Search For Delayed Photons Using Timing.

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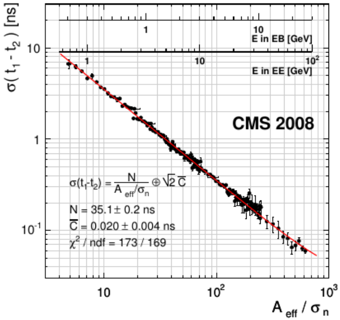
Outline

Introduction

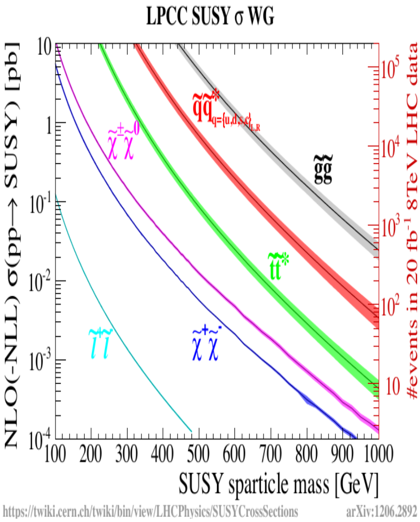
- **Long-Lived Particle Models**
  - ⋆ Gauge Mediated Supersymmetry Breaking (GMSB)
    - ▷ Next-to-lightest SUSY (NLSP) is Neutralino ($\tilde{\chi}_1^0$)
    - ▷ $eV - keV$ Lightest-SUSY particle (LSP) is Gravitino ($\tilde{G}$).
    - ▷ Gravitino is a Dark Matter Candidate.
  - ⋆ General Gauge Mediation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

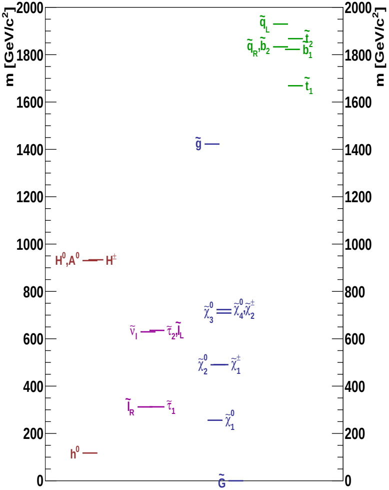
† ECAL timing resolution $\sigma_t < 500$ ps.

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



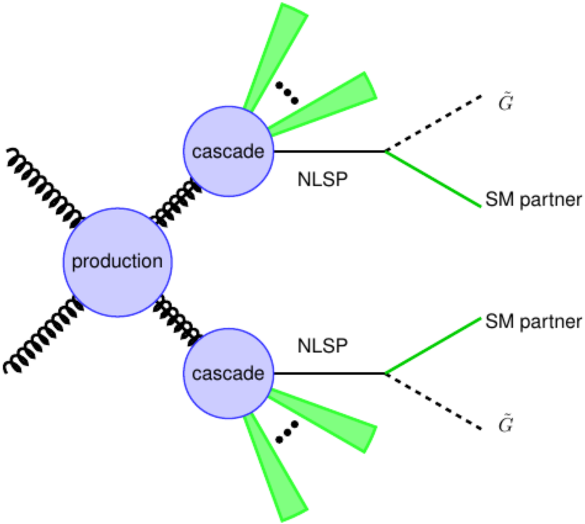
LHC Supersymmetry Production





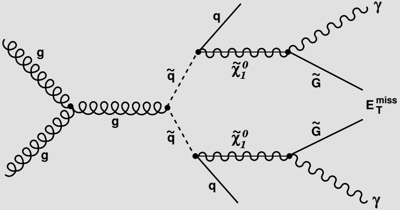
SUSY production mostly in strong interactions at LHC.

Cascade Decay Chain



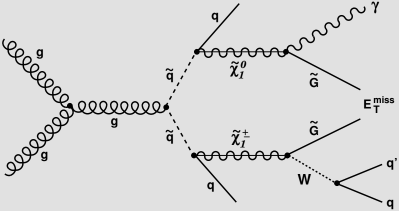
Y. Kats et al: arXiv:1110.6444v2

Double Photon



2 Photons, 2 Jets, Large MET

Single Photon



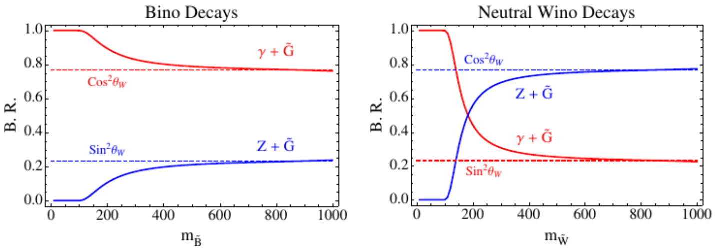
1 Photon, Jets, Large MET

Distance Travelled

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

Proper Decay Length

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



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)]**

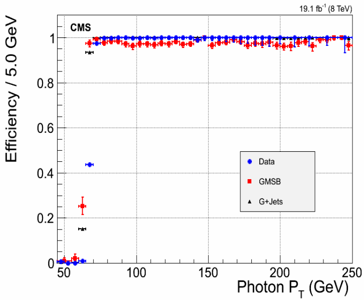
Λ [TeV]	100	120	140	160	180	300
$M_{\tilde{\chi}_1^0}$ $[GeV/c^2]$	140	169	198	227	256	430
$c\tau$	215	325	130	245	185	
(mm)	425	645	515	490	365	495
	1700	1290	1030	975	730	
	3400	1935	2060	1945	1100	995
	5100	2955	2920	2930	2195	2960
	6000	3870	3985	3910	3950	
	9300	5985	6000	5875	5980	6000
		9825	10450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

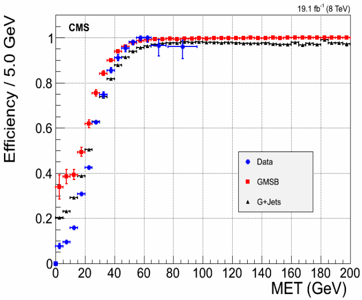
- **$\gamma+$ Jets MC**

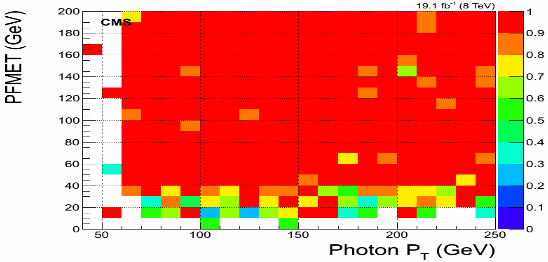
$\hat{p}_T$ [GeV /c]	σ_{LO} (pb)	Number of events
$50 - 80$	3322.3	1995062
$80 - 120$	558.3	1992627
$120 - 170$	108.0	2000043
$170 - 300$	30.1	2000069
$300 - 470$	2.1	2000130
$470 - 800$	0.212	1975231

HLT Trigger

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





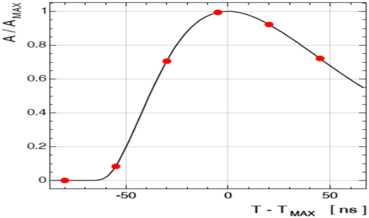


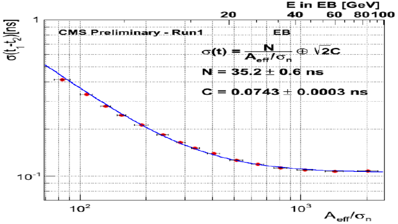
ECAL Timing

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

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

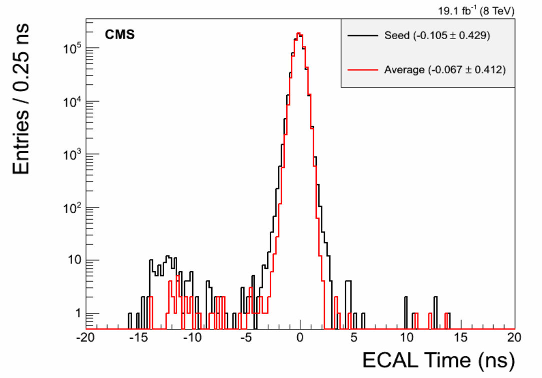
- **Time Performance**
  - Time resolution better than 200 ps for $E > 30$ GeV





ECAL Timing(2)

- **Photon Timing**
  - T_γ = Average Time of all Crystals.
  - T_γ = 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

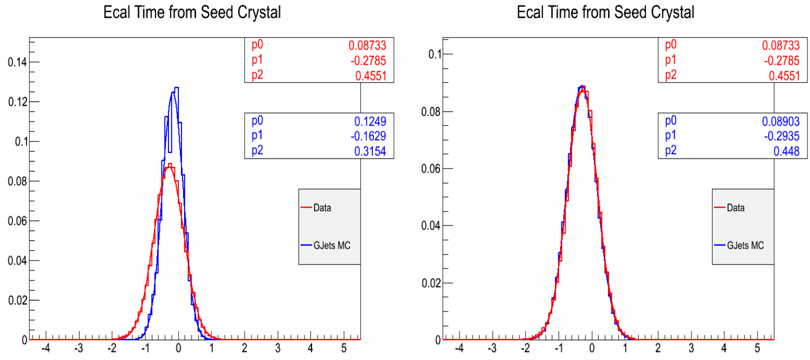
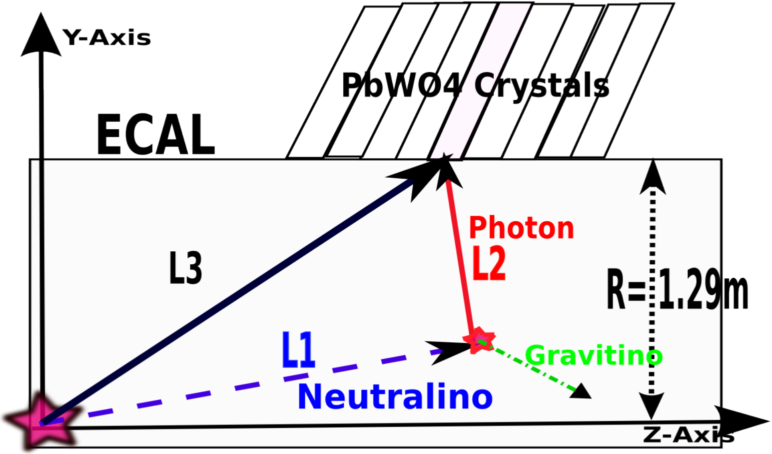


Figure : (LEFT): Before (RIGHT): After

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

Long-Lived Decay

- **Source of Delayed Photon?**
  - Slow moving particle; $\beta << 1$,
  - Non-nominal flight path,
  - Stopped in subdetectors,

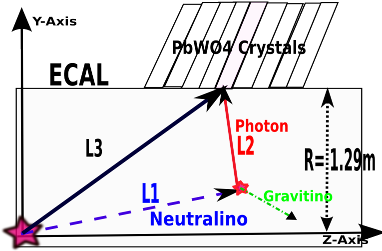


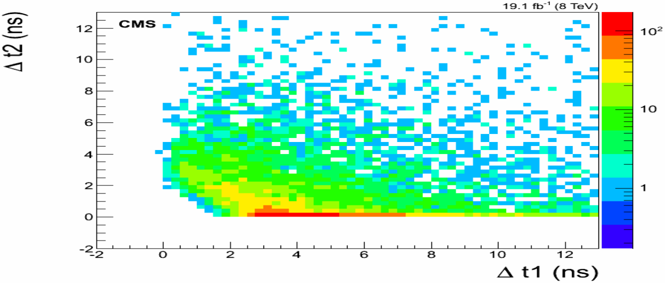
Slow Vs Off-Pointing Decay

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.

Object Selection Criteria

Variable	Selection Cuts
Photon $p_T(\gamma^{1(2)})$	$> 80(45)$ GeV
$\lvert\eta_\gamma\rvert$,(EB only),	$< 3.0(< 1.5)$
Semi-minor axis(S_{Minor})	$0.12 \leq S_{Minor} \leq 0.38$
H/E	< 0.05
Track Vito,$\Delta R(\gamma, track)$	> 0.6
HCAL,ECAL, Track, Isolation	$< 4.0, < 4.5, < 0.2$
Cone Size(Iso γ) $\Delta R(\gamma, SC)$	< 0.4
Spike Swiss-Cross	$1 - E_4/E_1) < 0.98$
Jets must satisfy	JetID Requirements
Leading Jet p_T	> 35 GeV
Number Of Constituents	> 1
$\Delta R(\gamma, jet) = \sqrt{(\phi_\gamma - \phi_{jet})^2 + (\eta_\gamma - \eta_{jet})^2}$	> 0.3
E_T^{miss}	> 25 GeV

Kinematics Distribution

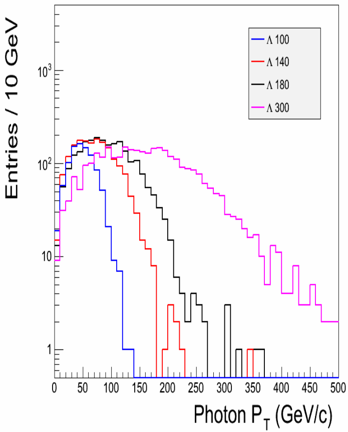


Figure : Photon p_T

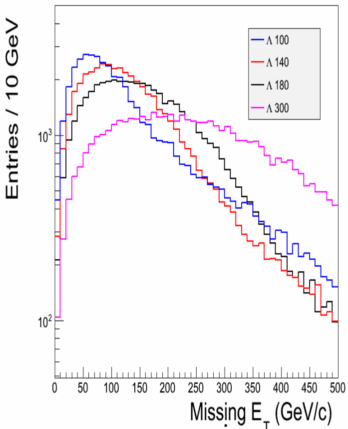


Figure : E_T^{miss}

- Different Λ values with the same $c\tau$(10 m). Photon p_T is harder with higher values of Λ.

Signal Efficiency and Acceptance

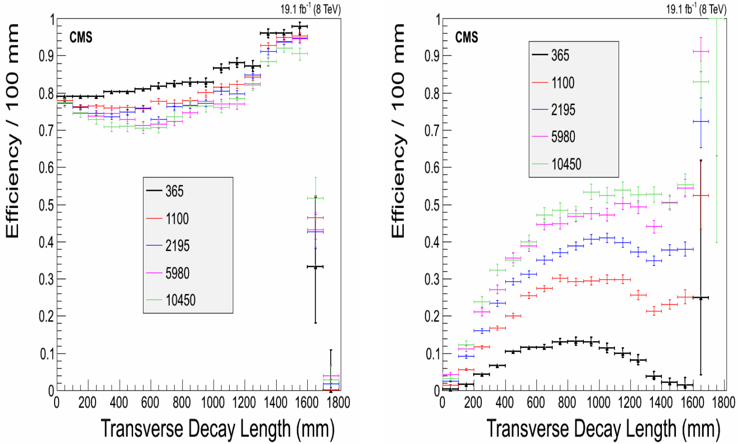


Figure : Efficiency
Figure : Acceptance

Sharp drop in efficiency immediately beyond ECAL radius for slow moving neutralino decay as source of delayed photon.

Signal Efficiency and Acceptance(II)

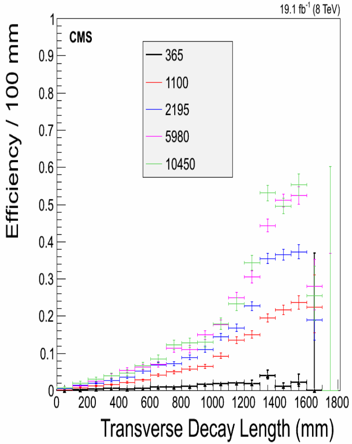


Figure : Slow Moving

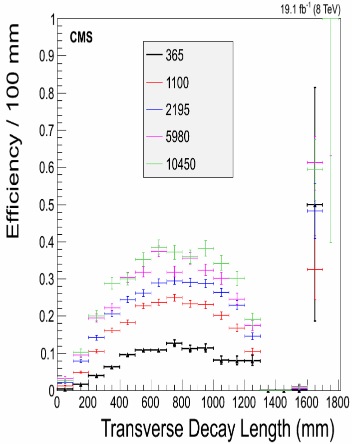


Figure : Off-Pointing

Acceptance peaks at transverse decay length 800 mm with delayed photons from off-pointing neutralino decays.

Signal Efficiency and Acceptance(III)

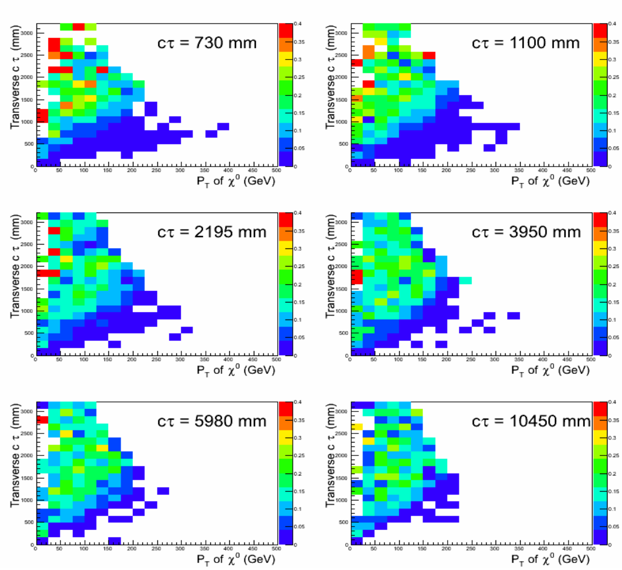


Figure : 2 Dim Efficiency

Background Estimation

Systematics

Background estimation is Data driven. Thus, most of a systematics come from signal,including:

Experimental Systematics

- Definition of Absolute or Zero time,
- ECAL time Resolution,
- Unclustered Energy,
- Jet energy scale,
- Jets energy resolution,
- Photon energy scale,
- Luminosity. We use standard CMS luminosity uncertainty.

Theoretical Systematics

- Choice of PDF.
- Re-normalization group equations.

Systematics(II)

Systematic Uncertainties

Source	Uncertainty(%)
Absolute time(Zero time)	$10 \sim 6$
Unclustered Energy	$10 \sim 4$
Photon Energy Scale	$4 \sim 2$
ECAL Time Resolution	$5 \sim 2$
Jet Energy Scale	$9 \sim 3$
Jet Energy Resolution	$9 \sim 2$
Luminosity	2.6
Choice of PDF	< 1

- Systematics is obtained by studying the effects of varying by a few amount of a particular source of systematic on the total number of objects passing object selection cuts.

Results

Events Passing Final Selection

Sample	Lifetime($c\tau$)[mm]	Number Of Events
GMSB $\Lambda = 180$ TeV	10500	
GMSB $\Lambda = 180$ TeV	6000	
GMSB $\Lambda = 180$ TeV	4000	
GMSB $\Lambda = 180$ TeV	3000	
GMSB $\Lambda = 180$ TeV	2000	
GMSB $\Lambda = 180$ TeV	1000	
GMSB $\Lambda = 180$ TeV	500	
Data	1.00	
Background Total	0.014	

CLs Upper Limits

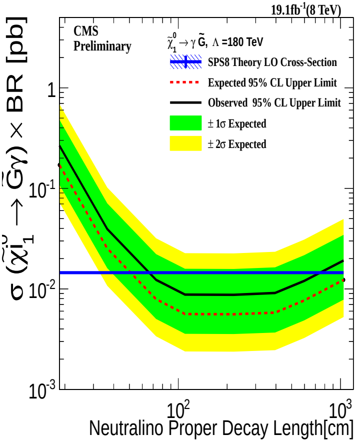


Figure : $c\tau$ Limits

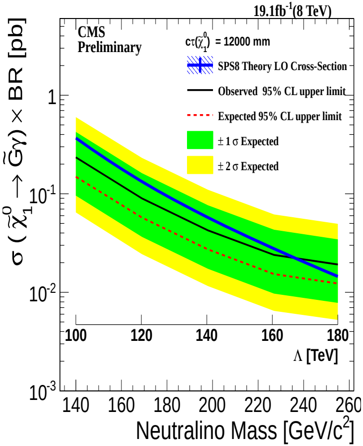
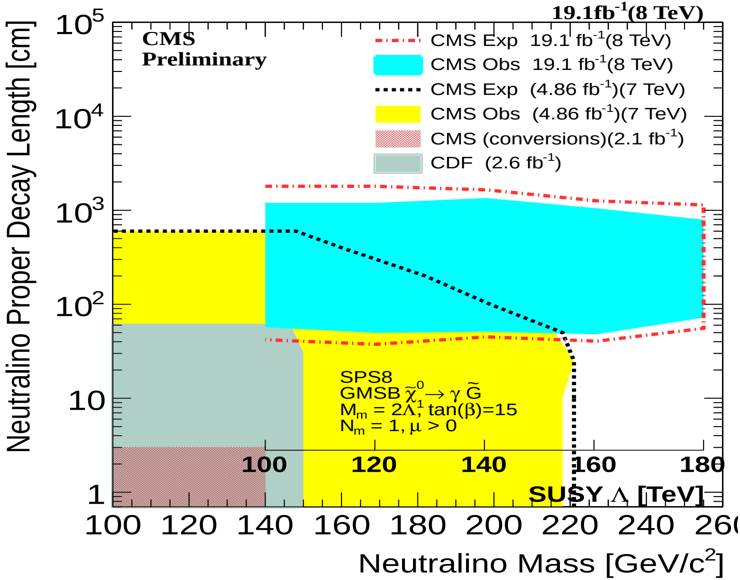


Figure : Mass Limit

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



19.1fb-1(8 TeV)
CMS
Preliminary
CMS Exp 19.1 fb-1(8 TeV)
CMS Obs 19.1 fb-1(8 TeV)
CMS Exp (4.86 fb-1)(7 TeV)
CMS Obs (4.86 fb-1)(7 TeV)
CMS (conversions)(2.1 fb-1)
CDF (2.6 fb-1)
SPS8
GMSB $\tilde{\chi}_1^0 \to \gamma \tilde{G}$
$M_m = 2\Lambda$, tan(β)=15
$N_m = 1$, μ > 0
Neutralino Proper Decay Length [cm]
Neutralino Mass [GeV/c2]
SUSY Λ [TeV]
100 120 140 160 180
100 120 140 160 180 200 220 240 260
1 10 10^2 10^3 10^4 10^5

Summary