Sensitivity to New Scalar Production and Decay in GMSB Scenarios with the $\gamma_{delayed}$ + MET Final State

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Overview

1. Introduction - Theory and Analysis Overview
2. Signal Modelling
3. Setting Limits
    - The slope of the timing distribution as a function of the model parameters
    - N^{95} limits as a function of Slope
    - Acceptances
    - Cross Section Limits
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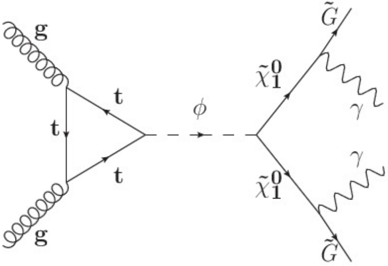
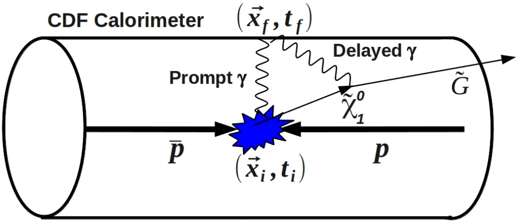
GMSB and Delayed Photons

- In Gauge Mediated SUSY Breaking (GMSB) models the Lightest SUSY Particle (LSP) is the Gravitino ($\tilde{G}$)
- Often the next-to lightest SUSY particle is often the $\tilde{\chi}_1^0$ and can decay to γ and $\tilde{G}$ (MET)
- The $\tilde{\chi}_1^0$ may have a lifetime on the order of a few nanoseconds. In this case, the photon's arrival time at the calorimeter would be delayed relative to expectations $\rightarrow$ Delayed photon ($\gamma_{Delayed}$) PRD 70 114032 (2004)



- In Light Neutralino and Gravitino (LNG) models, all but the LSP and NLSP are inaccessible at colliders. However, new scalar production can produce $\tilde{\chi}_1^0$ pairs with a large production cross section. PLB 702, 377(2011)

Delayed Photons and the Timing Signature



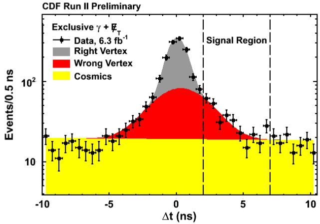
Using a simple time of flight equation, the time associated with the initial interaction(t_i), and the time of arrival at the detector(t_f) we can construct the variable Δt to separate delayed photons from other sources.

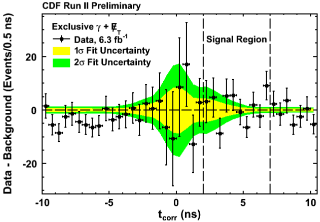
$$\Delta t = (t_\mathrm{f} - t_\mathrm{i}) - \frac{(|\vec{x}_\mathrm{f} - \vec{x}_\mathrm{i}|)}{c}$$

N.B.- A promply produced photon with a perfect detector has Δt=0, photons from heavy, long-lived particles have $\Delta t > 0$.

The Exclusive $\gamma + MET$ Final State and the Signal Region

3 distinct backgrounds estimated by data-driven methods (described in detail in CDF Notes 9924, 9171, and 8636)





- Right Vertex: Resolution of the detector(0.65ns) and scaled to match the data in the region below the signal region
- Wrong Vertex: Shape has an RMS of 2.0 ns, but with a non-zero mean
- Cosmic rays: Estimated from large time regions
- Model-independent result published in PRD 88, 031103(R)(2013) and updated since publication, see talk by Vaikunth Thukral.
- No evidence for new physics.

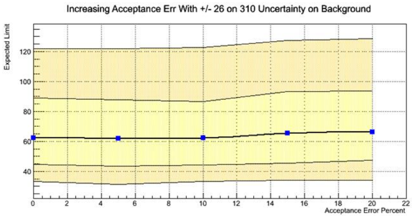
Previously: N^{95} Limit as a Counting Experiment

If the Signal Region is grouped into one bin, it results in a background of 310$\pm$26 events

Can set simple limits:

- Can write Cross Section Limit as: $$\sigma^{95} = \frac{N^{95}}{L * A}$$
- Can find the expected N^{95} limit assuming uncertainies on the acceptance and luminosity
- Take 6% uncertainty on L and 20% on the acceptance (see PRD(CDF 9171)/PRL(CDF 8636))

- Setting L=A=1 when using MCLimit gives $\sigma^{95} = N^{95}$, which we will show later to be extremely useful

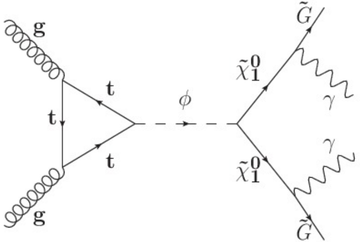


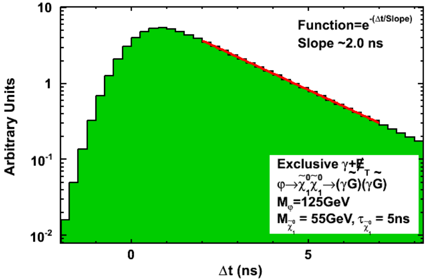
The expected N^{95} here is 69 events at 20% uncertainty on the acceptance. The bounds are only do to the pseudo-experiments run by MClimit.

GMSB Signal Timing Distribution

New scalar production is well modelled using three parameters: M_φ, $M_{\tilde{\chi}_1^0}$, and $\tau_{\tilde{\chi}_1^0}$

- Studies show that the Δt distribution for the signal typically looks like an exponential in the 2-7ns region. (JHEP09 (2013)041, PRD 70(2004) 114032, and PRD 78 032015/PRL 99 121801,)



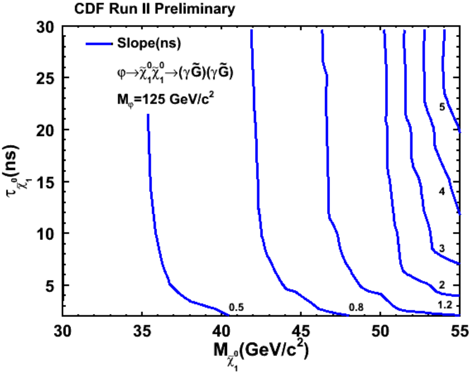


Pick a benchmark point of $M_\varphi = 125\text{GeV}, M_{\tilde{\chi}_1^0} = 55\text{GeV},$ and $\tau_{\tilde{\chi}_1^0} = 5\text{ns}$ (explained later).

N.B.- Results today have signal simulated using Pythia and PGS with the EMTiming modelled with a custom Monte Carlo (CDF 8636, CDF 9171)

Timing distribution as a function of the model parameters: Slope

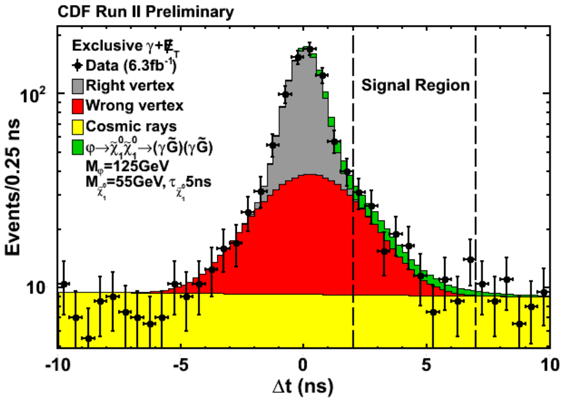
Studies show it is straight forward to estimate the slope as a function of M_φ, $M_{\tilde{\chi}_1^0}$, and $\tau_{\tilde{\chi}_1^0}$ produces a finite slope:



- Contour of constant slope for $M_\varphi = 125$ GeV
- Similar results for other φ masses
- Slope goes up as $M_{\tilde{\chi}_1^0}$ approaches $\frac{M_\varphi}{2}$

Data with the Modelled Timing Distributions

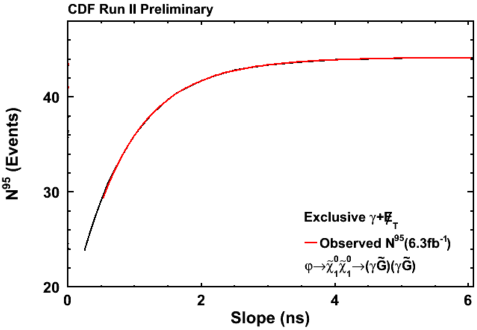
- Use control regions to estimate the backgrounds in the signal region as a function of time (CDF Notes 9924, 9171, and 8636)
- Use MC limit to estimate the 95% C.L. upper limit on the number of signal events (N^{95}) for each slope (model parameter)



Results: N^{95} Limit verses Slope

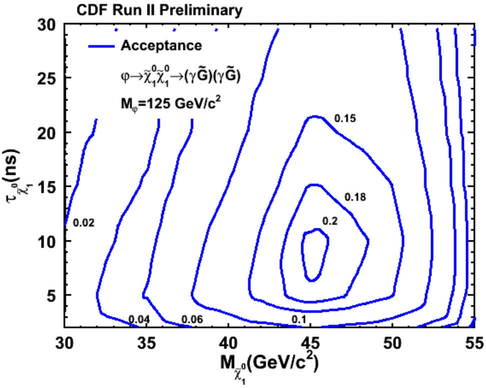
- Since each M_{φ}, $M_{\tilde{\chi}_1^0}$, and $\tau_{\tilde{\chi}_1^0}$ gives a known slope value, can set N^{95} vs. Slope
- Again the Cross Section Limit σ will be:

$$\sigma = \frac{N^{95}}{L * A}$$



For simplicity agian we have used 6% uncertainty on L and 20% on the acceptance (see PRD(CDF 9171)/PRL(CDF 8636)). But even with these assumptions we see that the limits have been improved drastically. More on the acceptance next.

Acceptances

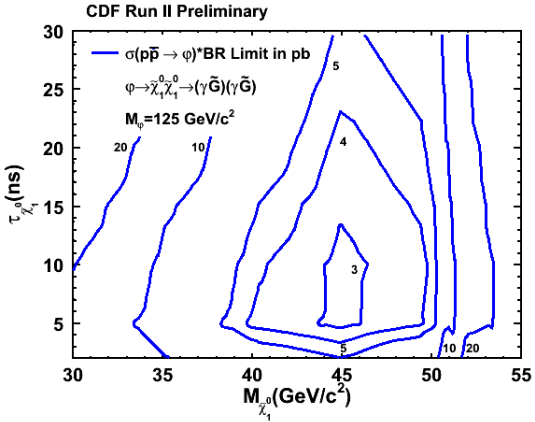


- To estimate the acceptance, we follow JHEP09 (2013)041 and use a customized PGS for each mass/lifetime configuration (will be fairly close... move to CDFsim in progress)
- Highest Acceptance for roughly: $M_{\tilde{\chi}_1^0} \approx \dfrac{M_\varphi - 24\text{GeV}}{2}$ and $\tau_{\tilde{\chi}_1^0} \approx$ 5-10 ns
- Correlates to the best balance between having the $\tilde{\chi}_1^0$ decay within the detector
- Produces photons that are measured in the signal region (consistent with PRD 2008 (CDF 9171))

95% Confidence Limits on Cross Section

Convert to cross section limits: Use L=6.3$fb^{-1} \pm 6\%$, $\sigma_{Acc} = 20\%$ (Acc. from previous slide), and each $M_{\varphi}, M_{\tilde{\chi}_1^0}$, and $\tau_{\tilde{\chi}_1^0}$ combination gives a N^{95} which we can plug in to get σ_{95}.

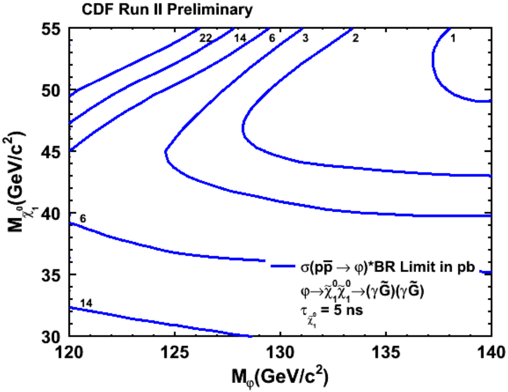
Note the limits are optimal around 5ns as in previous studies (PRD(CDF 9171)/PRL(CDF 8636)).



Cross Section Limits for Variable Scalar Masses

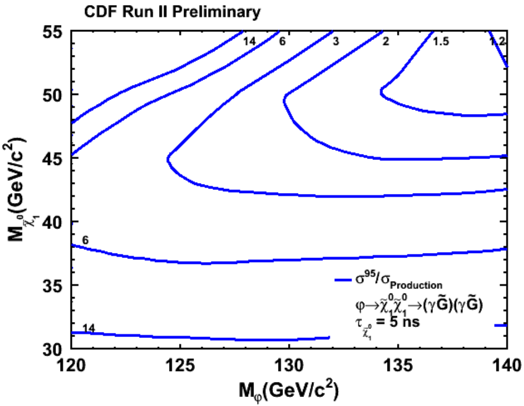
Next fix $\tau_{\tilde{\chi}_1^0}$=5ns: get limits as a function of M_φ and $M_{\tilde{\chi}_1^0}$.
Note: better cross section limits for larger φ masses as expected.

Optimal cross section limits for $M_{\tilde{\chi}_1^0} \approx \dfrac{M_\varphi - 24\mathrm{GeV}}{2}$.



Ratio of Observed to Expected Cross Section

Compare σ^{95} to simple model of scalar production with BR=100%.
SM Higgs is 1 pb at 125GeV.



Plan:

Move to higher $\tilde{\chi}_1^0$ and φ masses to find our optimal sensitivity

Currently uses the approximation that $\sigma_{Production} = \frac{(125\ \mathrm{GeV})^3}{(M_\varphi)^3}$.

Moving to using PLB 702 (2011) 377382 (thanks to Tom Junk).

Conclusions

1. We have preliminary limits on new scalar production and decay via $\varphi \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \gamma_{delayed} + MET$
2. Limits as a function of M_φ, $M_{\tilde{\chi}_1^0}$,and $\tau_{\tilde{\chi}_1^0}$
3. Cross Section Limits appear optimal for $\tau_{\tilde{\chi}_1^0}$ ≈5ns and $M_{\tilde{\chi}_1^0} \approx \frac{M_\varphi - 25}{2}$
4. Sensitivity appears best at larger masses than we have already considered → Now simulating larger φ mass points
5. The rest of the data with final acceptances and uncertainties to come using CDFsim (in progress)
6. Plan: Bless these results, then publish a PRL on these results as well as a full PRD on the analysis methods which are all new and not spelled out in the PRD-RC.

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