Search For Delayed Photons Using Timing.

Tambe E. Norbert[1] Shih-Chuan Kao[1] Yuichi Kubota[1]

[1]University Of Minnesota

Long-Lived Meeting,
November 23, 2014

Outline

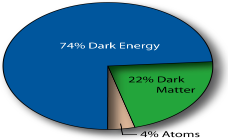
The Universe Set

The set $S = \{\cdots \mathbf{0}, \frac{1}{2}, 1, \frac{3}{2}, 2 \cdots\} \cdot \hbar$

where s is the spin of a particle. Currently we know:

- $\mathbf{s} = \frac{\mathbf{1}}{\mathbf{2}}\hbar$ Describes all the matter in our universe.
- $\mathbf{s} = \mathbf{1}\hbar$ Describes gauge interactions.
- $\mathbf{s} = \mathbf{0}\hbar$ Responsible for giving mass.
- $\mathbf{s} = \mathbf{2}\hbar$ Describes gravity (gauged?).
- $\mathbf{s} = \frac{\mathbf{3}}{\mathbf{2}}\hbar$?? **Dark Matter**?

However, this magic set only describes $\approx 4\%$ of our total



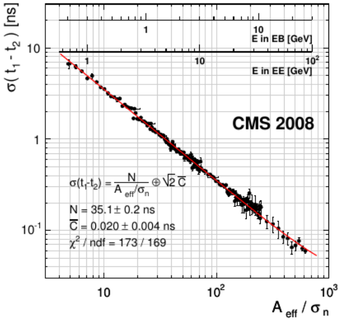
universe.

Introduction

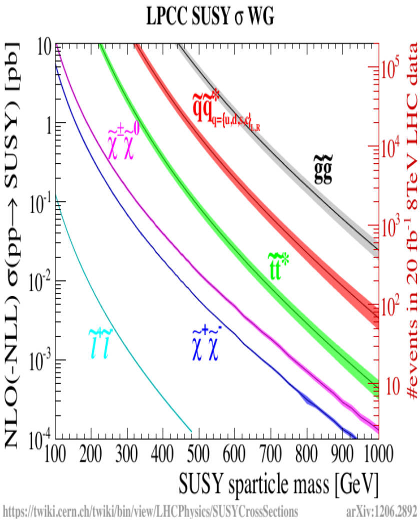
- **Long-Lived Particle Models**
  - ⋆ Gauge Mediated Supersymmetry Breaking (GMSB)
    - ▷ Next-to-lightest SUSY (NLSP) is Neutralino ($\tilde{\chi}_1^0$)
    - ▷ $eV - keV$ Lightest-SUSY particle (LSP) is Gravitino ($\tilde{G}$).
    - ▷ Gravitino is a Dark Matter Candidate.
  - ⋆ General Gauge Mediation (GGM)
    - ▷ NLSP is a mixture of fermions (Bino, Wino, Higgsino).
    - ▷ Several SUSY particles can be NLSP.
- **ECAL Resolution**

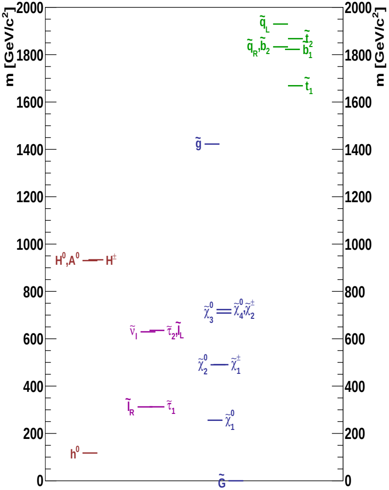
† ECAL timing resolution $\sigma_t < 500$ ps.

† Use timing to identify photons and electrons from long-lived decay.



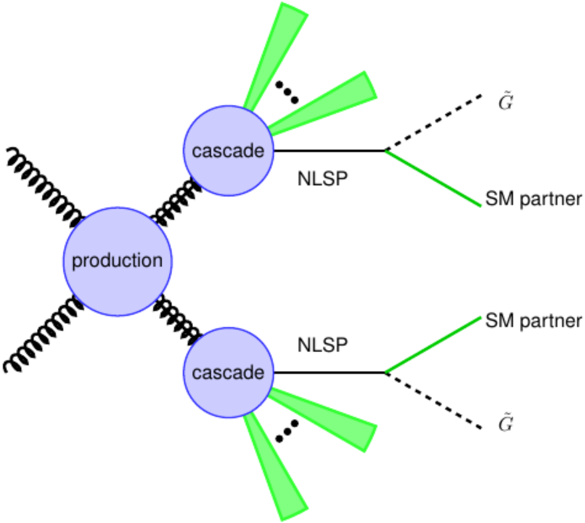
LHC Supersymmetry Production





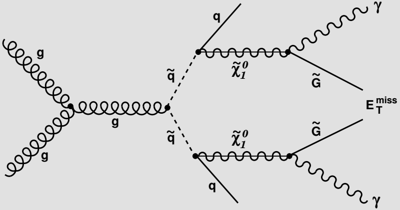
SUSY production mostly in strong interactions at LHC.

Cascade Decay Chain



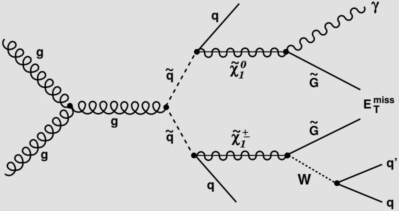
Y. Kats et al: arXiv:1110.6444v2

Double Photon



2 Photons, 2 Jets, Large MET

Single Photon



1 Photon, Jets, Large MET

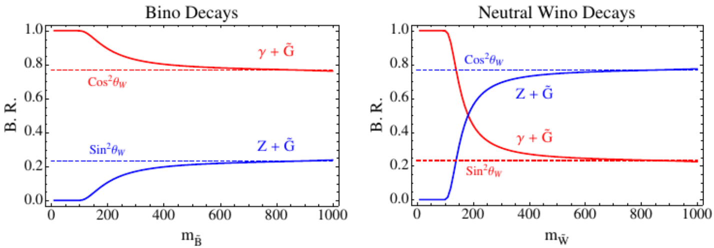
Tranverse Decay Distance

Distance Travelled

$$\mathrm{L}_T = c\tau \cdot (\gamma \beta_T) = c\tau \cdot \left(\frac{p_T}{m}\right)$$

Proper Decay Length

$$c\tau_{\mathtt{NLSP}} = C^2_{\mathtt{grav}} \frac{1}{\kappa} \left(\frac{m_{\mathtt{NLSP}}}{GeV}\right)^{-5} \left(\frac{\sqrt{\mathrm{F}}}{TeV}\right)^4$$



J. Ruderman, D. Shih arXiv:1103.6083

Datasets

- **Data ($19.1 fb^{-1}$)**

Dataset Name	Recorded Luminosity $[fb^{-1}]$
/Run2012B/SinglePhoton/EXODisplacedPhoton-PromptSkim-v3	5.1
/Run2012C/SinglePhoton/EXODisplacedPhoton-PromptSkim-v3	6.9
/Run2012D/SinglePhoton/EXODisplacedPhoton-PromptSkim-v3	7.1
/Run2012C/Cosmics/Run2012C-22Jan2013-v1/RECO	3130384(events)
/Run2012D/Cosmics/Run2012C-22Jan2013-v1/RECO	52430 (events)
/SingleElectron/Run2012A-22Jan2013-v1/AOD	5.2
/DoubleElectron/Run2012C-22Jan2013-v1/AOD	4.8

- **Signal MC [GMSB (SPS8)]**

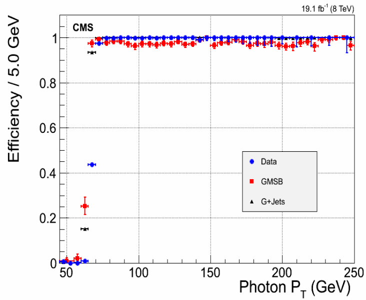
Λ [TeV]	100	120	140	160	180	300
$M_{\tilde{\chi}_1^0}$ $[GeV/c^2]$	140	169	198	227	256	430
$c\tau$	215	325	130	245	185	
(mm)	425	645	515	490	365	495
	1700	1290	1030	975	730	
	3400	1935	2060	1945	1100	995
	5100	2955	2920	2930	2195	2960
	6000	3870	3985	3910	3950	
	9300	5985	6000	5875	5980	6000
		9825	10450	9815	10450	10450

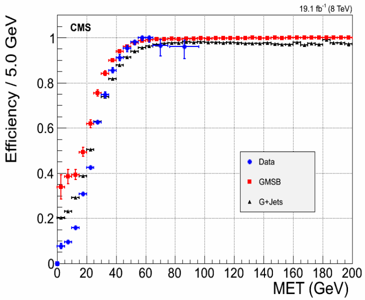
- **$\gamma+$ Jets MC**

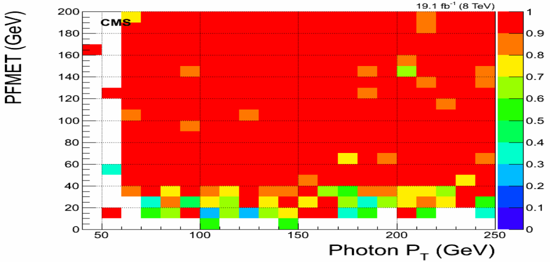
$\hat{p}_T$ [GeV /c]	σ_{LO} (pb)	Number of events
$50-80$	3322.3	1995062
$80-120$	558.3	1992627
$120-170$	108.0	2000043
$170-300$	30.1	2000069
$300-470$	2.1	2000130
$470-800$	0.212	1975231

HLT Trigger

- **HLT_DisplacedPhoton65_CaloIdVL_IsoL_PFMET25**
  - HLT_Photon50_CaloIdVL_IsoL (Study Trigger)





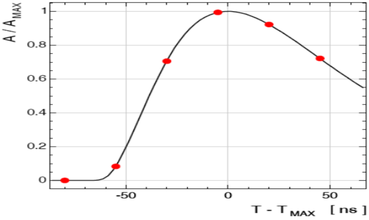


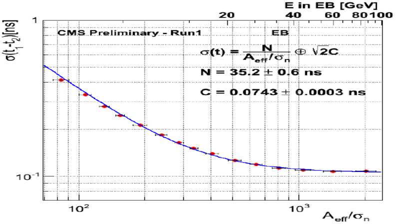
ECAL Timing

- **Time Reconstruction**
  - 10 digitized samples used.
  - Fit and Weighted methods used to extract time.
- **Time Measurement**

$$T_{MAX} = \frac{\sum_i \frac{T_{MAX,i}}{\sigma_i^2}}{\sum_i \frac{1}{\sigma_i^2}}$$

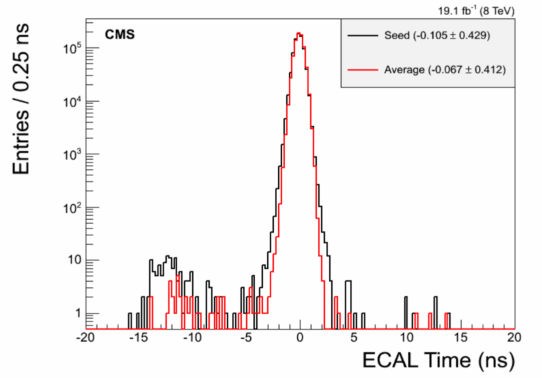
- **Time Performance**
  - Time resolution better than 200 ps for $E > 30$ GeV





ECAL Timing(2)

- **Photon Timing**
  - $T_\gamma =$ Average Time of all Crystals.
  - $T_\gamma =$ Seed (most energetic) Crystal Time.



- Similar behavior seen in Seed and Average Time.
- We use seed time as Photon Measured Time in this analysis.

ECAL Timing(3): MC Vs Data

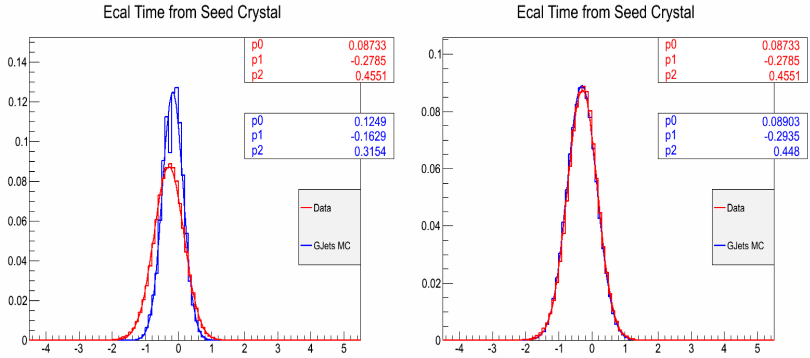
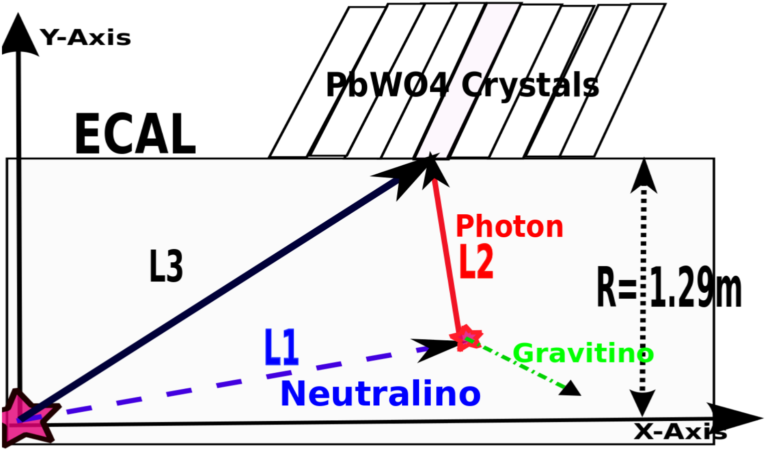


Figure : (LEFT): Before (RIGHT): After

- Timing corrections from data applied to $\gamma+$ Jets MC.
- $\gamma+$ Jets MC timing aligns better with data after corrections are applied.

Long-Lived Decay

- **Why Long-Lived?**
  - Slow moving particle; $\beta << 1$,
  - Non-nominal flight path,
  - Stopped in subdetectors,

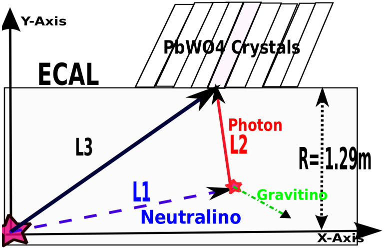


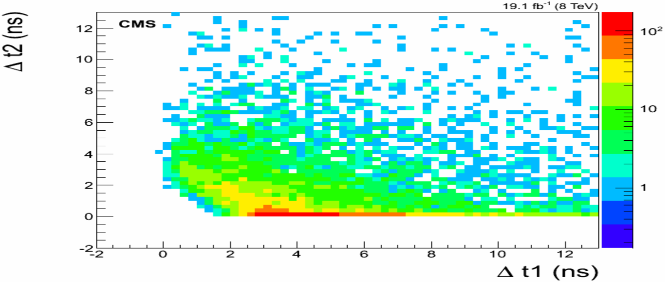
Slow Vs Off-Pointing Decay

Photon Arrival Time

$$\Delta t_1 = (L1/c\beta) - (L1/c)$$

$$\Delta t_2 = (L1 + L2 - L3)/c$$





Delayed photons mostly from slow moving neutralino decays.

Event Selection

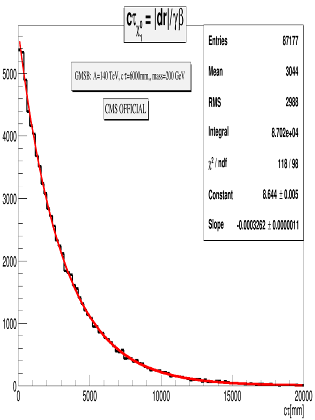


Figure : 1/Slope = 3065.60 mm

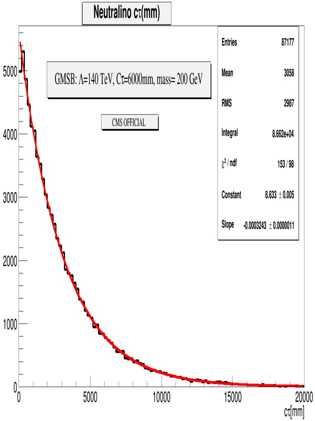
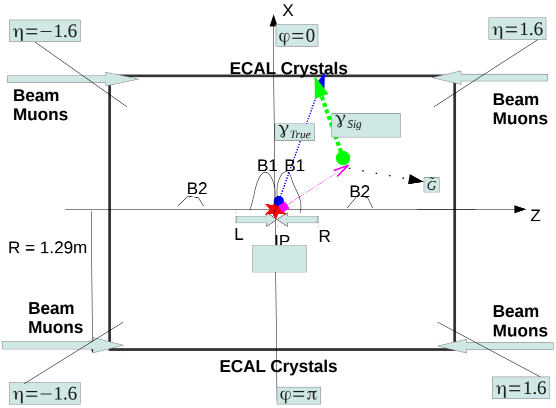


Figure : 1/Slope = 3083.56 mm

Sample is $c\tau = 6000$ mm but we measure $c\tau \approx 3000$ mm

Kinematics Distribution

Background Estimation



Systematics

Limits

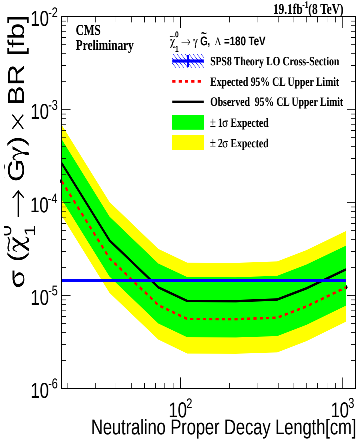


Figure : $c\tau$ Limits

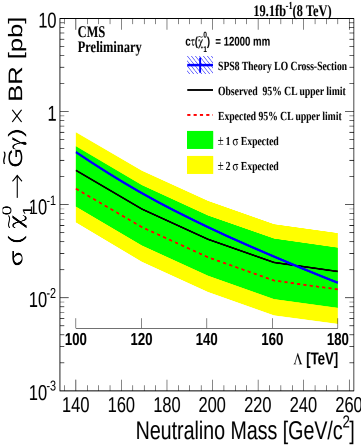
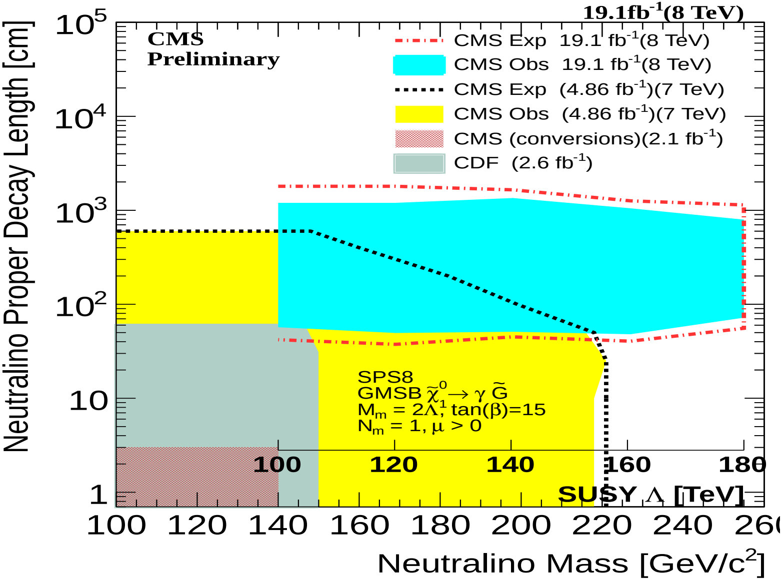


Figure : Mass Limit

sample is $c\tau = 12000$ mm but we measure $c\tau \approx 10500$ mm

$c\tau$-Mass Limits



Are we measuring the original $c\tau$ of the neutralino?

CMS Official GMSB Samples				
Λ[TeV]	mass[GeV]	C_{grav}	$c\tau$[mm]	Fit Value[mm]
120	169	93.5	1000	657.89
120	169	162	3000	1942.12
140	198	162	3000	1550.38
140	198	187	4000	2064.83
140	198	229	6000	3083.56
180	256	93.5	1000	378.64
180	256	132	2000	749.45
180	256	162	3000	1104.85
180	256	229	6000	2203.61

We seem to be measuring neutralino $c\tau$ by some factor off.

By how much are we off in neutralino $c\tau$ measurements?

CMS Official GMSB Samples			
Λ[TeV]	cτ[mm]	Fit Value[mm]	Factor Off
120	3000	1942.12	1.54
140	3000	1550.38	1.93
180	3000	1104.85	2.71
140	6000	3083.56	1.9
180	6000	2203..61	2.7

Factor is The SAME for different neutralino $c\tau$ with same Λ value. However, factor is NOT THE SAME for the same $c\tau$ with different Λ values.

Is this due to how sample is generated?

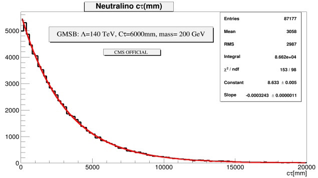


Figure : $1/\text{Slope} = 3083.56$ mm

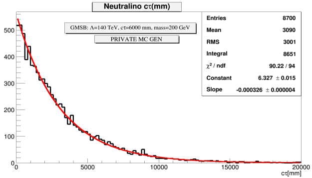


Figure : $1/\text{Slope} = 3067.48$ mm

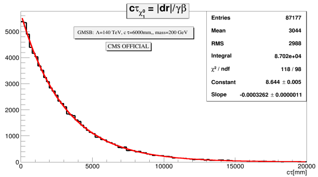


Figure : $1/\text{Slope} = 3065.60$ mm

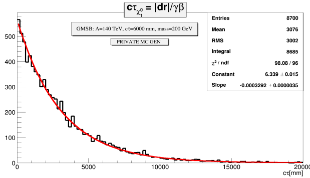


Figure : $1/\text{Slope} = 3037.66$ mm

Private GMSB sample seems to show same offset measurements

To Be Completed

- Offset in neutralino $c\tau$ seems to have a more subtle origin than expected. Probably how mass enters into the lifetime definition and implementation at MC generation level.
- GMSB samples with the same sample $c\tau$, hence C_{grav}, but with different Λ values have different offset factor.
- The observation that the $c\tau$ value for a given sample with Λ is different from the measured value is very unclear, even without looking at samples with different Λ values.
- Our next step involves understanding cause of this offset.