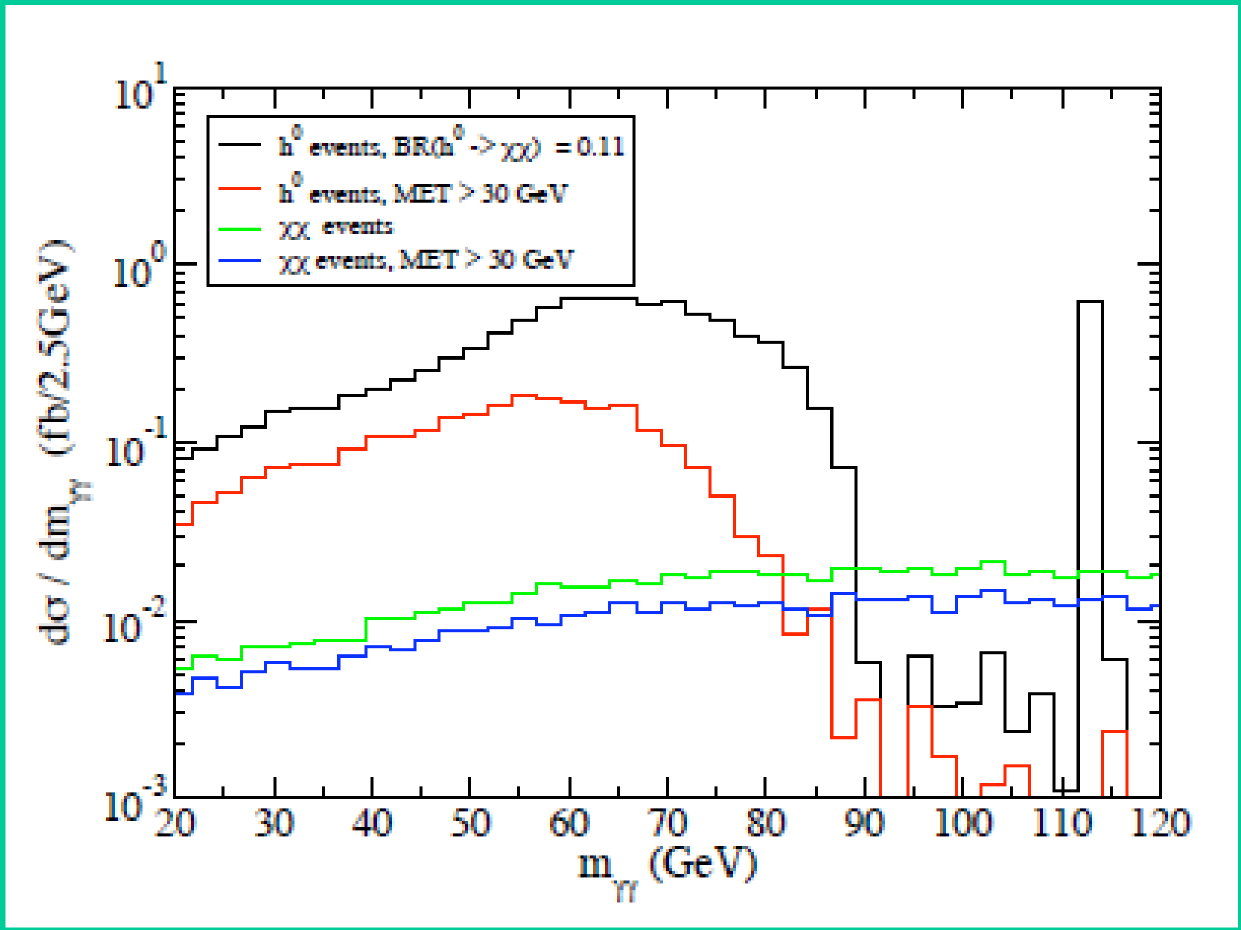
$$\mu > 250\ \mathrm{GeV}$$

⇨

Light χ_1
Evades
Detection

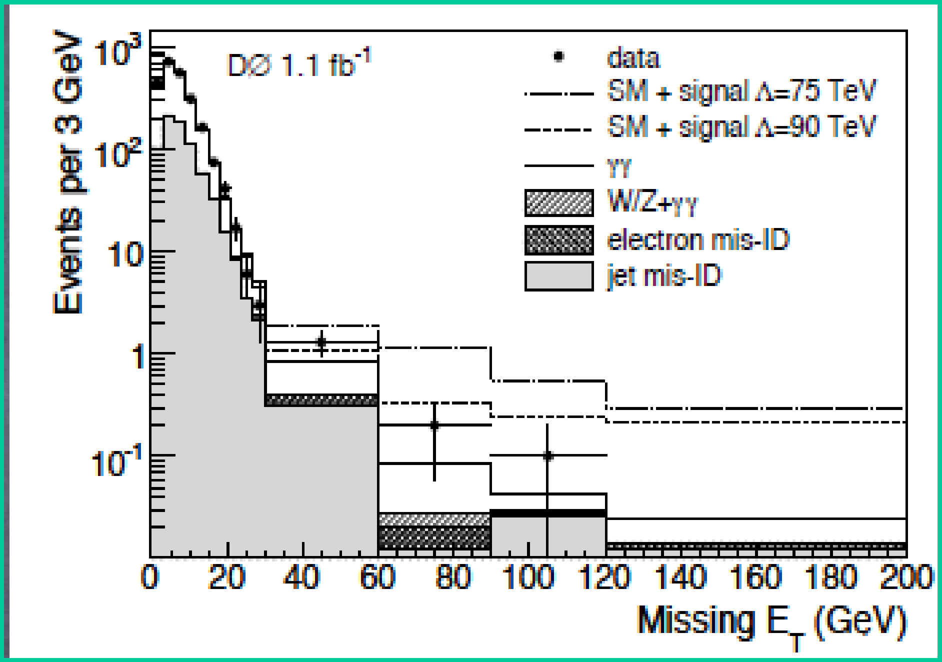
1) At Tevatron

$$p_T^\gamma > 25 \text{ GeV} \quad \text{and} \quad |\eta| < 1.1$$



D0 GMSB Search

$$p_T^\gamma > 25 \text{ GeV},\ \ |\eta| < 1.1,\ \ \not{E}_T > 30 \text{ GeV}$$



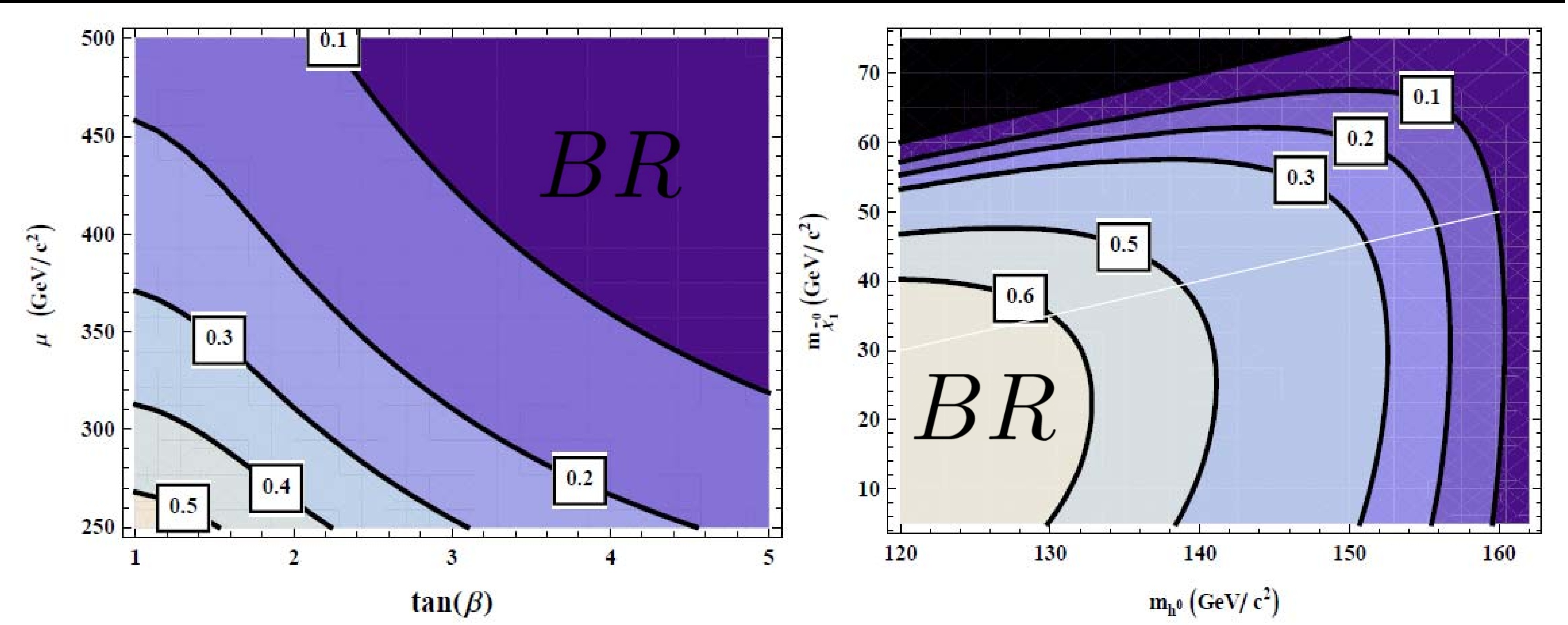
Abazov et. al. (2007): 0710.3946 [hep-ex]

Sensitivity: $$\frac{S}{\sqrt{B}} = 3,\ \ 10\ fb^{-1}$$

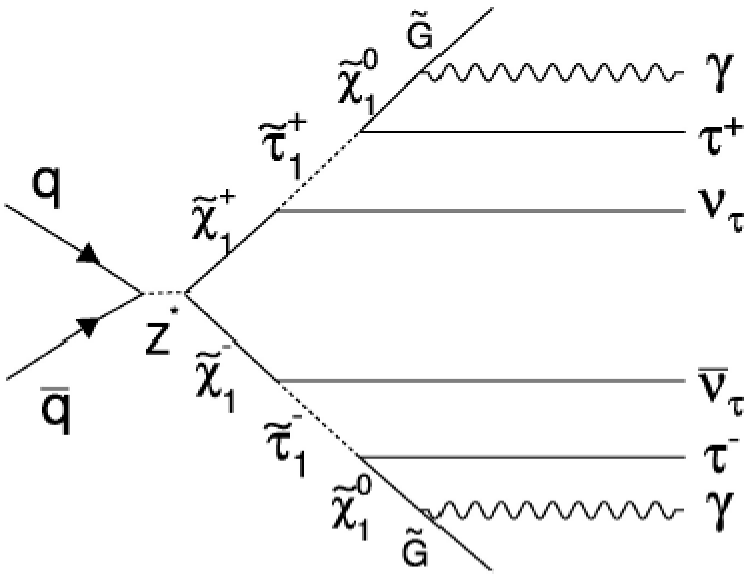
2) Significant BR

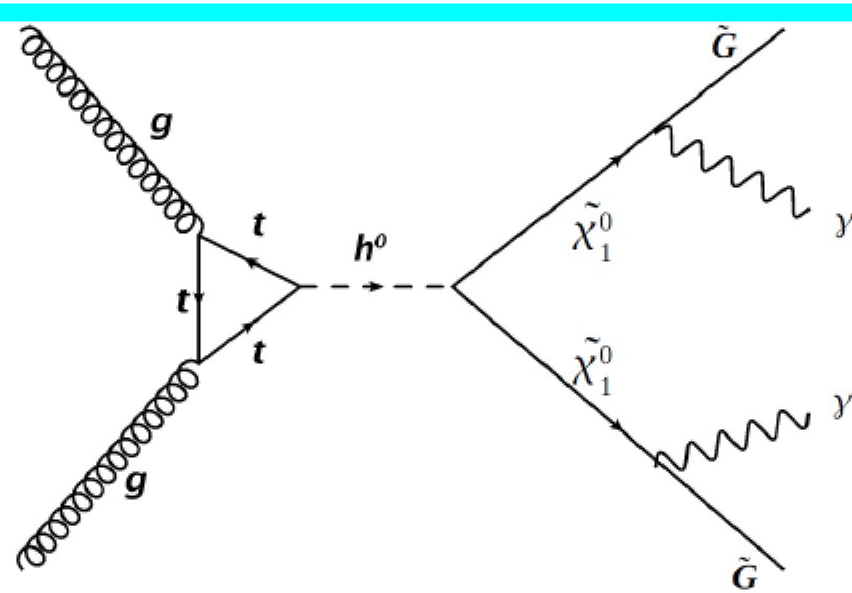
$$\mathcal{L} \supset \frac{g}{\sqrt{2}}\lambda' \psi_{H_u} H_u^* \;\Rightarrow\; g_{h^0\chi_1\chi_1} \sim \epsilon$$

[redacted]



GMSB SUSY at the Tevatron





GMSB models provide compelling motivation for looking for SUSY with long lifetime

$\gamma\gamma$+MET (short lifetime) or

γ+MET+Jet (long lifetime)

Slightly simpler but less common models provide motivation for looking at exclusive γ+MET and $\gamma\gamma$+MET

Models of this kind are previously unexplored and a new window of opportunity

BOTH THESE SEARCHES HAVE BEEN PERFORMED HERE AT CDF 2007 & 2010

Phys. Rev. D 70 (2004) 114032 &
Phys. Lett B 702 (2011) 377

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Prompt Decays to Neutralinos in GMSB (phenomenology)

Study a parameter point:

$$M_1 = 50 \text{ GeV}, \;\; \mu = 300 \text{ GeV}, \;\; \tan\beta = 5.5, \;\; m_A = 1000 \text{ GeV}$$

$$\Downarrow$$

$$BR(h^0 \to \chi_1\chi_1) = 0.1, \;\; m_h = 115 \text{ GeV}, \;\; m_{\chi_1} = 47 \text{ GeV}$$

Table 1

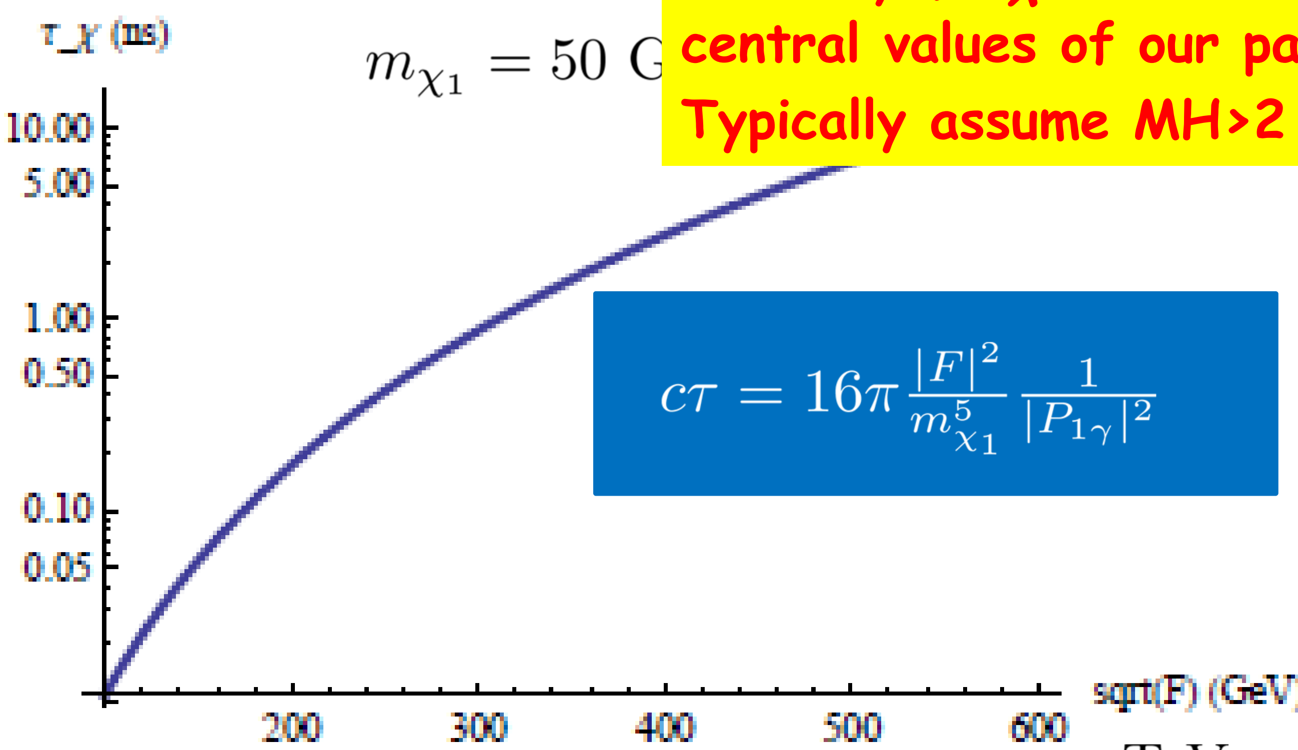
Table of requirements to select exclusive $\gamma_{delayed} + \not{E}_T$ events. In this table we assume $m_{h^0} = 135$ GeV/c^2, $m_{\tilde{\chi}_1^0} = 55.5$ GeV/c^2 and $\tau_{\tilde{\chi}_1^0} = 5$ ns. The acceptance is the fraction of events passing all the requirements, and takes into account the 75% jet veto efficiency starting in that row. We take a 20% uncertainty on the acceptance. The backgrounds are scaled to expectations for 10 fb^{-1} and we assume a 30% uncertainty.

Cut	Signal acceptance	Background events
$\lvert\eta^{\gamma}\rvert < 1.1$	35.4%	–
$\not{E}_T > 50$ GeV	1.69%	–
$E_T^{\gamma} > 40$ GeV	1.68%	–
Jet veto	1.66%	2100
$t_{corr} > 2$ ns	0.30%	89
$E_T^{\gamma} > 50$ GeV	0.28%	52

Decays may be prom

For the reasons above we considered
lifetime combinations in the phenomen
< mh0 < 160 GeV/c2, 30 GeV/c2 < m
1 < 20 ns. For simplicity we choose c
GeV/c2, m ˜χ 0 1 = 55.5 GeV/c2 and
central values of our parameters.
Typically assume MH>2 MCh10

$m_{\chi_1} = 50$ G



$$c\tau = 16\pi \frac{|F|^2}{m_{\chi_1}^5} \frac{1}{|P_{1\gamma}|^2}$$

TeV

Can have ns lifetimes and displaced decays