Study of the gauge mediation signal with nonpointing photons at the CERN LHC

Physics at LHC

July 2004, Vienna

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Reference: Physical Review **D69**: 035003, 2004 (hep-ph/0309031).

Introduction

In GMSB models,

- LSP is the gravitino ($\tilde{G}$), while NLSP is either neutralino ($\tilde{\chi}_1^0$) or sleptons ($\tilde{\ell}$).
- The lifetime of NLSP is a free parameter.

Strategy depends on NLSP and its lifetime.[a]

NLSP	short lifetime	long lifetime
$\tilde{\chi}_1^0$	Prompt decay of $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ (isolated γ and large E_T^{miss})	Quasi-stable $\tilde{\chi}_1^0$ (large E_T^{miss}, similar to SUGRA)
$\tilde{\ell}$	Prompt decay of $\tilde{\ell} \to \ell\tilde{G}$ (isolated leptons and E_T^{miss})	Quasi-stable $\tilde{\ell}$ (“heavy muon”-like)

[a] See ATLAS Physics TDR for details.

Here we study the case of

NLSP=$\tilde{\chi}_1^0$ with intermediate lifetime :

NLSP may decay into $\gamma\tilde{G}$ in the detector.

Search for events with nonpointing photons and E_T^{miss}.

and we demonstrate:

- The $\tilde{G}$ direction can be determined using the nonpointing photon.
- Together with **the mass relation method**[a], we can determine properties of SUSY particles.
  - Determination of sparticle masses
  - Sensitivity to NLSP lifetime

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[a] See for example, M.M. Nojiri, G. Polleselo, D. Tovey, hep-ph/0312318 (Les Houches workshop 2003).

From the measurement of a nonpointing photon;

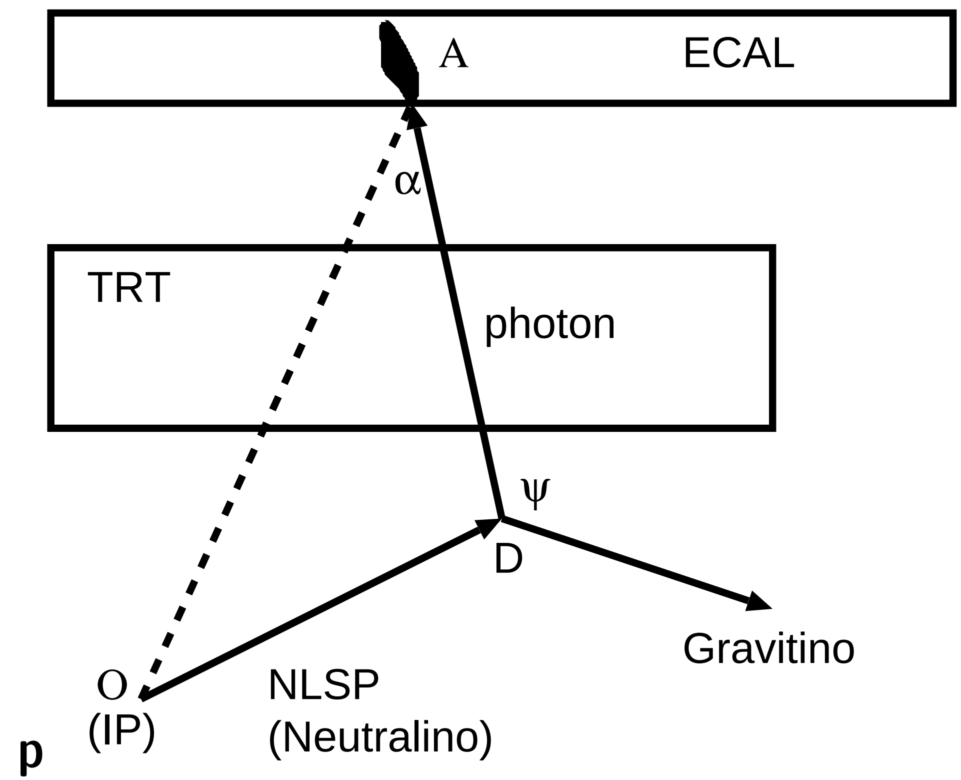
$$
\begin{aligned}
L &= |\overrightarrow{\mathrm{OA}}| \\
\cos\alpha &= \text{cosine of } (\overrightarrow{\mathrm{OA}} \text{ and } \vec{p}_\gamma) \\
\Delta t_\gamma &= t_\gamma - L/c
\end{aligned}
$$

we obtain the $\tilde{G}$ direction as ;

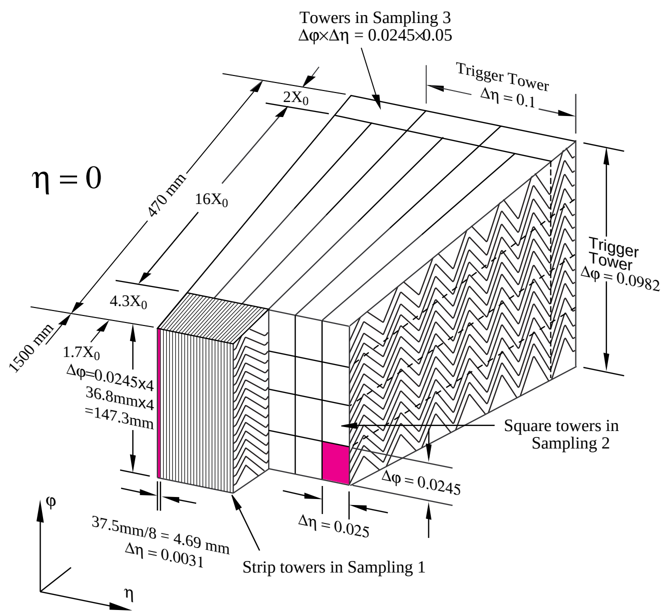
$$\cos\psi = \text{cosine of } (\vec{p}_\gamma, \vec{p}_{\tilde{G}}) = \frac{1-\xi^2}{1+\xi^2}$$

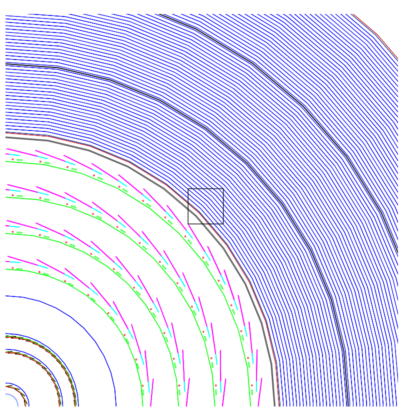
$$\text{where } \xi = \frac{c\Delta t_\gamma + L(1-\cos\alpha)}{L\sin\alpha}$$

Believe this ! (You can check this relation by yourselves, as a good exercise of relativistic kinematics.)



ATLAS ECAL & TRT





ATLAS ECAL has potentially

- good time resolution : $\sigma_t \sim 0.1$ nsec for $E_\gamma > 30$ GeV,
- good θ resolution : $\sigma_\theta \sim 60\ \mathrm{mrad}/\sqrt{E_\gamma}$ (E_γ in GeV),
- but only poor ϕ resolution.

ATLAS TRT (Transition radiation tracker) has a photon conversion probability of $\mathcal{O}(10)\%$ ($\gamma \rightarrow e^+e^-$).

- The ϕ angle can be very precisely measured by the e^+e^- pair.
- we assume the resolution to be $\sigma_\phi \sim 1\ \mathrm{mrad}$ (much better than σ_θ by ECAL).

Dalitz decay events ($\tilde{\chi}_1^0 \rightarrow e^+e^-\tilde{G}$) can also be used, but are not considered here.

Event simulation

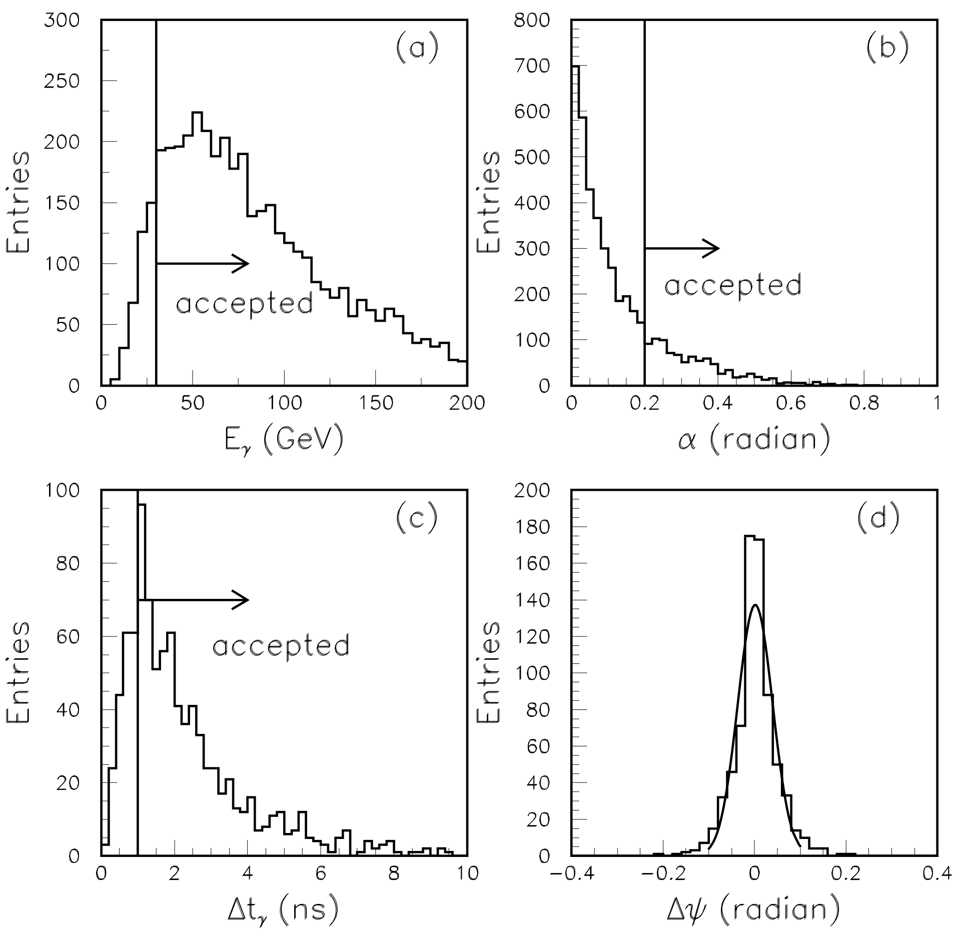
Four vectors

- SUSY parameter : GMSB Point 1 by ISASUSY ($\sigma_{\rm SUSY}$=7.2 pb).
- Event generation with HERWIG.
- NLSP is kept "stable" at this stage.
- 100,000 SUSY events are generated, corresponding to 13.9 fb^{-1}.

Detector simulation

- ATLFAST is used for all particles but NLSPs.
- At the analysis stage photons from the NLSP decayss are simulated with a simple smearing method, taking into account of
  - lifetime of NLSP,
  - photon conversion probability in TRT, and
  - energy and position resolutions of photons

Photon selection and ψ resolution



Cuts to select nonpointing photons;

(a) $E_\gamma > 30$ GeV,

(b) $\alpha > 0.2$ rad., and

(c) $\Delta t_\gamma > 1.0$ ns.

(d) Distribution of $\Delta\psi \equiv \psi - \psi_{\mathbf{true}}$.

The resolution σ_ψ ~40 mrad.

Event trigger is guaranteed by the condition (a).

Mass relation method

Consider the decay chain;

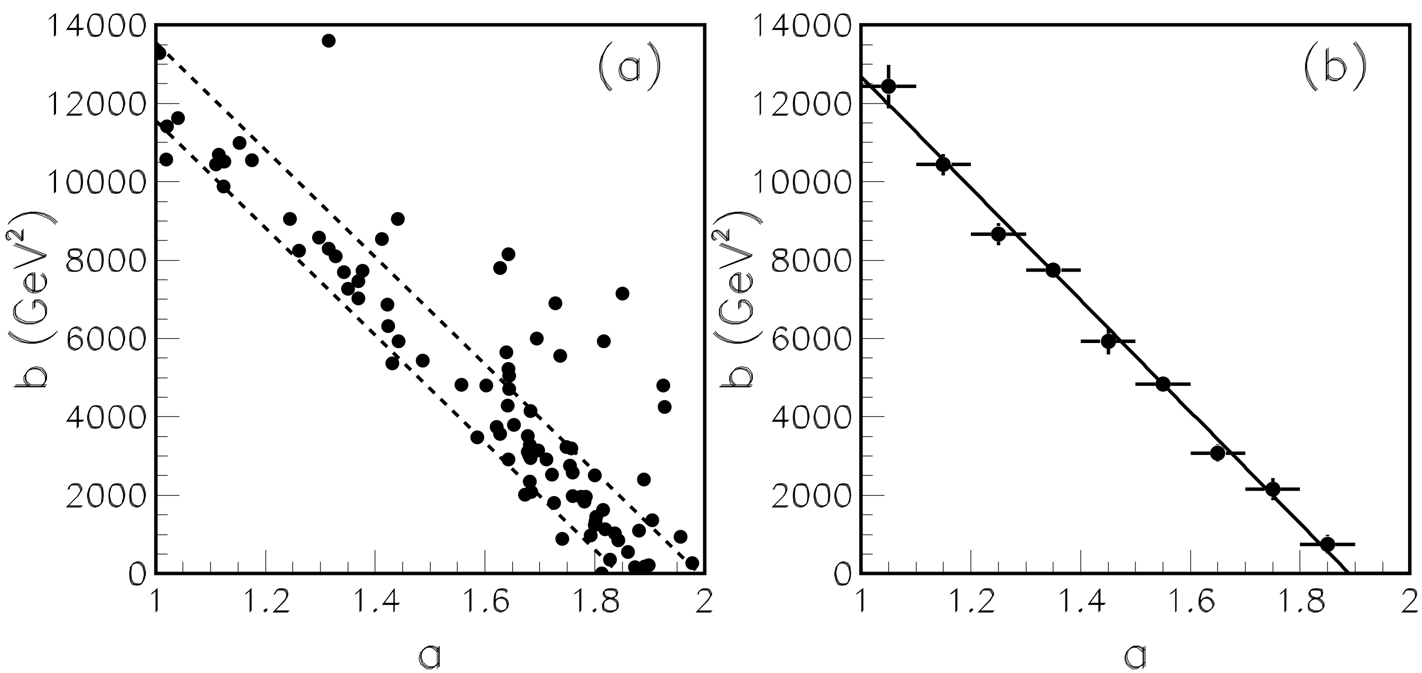
$$\tilde{\ell} \to \ell\tilde{\chi}_1^0 \to \ell\gamma\tilde{G},$$

where $\cos\psi = \cos\theta_{\gamma\tilde{G}}$ is measured and $E_{\tilde{G}}$ is unknown.

$$\begin{aligned}
m_{\tilde{\chi}_1^0}^2 &= (p_\gamma + p_{\tilde{G}})^2 = 2E_\gamma E_{\tilde{G}}(1-\cos\psi) \\
m_{\tilde{\ell}}^2 &= (p_\gamma + p_{\tilde{G}} + p_\ell)^2 \\
&= 2E_\gamma E_{\tilde{G}}(1-\cos\psi) + 2E_{\tilde{G}}E_\ell(1-\cos\theta_{\ell\tilde{G}}) + 2E_\ell E_\gamma(1-\cos\theta_{\ell\gamma}) \\
&= \left(1 + \frac{E_\ell(1-\cos\theta_{\ell\tilde{G}})}{E_\gamma(1-\cos\psi)}\right) m_{\tilde{\chi}_1^0}^2 + 2E_\ell E_\gamma(1-\cos\theta_{\ell\gamma}) \\
&= a m_{\tilde{\chi}_1^0}^2 + b
\end{aligned}$$

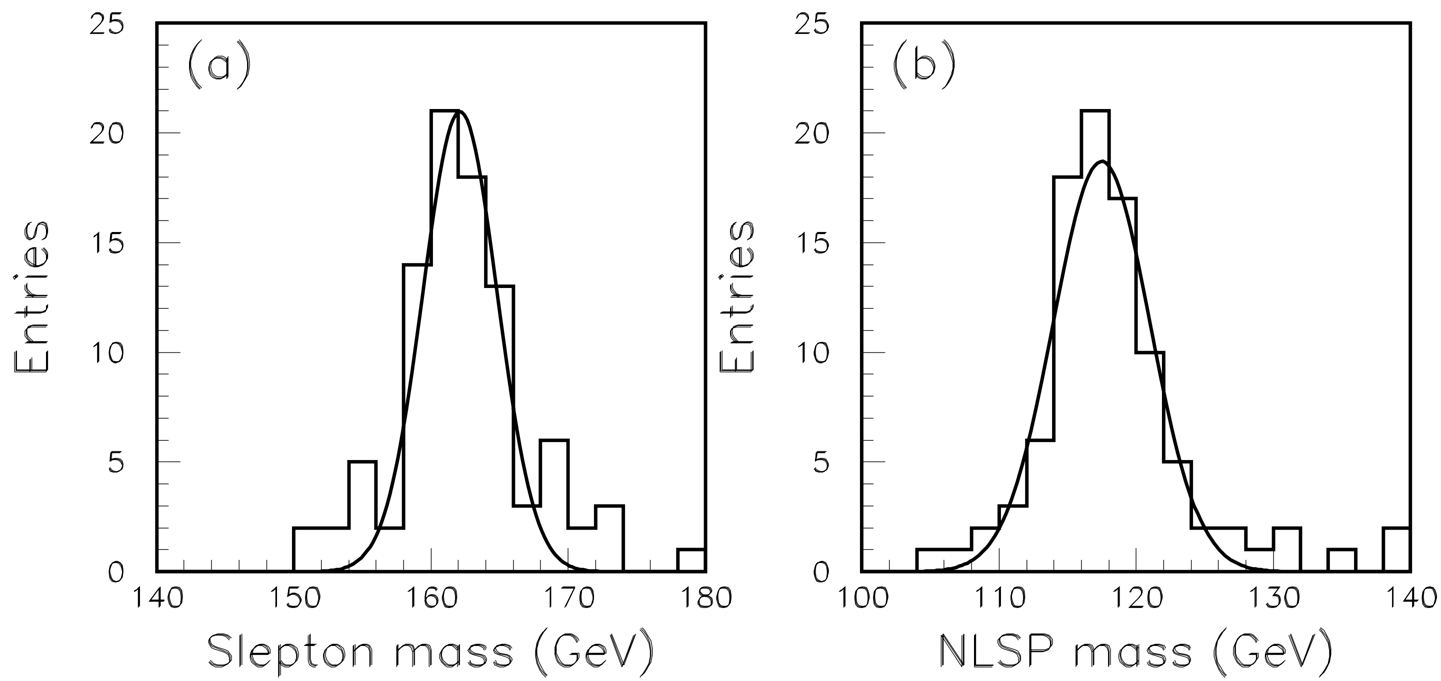
The parameters (a, b) can be calculated event by event, as E_ℓ, E_γ, and the three opening angles are all measured.

- In an event having an nonpointing photon and leptons, the combination minimizing the invariant mass $m_{\ell\gamma}$ is used to calculate a and b.
- The scatter plot (a, b) is fitted to the linear function : $b = m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2 a$.



Mass resolutions

- The mass resolution is estimated by repeating the simulation 100 times.
- True masses : $m_{\tilde{\ell}} = 161.6$ GeV and $m_{\tilde{\chi}_1^0} = 117.0$ GeV.
- Fitted masses : $m_{\tilde{\ell}} = 162.1 \pm 2.7$ GeV and $m_{\tilde{\chi}_1^0} = 117.5 \pm 3.5$ GeV.
- If one of the two masses is known, the resolution becomes much better (~ 300 MeV).



Once masses are determined ...

The decay chain $\tilde{\ell} \longrightarrow \ell\tilde{\chi}_1^0 \longrightarrow \ell\gamma\tilde{G}$ can be fully reconstructed by solving following equations:

$$\begin{aligned}
\vec{x}_\gamma &= \vec{v}_{\tilde{\chi}_1^0} t_D + \vec{v}_\gamma (t_\gamma - t_D) \\
p_{\tilde{\ell}}^2 &= (p_{\tilde{\chi}_1^0} + p_\ell)^2 = m_{\tilde{\ell}}^2 \\
p_{\tilde{\chi}_1^0}^2 &= m_{\tilde{\chi}_1^0}^2 \\
p_{\tilde{G}}^2 &= (p_{\tilde{\chi}_1^0} - p_\gamma)^2 = m_{\tilde{G}}^2 = 0
\end{aligned}$$

where

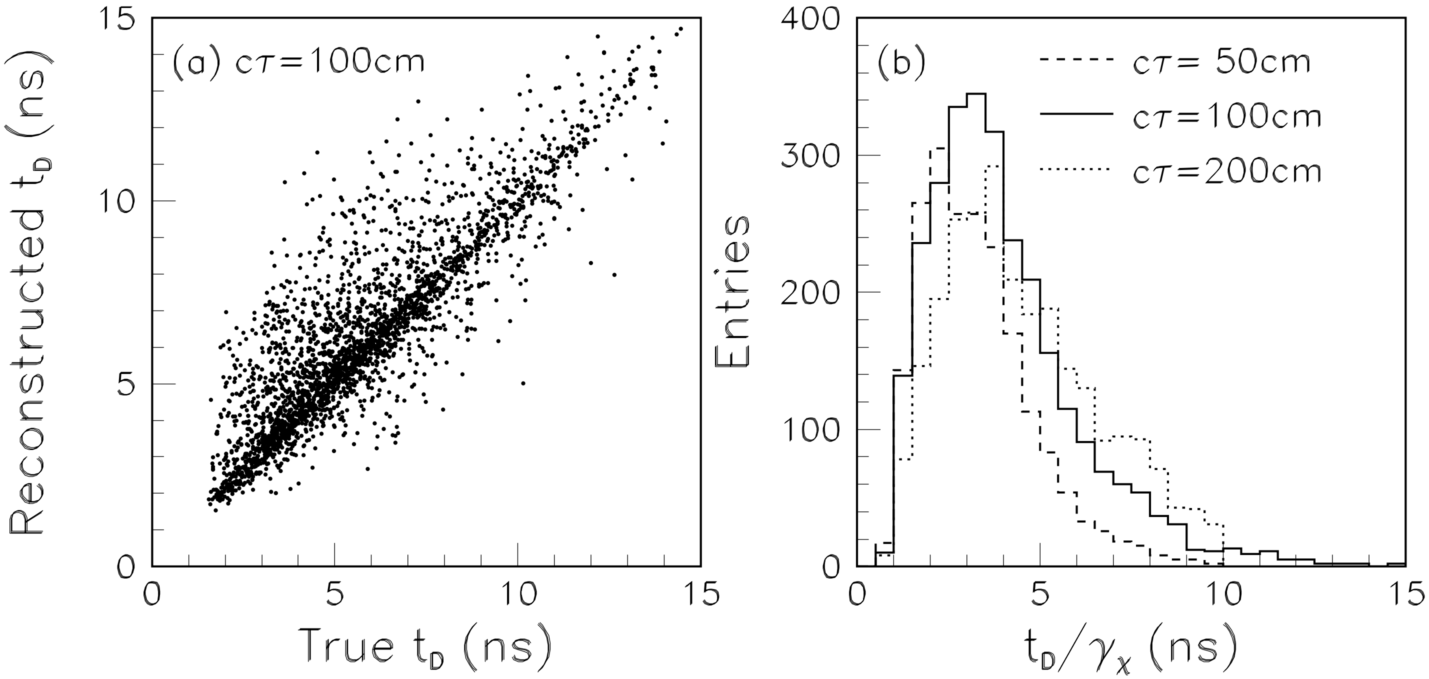
- $\vec{x}_\gamma$ and t_γ are measured position and arrival time of the photon,
- $\vec{v}_{\tilde{\chi}_1^0}$ and $\vec{v}_\gamma$ are velocities ($|\vec{v}_\gamma| = c$),
- t_D is the NLSP decay time, and
- $p_{\tilde{\ell}}$, $p_{\tilde{\chi}_1^0}$, $p_{\tilde{G}}$ are four-momenta.

Photon conversion is NOT required for this analysis.

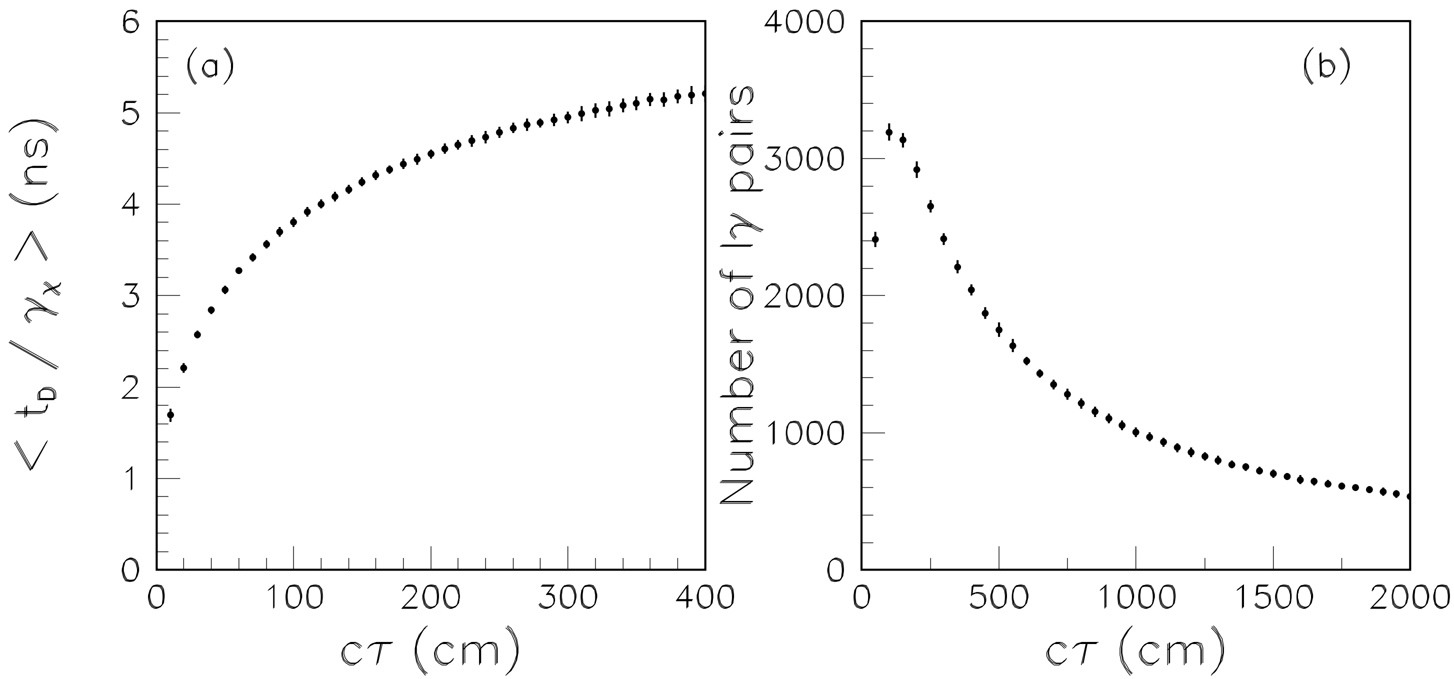
Decay time distribution

There are two solutions for a $\ell\gamma$ pair. We take a solution if the reconstructed decay point has $r < 100$ cm and $|z| < 300$ cm (e.g. inside the barrel ECAL).

The decay kinematics are fully reconstructed, including the decay position and time !



Sensitivity to the NLSP lifetime

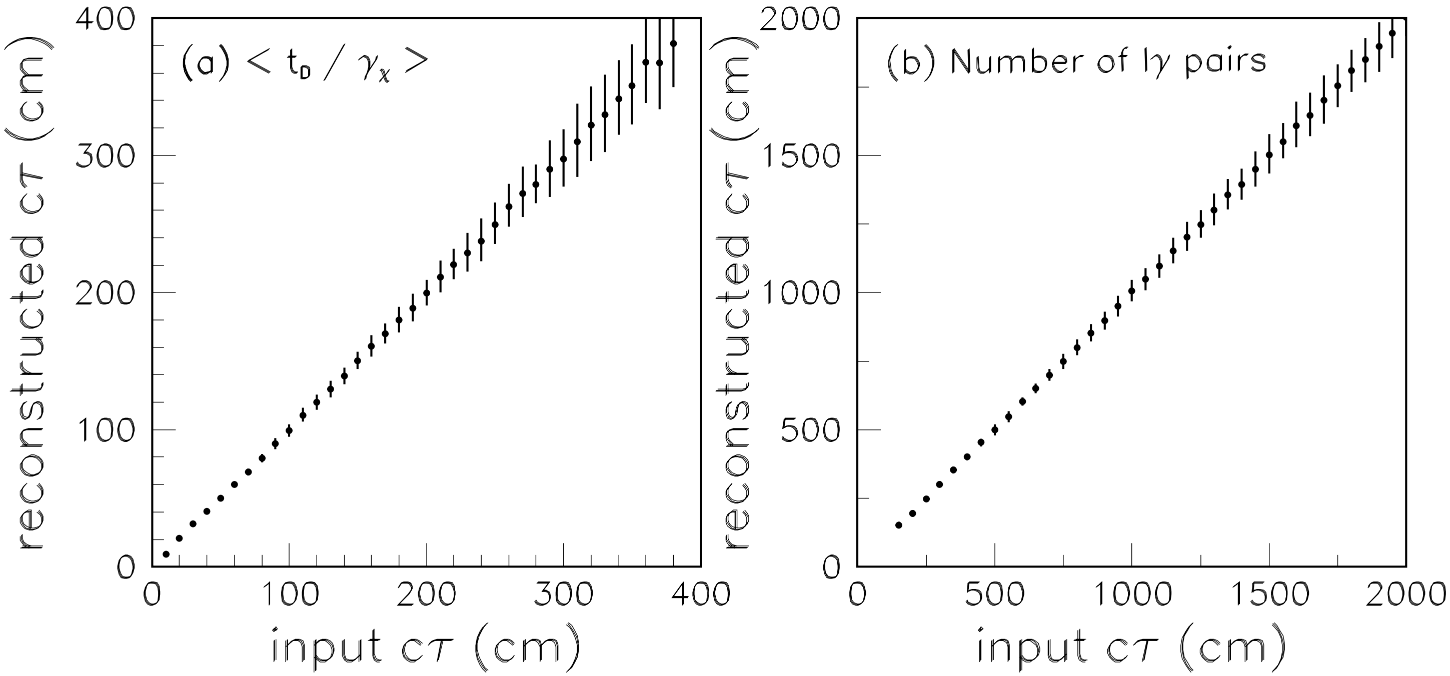


Ideally the NLSP lifetime $c\tau$ is proportional to $\langle t_D/\gamma_\chi \rangle$, but we suffer from the detector acceptance and the wrong solution. The NLSP lifetime can be determined by

(a) the average $\langle t_D/\gamma_\chi \rangle$ for short $c\tau$ and

(b) the number of $\ell\gamma$ pairs for long $c\tau$.

Sensitivity to the NLSP lifetime



$$c\tau \propto \left(\frac{100\ \mathrm{GeV}}{m_{\tilde{\chi}_1^0}}\right)^5 \left(\frac{\sqrt{F_0}}{100\ \mathrm{TeV}}\right)^4 \times 10^{-2}\ \mathrm{cm}$$

Measurement of $c\tau \longrightarrow$ measurement of F_0: the “fundamental” SUSY parameter.

Summary

- The direction of $\tilde{G}$ from the decay $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ can be determined by precisely measuring the photon's direction and arrival time.
- Together with the mass relation method, we can determine properties of SUSY particles.
  - masses of the lightest neutralino (NLSP) and sleptons,
  - lifetime of NLSP.
- Full detector simulation is necessary to understand systematic errors and effects of background.