Search for GMSB NLSPs at LHC

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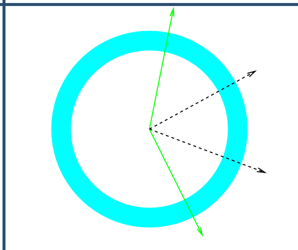
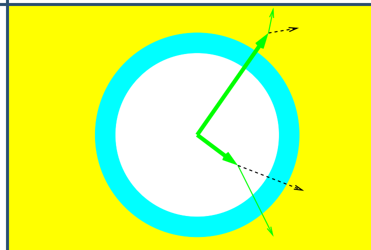
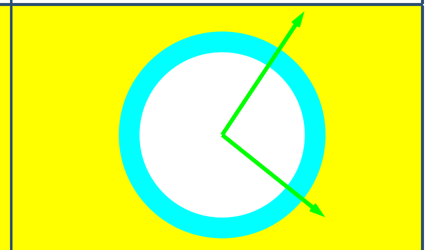
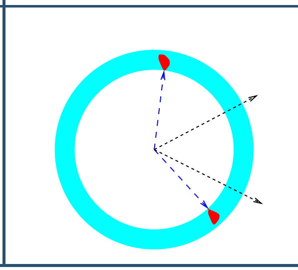
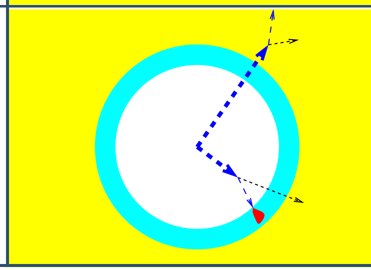
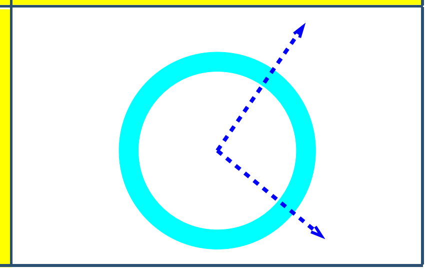
on behalf of CMS and ATLAS collaborations,

- GMSB - very short introduction
- Stau NLSP: long lived WIMPs
  - ATLAS
    see “R-hadron and long lived particle searches at LHC” presented by Shikma BRESSLER in the present session
  - CMS
    some details of the TOF method
- Neutralino NLSP:
  non-pointing photons
  - ATLAS
    ECAL plus converted photons
  - CMS
    ECAL full detector simulation
- Conclusions

Non-standard SUSY signatures

NLSP	$c\tau \simeq 0$	$c\tau \simeq$ det. size	$c\tau >>$ det. size
$\tilde{\tau}_1 \rightarrow \widetilde{G}\tau$			
$\widetilde{\mathbf{N}}_\mathbf{1} \rightarrow \widetilde{G}\gamma$			

GMSB as an example framework for non-standard SUSY signatures

The decay NLSP – LSP could have dramatic influence on SUSY phenomenology. NLSP could have significant lifetime and could be charged. Highlighted boxes in the above table correspond to situation in which detectors must be used in a special way.

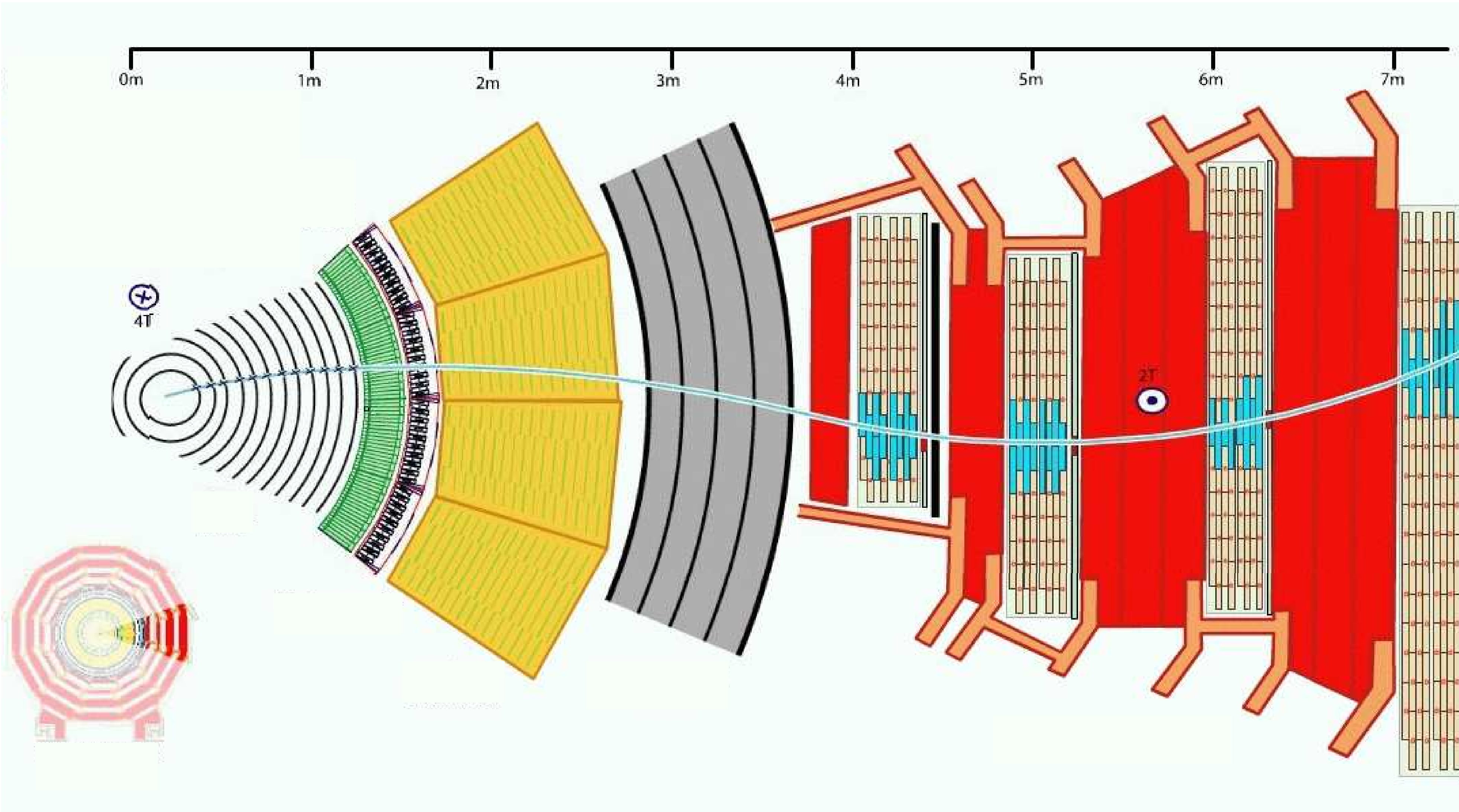
They are: Heavy Stable Charged Particles

and decaying in flight (neutral or charged) NLSPs.

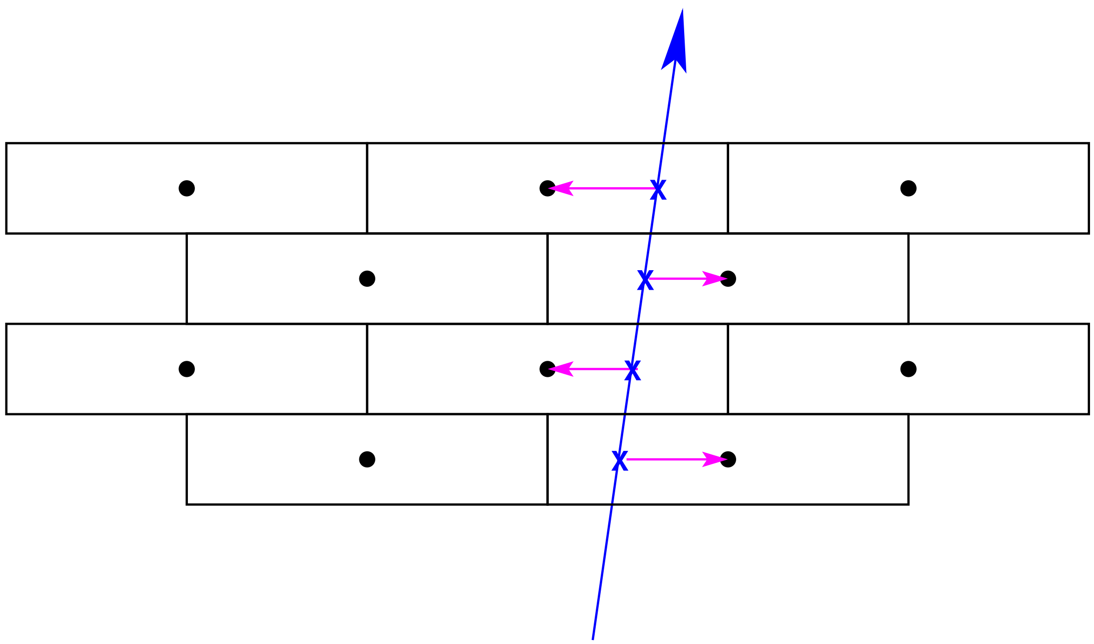
Minimal GMSB model is defined by six parameters:

Λ – effective SUSY mass scale, N – number of messenger generations, M – messenger mass scale, $\tan\beta$, $\mathrm{sgn}\,\mu$ and C_g – ratio of the intrinsic SUSY breaking scale to messenger SB scale, governing goldstiono coupling and hence – NLSP lifetime.

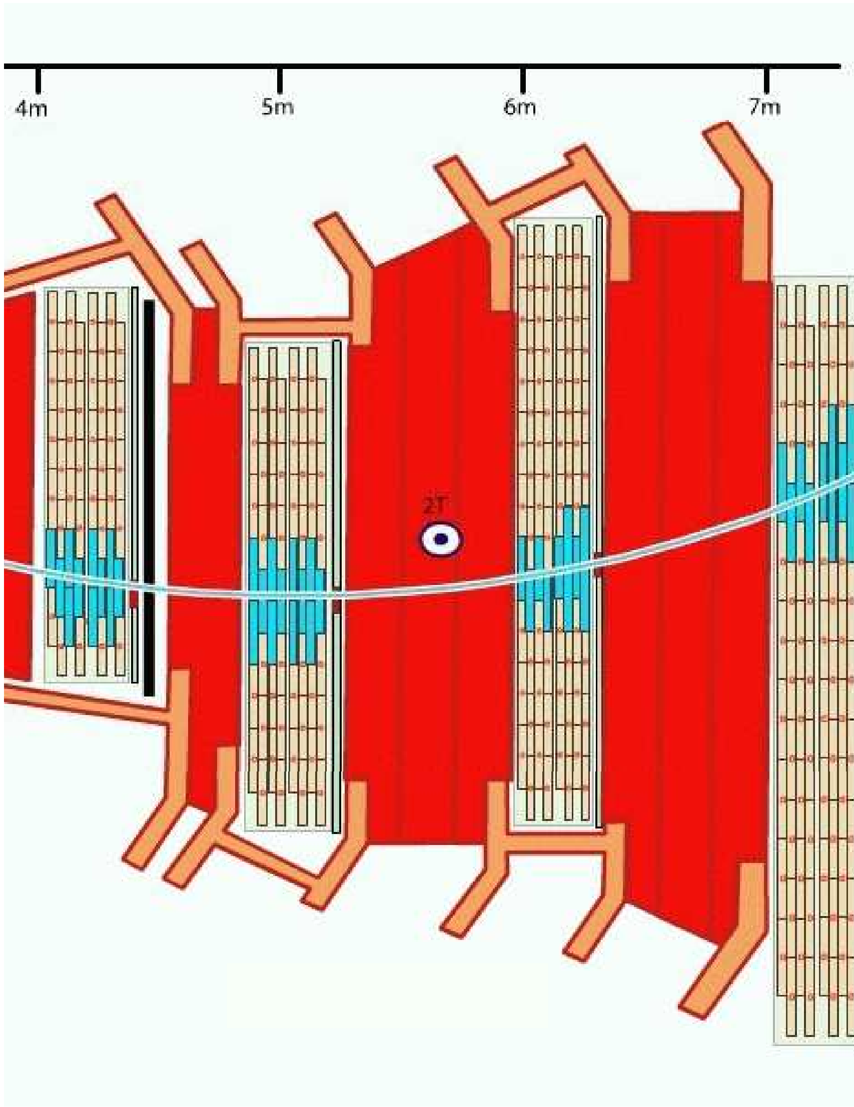
CMS: $\tilde{\tau}_1$ NLSP: long-lived charged



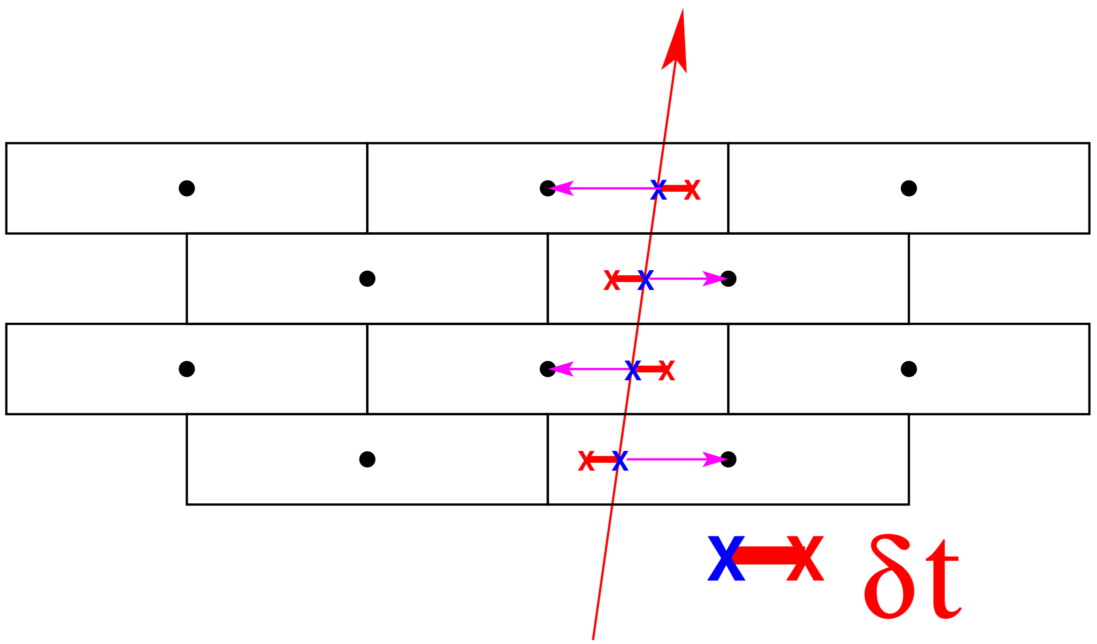
CMS: $\tilde{\tau}_1$ NLSP: long-lived charged

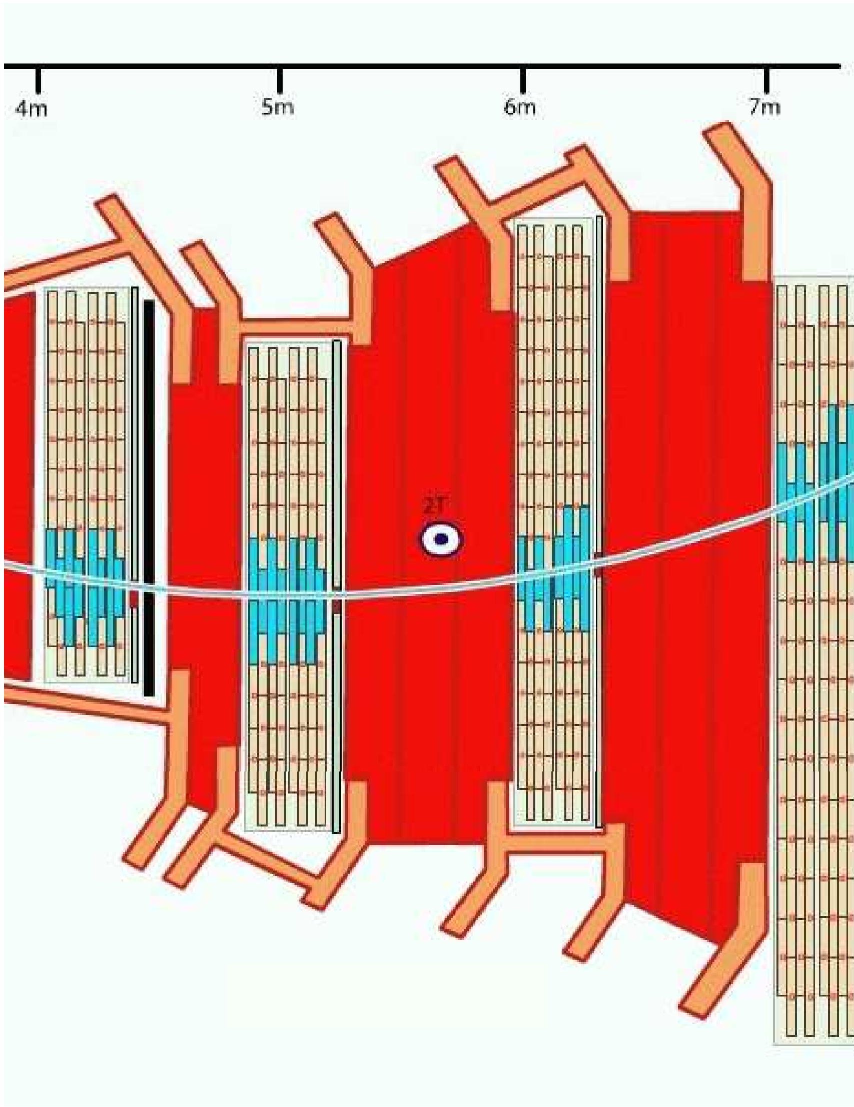


in a given super-layer hits due to muon should align if timing is correct



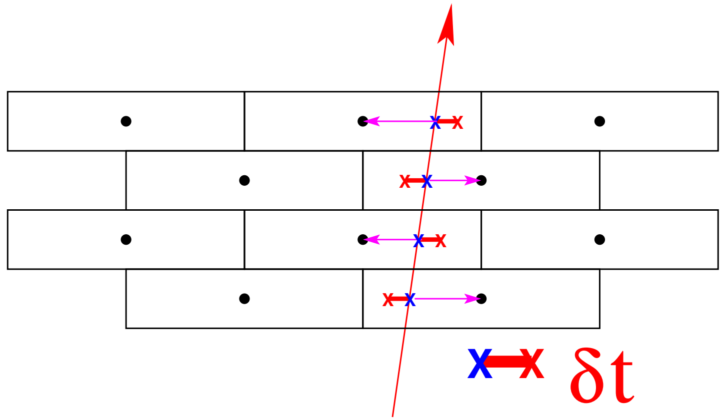
CMS: $\tilde{\tau}_1$ NLSP: long-lived charged





hits due to delayed particle do not align, they are shifted backward from the wire

CMS: $\tilde{\tau}_1$ NLSP: long-lived charged



$$\frac{\delta_x}{v_{\mathrm{drift}}} = \delta_t = t_{\beta<1} - t_c = \frac{L}{c}(\frac{1}{\beta} - 1)$$

and hence

$$\frac{1}{\beta} = 1 + \frac{\delta_x}{L}\frac{c}{v_{\mathrm{drift}}}$$

and finally

$$\frac{1}{\beta} = 1 + \frac{c}{v_{\mathrm{drift}}}\frac{1}{N}\sum_{i=1}^{N}\frac{\delta_x^i}{L_i}$$

where L is the flight distance, v_{drift} is the drift velocity and $\delta_x^i = |x_i^{\mathrm{hit}} - x_i^{\mathrm{wire}}| - |x_i^{\mathrm{reco}} - x_i^{\mathrm{wire}}|$

CMS: $\tilde{\tau}_1$ NLSP: full simulation

Preselection

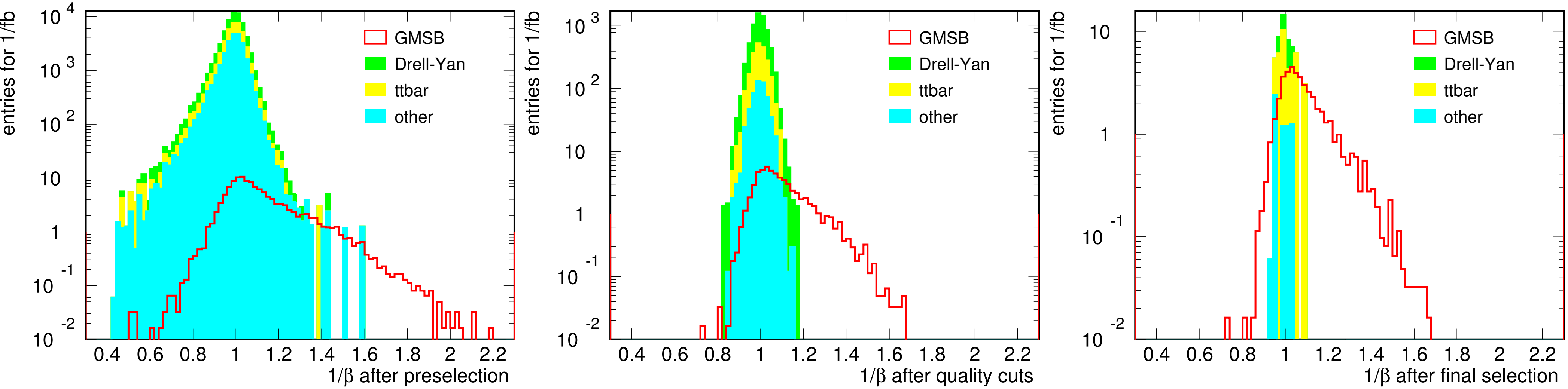
- Single muon HLT trigger;
- Momentum greater than 80 GeV;

Quality requirements

- left & right hits in each super-layer
- $\phi \& \eta$ in each station
- at least 15 hits per candidate
- $\mathrm{RMS}(\beta^{-1}) < 0.06$

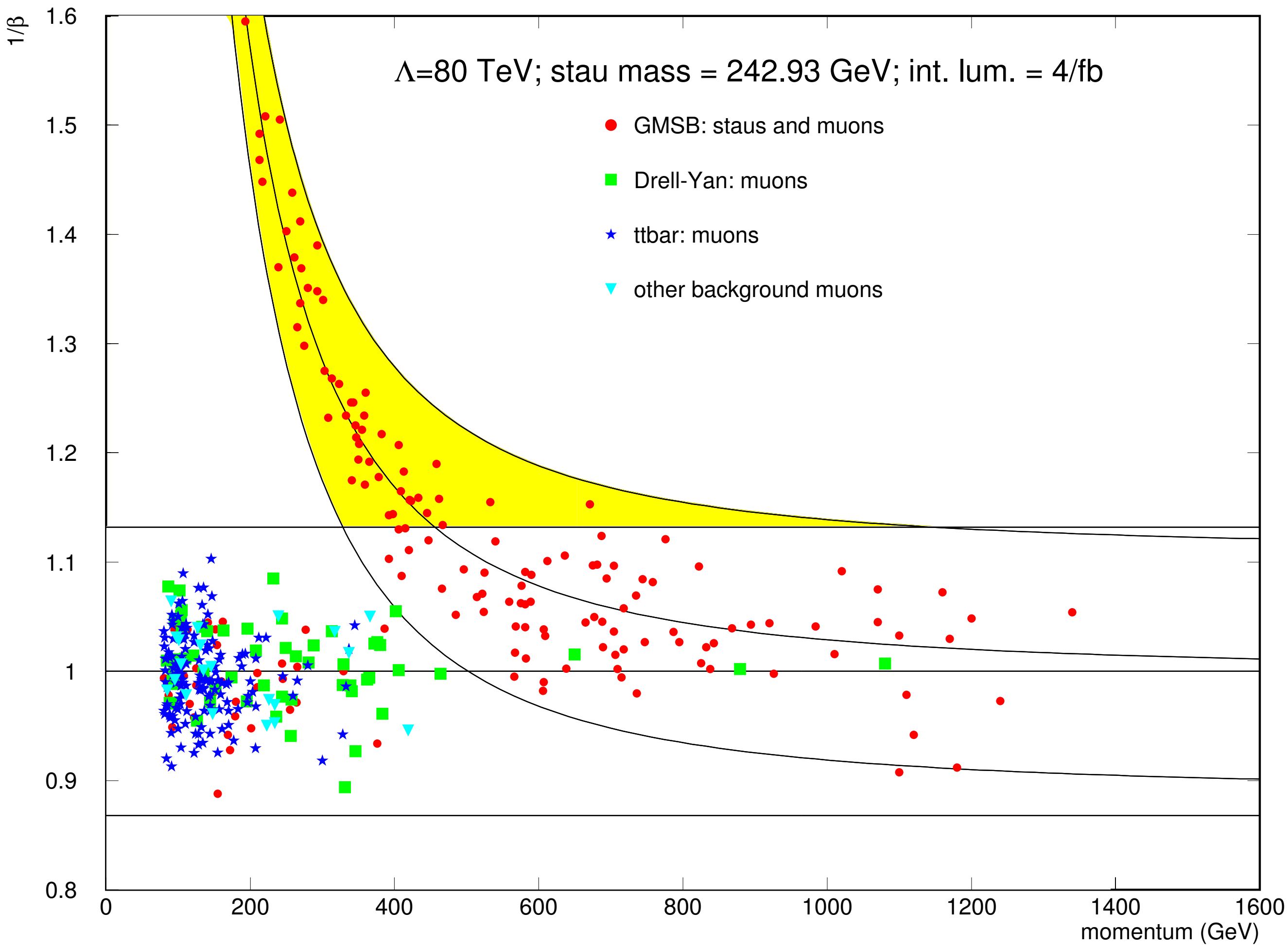
Selection

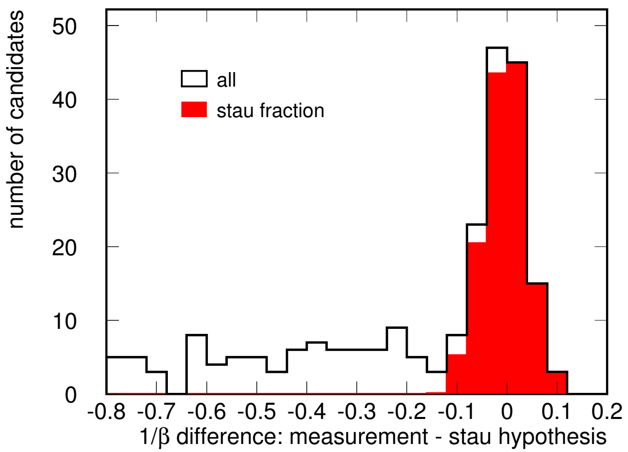
- At least two energetic muon candidates $p_T^{2\mu} > 60$ GeV;
- Mass of the pair of muon candidates: $M_{\mu\mu} > 110$ GeV;
- Effective event mass: $M_{\text{eff}} > 360$ GeV;

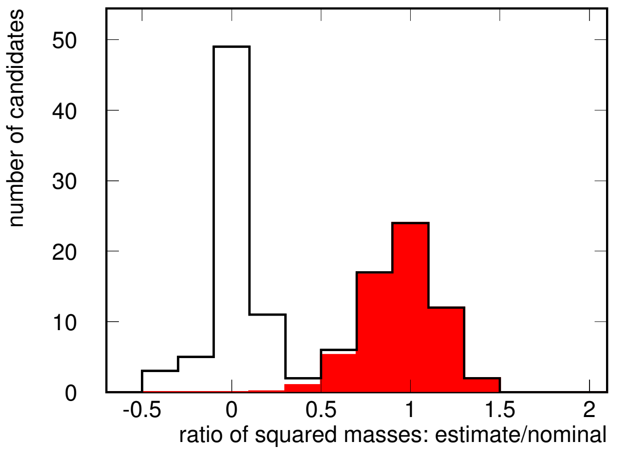


$\Lambda = 80\,TeV;\, \mathcal{L} = 1/\text{fb}$ Drell-Yan; $t\bar{t}2\mu$; all other bkg.

CMS: $\tilde{\tau}_1$ NLSP: $\Lambda = 80$TeV results







CMS: $\tilde{\tau}_1$ NLSP: significance

Number of background events at different stages of the selection for 1/fb

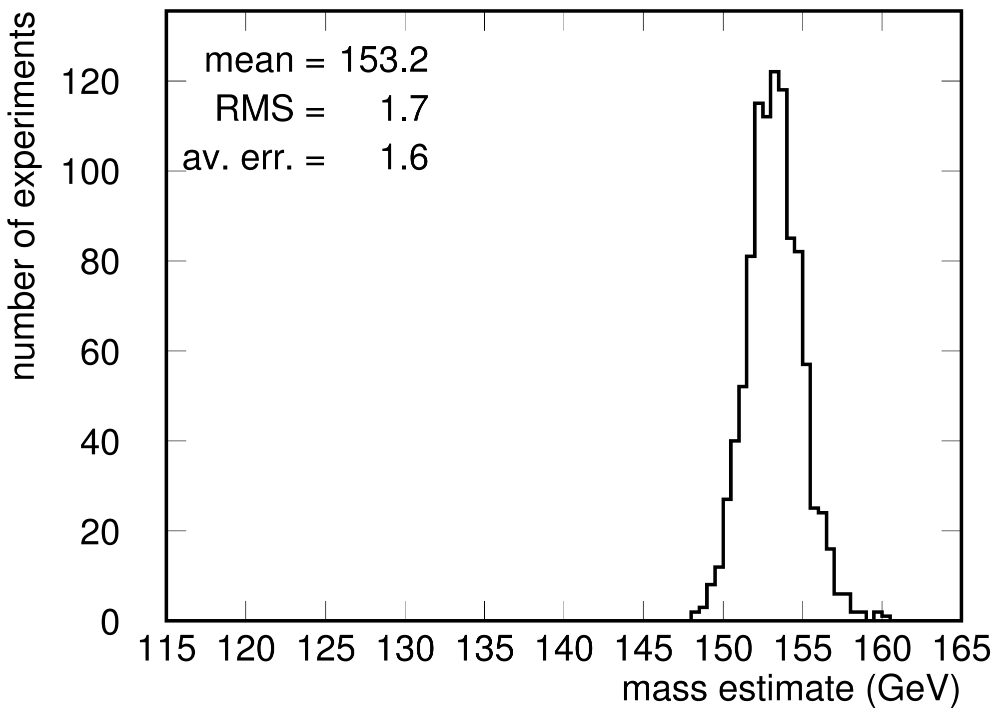
dataset	preselection	quality	selection	"yellow"
signal $\Lambda = 50$TeV	1714.1	956.4	666.4	155.054
signal $\Lambda = 80$TeV	108.8	59.8	45.0	12.019
Drell-Yan 2mu $\hat{s} > 115$GeV	8105.6	4422.6	13.6	0.012
tt 2mu	2686.0	1624.4	33.7	0.029
WW 2mu	573.7	327.7	6.0	0.005
ZZ 2mu	202.0	110.1	0.1	0.000
ZW 2mu	231.6	121.3	0.0	0.000
Σ	11798.9	6606.1	53.4	0.046

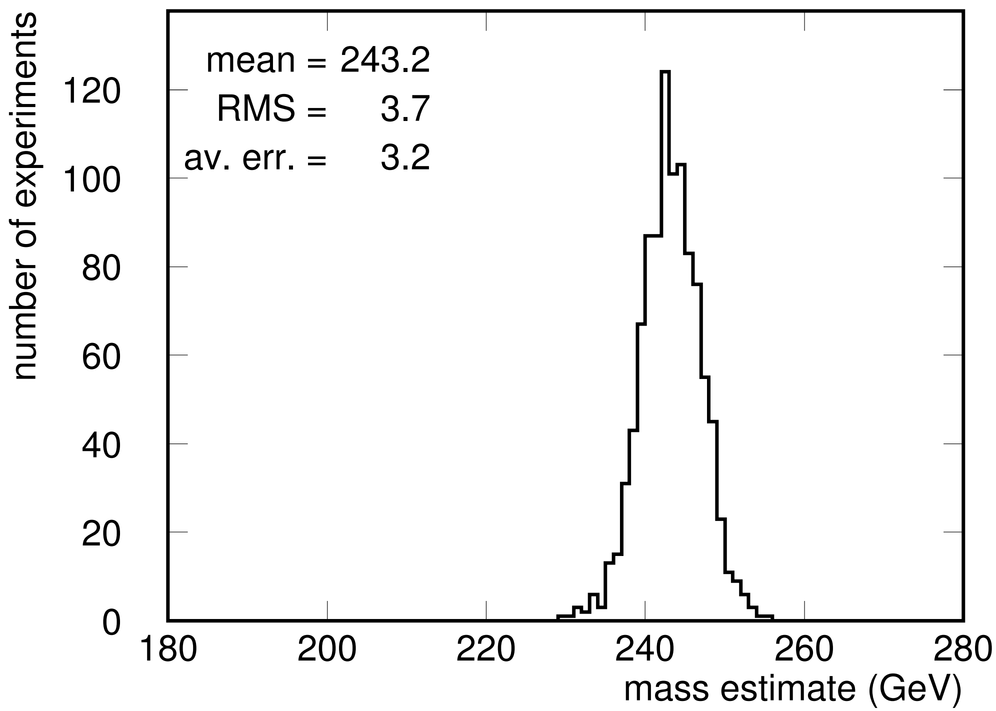
The upper limit for number of expected background events in the "yellow" signal region was evaluated to be 0.05 events for 1/fb.

Using $S_{c12} = 2(\sqrt{s+b} - \sqrt{b})$ the 5σ is obtained with 8 signal events.

This correspond to
$\mathcal{L} = 52/\mathrm{pb}$ for $\Lambda = 50\,TeV$ and $\mathcal{L} = 667/\mathrm{pb}$ for $\Lambda = 80\,TeV$.

CMS: $\tilde{\tau}_1$ NLSP: mass estimate





1000 pseudo-experiments for $\mathcal{L} = 0.5/\mathrm{fb}$

$$M_{\tilde{\tau}_1}^{\mathrm{gener.}} = 152.31\,\text{GeV}$$

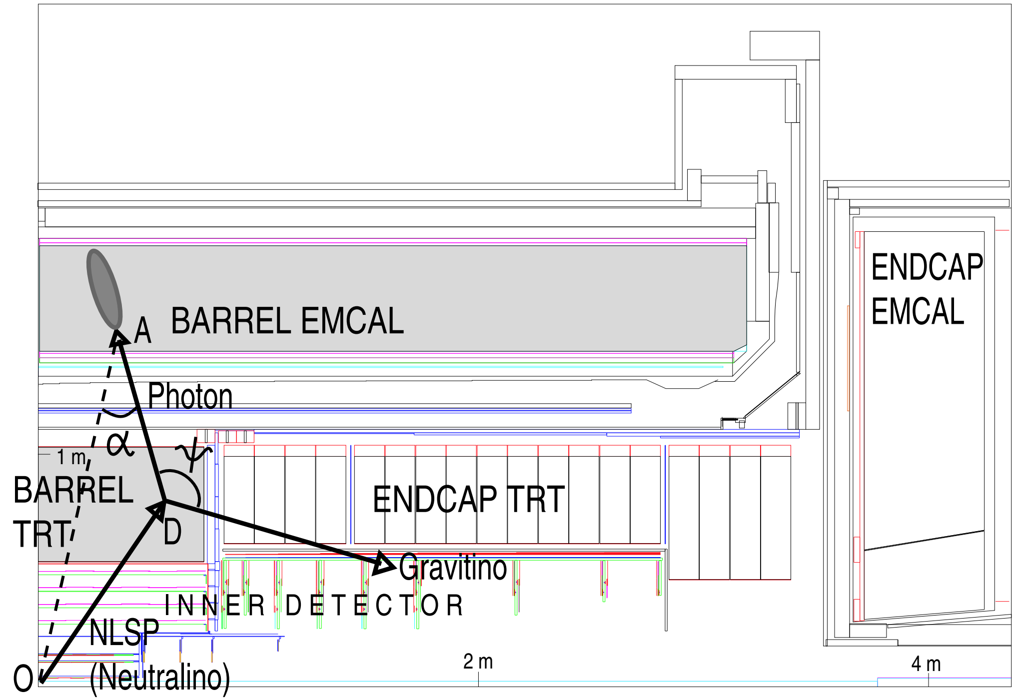
$$M_{\tilde{\tau}_1}^{\mathrm{est.}} = \{153.2 \pm 1.6(\mathrm{stat.}) \pm 0.9(\mathrm{syst.})\}\text{GeV}$$

1000 pseudo-experiments for $\mathcal{L} = 4/\mathrm{fb}$

$$M_{\tilde{\tau}_1}^{\mathrm{gener.}} = 242.93\,\text{GeV}$$

$$M_{\tilde{\tau}_1}^{\mathrm{est.}} = \{243.2 \pm 3.2(\mathrm{stat.}) \pm 1.4(\mathrm{syst.})\}\text{GeV}$$

In the ATLAS analysis (*K. Kawagoe, T. Kobayashi, M.M. Nojiri, A. Ochi* Phys. Rev. D69(2004)035003) an interesting technique was developed to determine the masses of the slepton and neutralino from events with a lepton and converted photon arising from the cascade decay $\widetilde{\ell} \to \ell \widetilde{\chi}_1^0 \to \ell \gamma \widetilde{G}$.



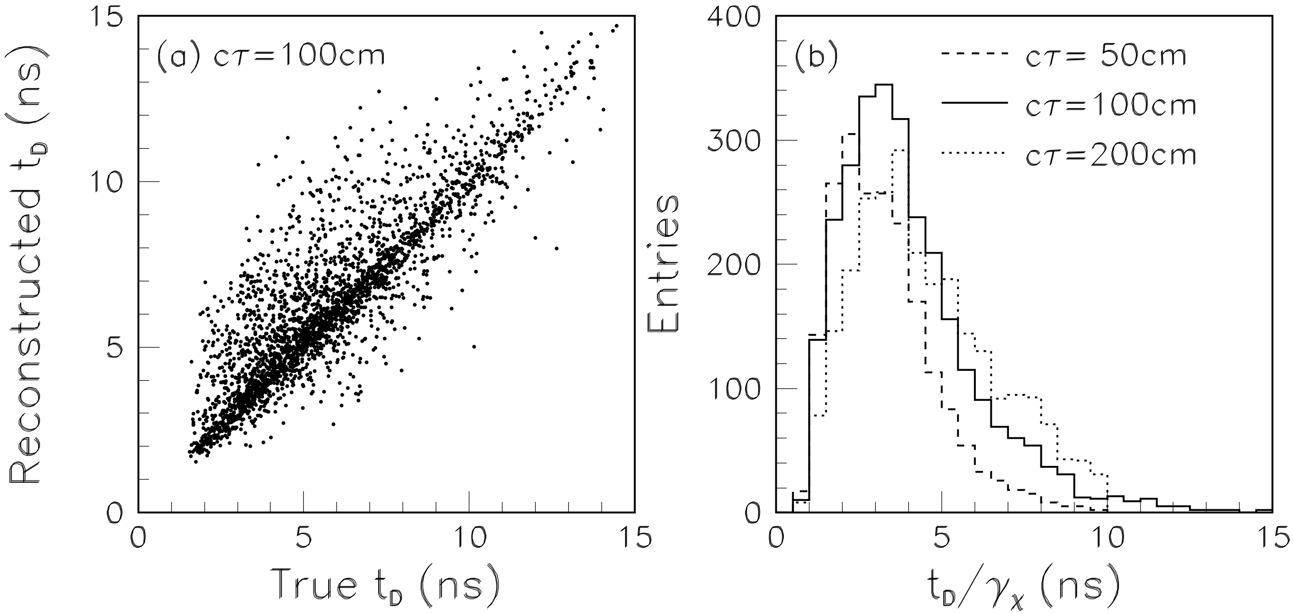
GMSB parameters chosen:

$\Lambda = 90$ TeV, $M = 500$ TeV, $N = 1$, $\tan\beta = 5$, $\mu > 0$

Corresponding neutralino and slepton masses:

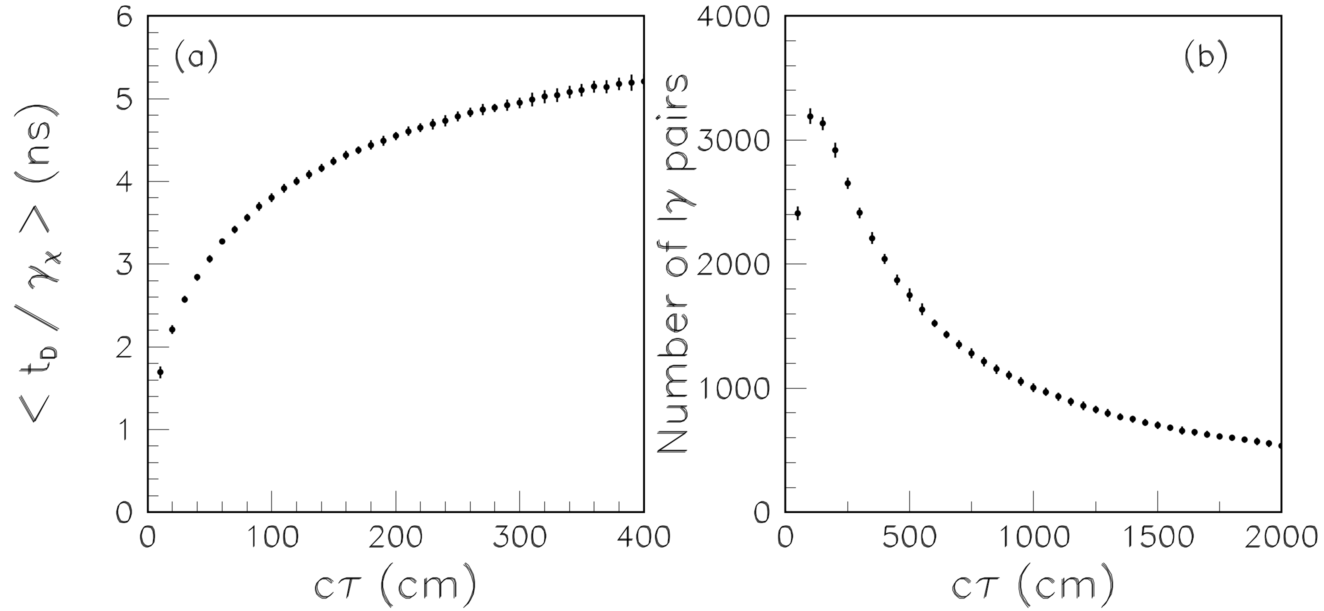
$M(\widetilde{\chi}_1^0) = 117$ GeV, $M(\widetilde{\ell}_R) = 162$ GeV

ATLAS: $\widetilde{\chi}_1^0 \rightarrow \widetilde{G}\gamma$



Longitudinal segmentation of the ECAL of ATLAS allows for precise determination of the polar angle of a non-pointing photon with very good resolution of $0.06/\sqrt{E_\gamma/\text{GeV}}$. More over, the arrival time could be measured with 100 ps resolution.

The method developed by ATLAS use lepton non-pointing photon pairs from $\widetilde{\ell} \rightarrow \ell \widetilde{\chi}_1^0 \rightarrow \ell \gamma \widetilde{G}$ decay chain which allow to estimate analytically proper time of $\widetilde{\chi}_1^0$ decay.



(a) average $\langle t_D/\gamma_\chi \rangle$ and
(b) number of lepton non-pointing photon pairs

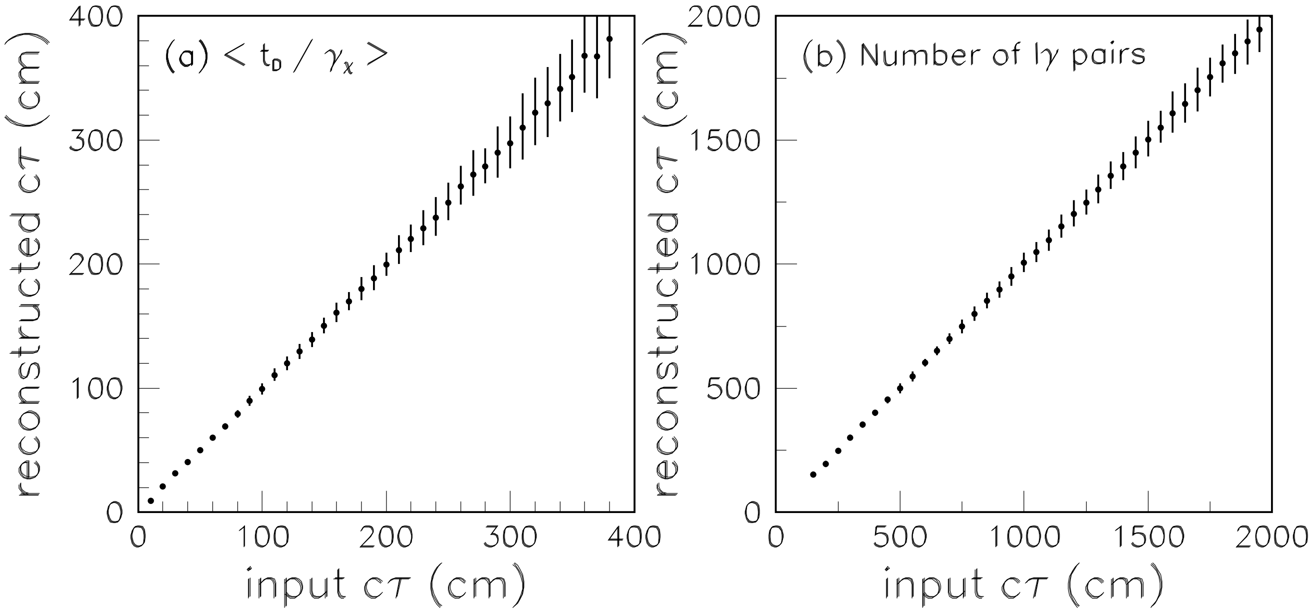
after the following selection:

$E_\gamma > 30$ GeV, $\Delta\theta > 0.2$, $\Delta t_\gamma > 1\,\mathrm{ns}$

$M_{\mathrm{eff}} > 400$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} > 0.1 M_{\mathrm{eff}}$

for integrated luminosity of 13.9/fb

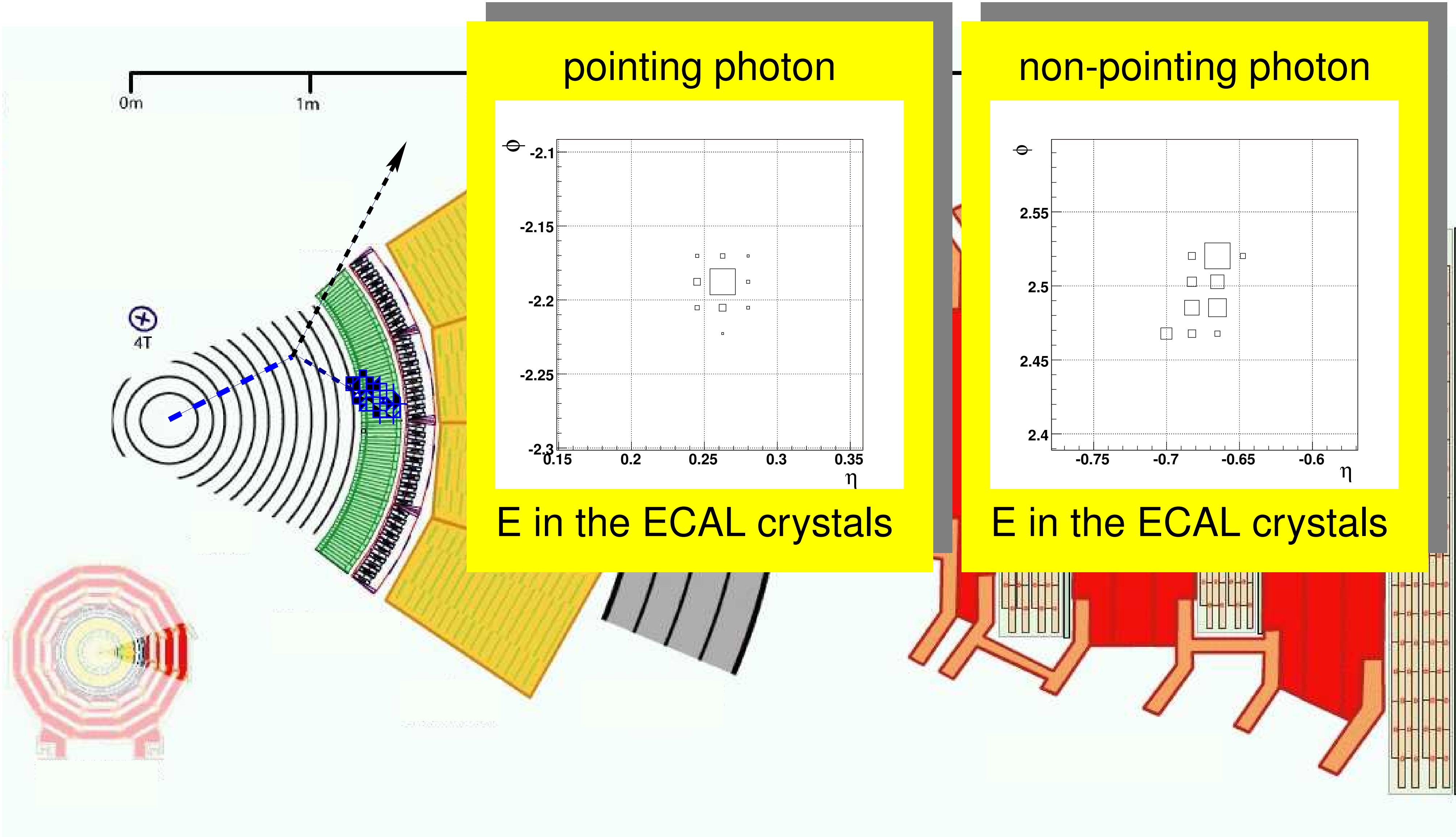
ATLAS: $\widetilde{\chi}_1^0 \to \widetilde{G}\gamma$



Plots show good reliability of the $c\tau$ determination for both methods and absolute resolution for each simulated $c\tau$s (error bars).

The relative resolution of $c\tau$ ranges
from 3% to 17% (for $c\tau = 10\,\mathrm{cm}$) for average proper time method $\langle t_D/\gamma_\chi \rangle$ and
form 3% to 6% for lepton non-pointing γ pair counting method.

CMS: $\tilde{\chi}_1^0 \to \tilde{G}\gamma$



CMS: $\tilde{\chi}_1^0$ NLSP: non-pointing γ

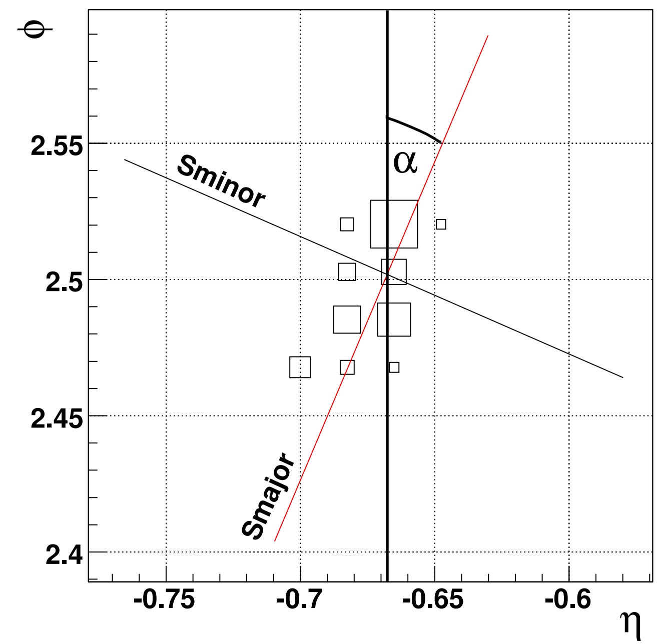
The energy distribution in the ECAL crystals could be characterized by the covariance matrix.
After diagonalizing variances along major and minor axes are given by

$$S_{\rm major} = \frac{S_{\phi\phi} + S_{\eta\eta} + \sqrt{(S_{\phi\phi} - S_{\eta\eta})^2 + 4S_{\phi\eta}^2}}{2}$$

$$S_{\rm minor} = \frac{S_{\phi\phi} + S_{\eta\eta} - \sqrt{(S_{\phi\phi} - S_{\eta\eta})^2 + 4S_{\phi\eta}^2}}{2}$$

A measure of the elongation of the deposit is an asymmetry

$$\Delta = \frac{S_{\rm major} - S_{\rm minor}}{S_{\rm major} + S_{\rm minor}}$$



Another useful variable is:

α: angle between major axis and ϕ axis

If $\mathrm{major} || \phi$ then $\alpha = 0$

If $\mathrm{major} || \eta$ then $\alpha = \pm\pi/2$

CMS: $\widetilde{\chi}_1^0$ NLSP: significance

Number of background events at different stages of the selection for 10/fb

dataset	preselection	selection	non-pointing	hard, pointing
SPS8 $\Lambda = 140$ TeV $c\tau = 0$	2104.28	402.98	2.96	289.39
SPS8 $\Lambda = 140$ TeV $c\tau = 25\,\mathrm{cm}$	2061.69	379.71	29.10	243.76
SPS8 $\Lambda = 140$ TeV $c\tau = 50\,\mathrm{cm}$	1948.33	361.60	45.87	215.88
SPS8 $\Lambda = 140$ TeV $c\tau = 100\,\mathrm{cm}$	1564.12	298.12	56.03	182.99
SPS8 $\Lambda = 140$ TeV $c\tau = 200\,\mathrm{cm}$	1037.60	166.66	34.64	99.39
SPS8 $\Lambda = 140$ TeV $c\tau = 400\,\mathrm{cm}$	645.77	114.89	26.16	67.19
ΣZjets	6137.93	0.65	0.00	0.37
ΣWjets	8301.93	2.76	0.00	1.46
ΣQCD	787797.19	54.90	0.27	2.32
VVjets_inclusive	836.35	0.00	0.00	0.00
TTbar_inclusive	4662.89	16.34	0.00	6.13
Σtotal	807736.31	74.65	0.27	10.27

preselection: single γ HLT, $p_T^{1\gamma} > 80$ GeV ;

selection: $|\eta^{1j}| < 1.7$, $\Delta\phi(\mathrm{jj}) > 20^\circ$,
$p_T^{4j} > 50$ GeV, $p_T^{\mathrm{miss}} > 160$ GeV

non-pointing selection:
$\Delta > \frac{1}{3}$, $\alpha \neq 0, \frac{\pi}{2}$

hard, pointing selection:
NOT non-pointing,
$p_T^{4j} > 60$ GeV, $p_T^{\mathrm{miss}} > 220$ GeV

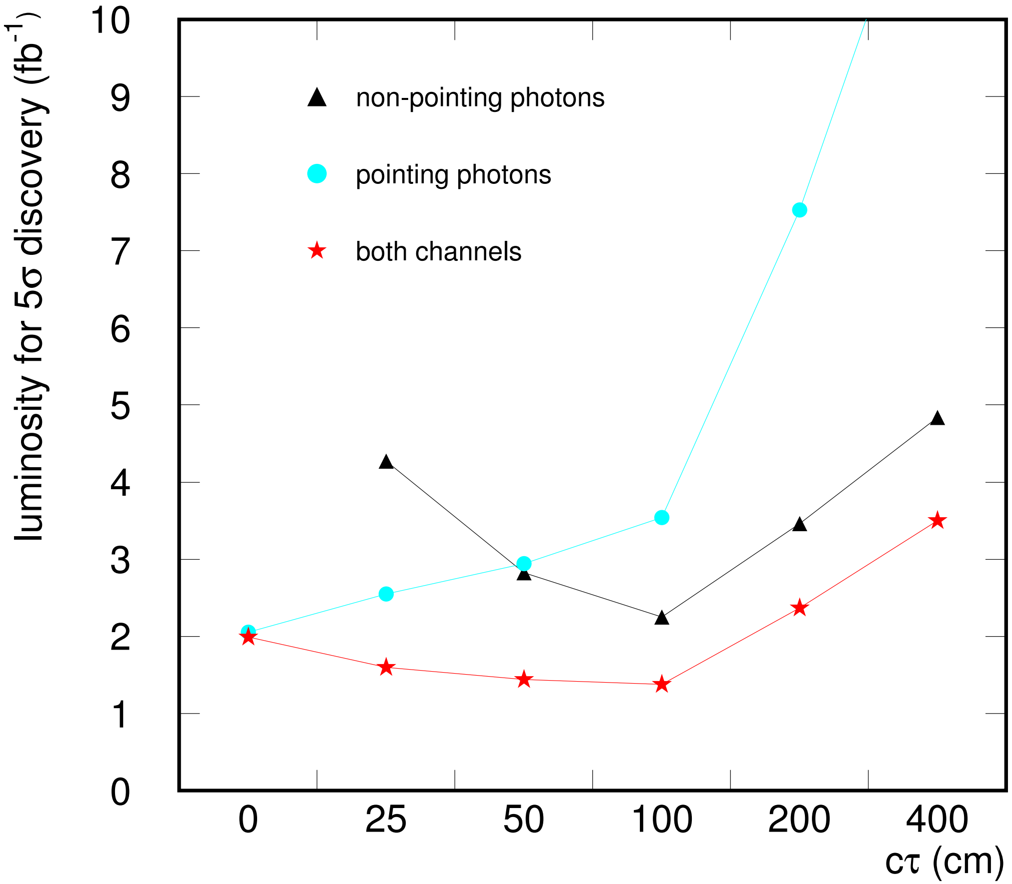
CMS: $\widetilde{\chi}_1^0$ NLSP: significance

The signal significance is calculated using the formula

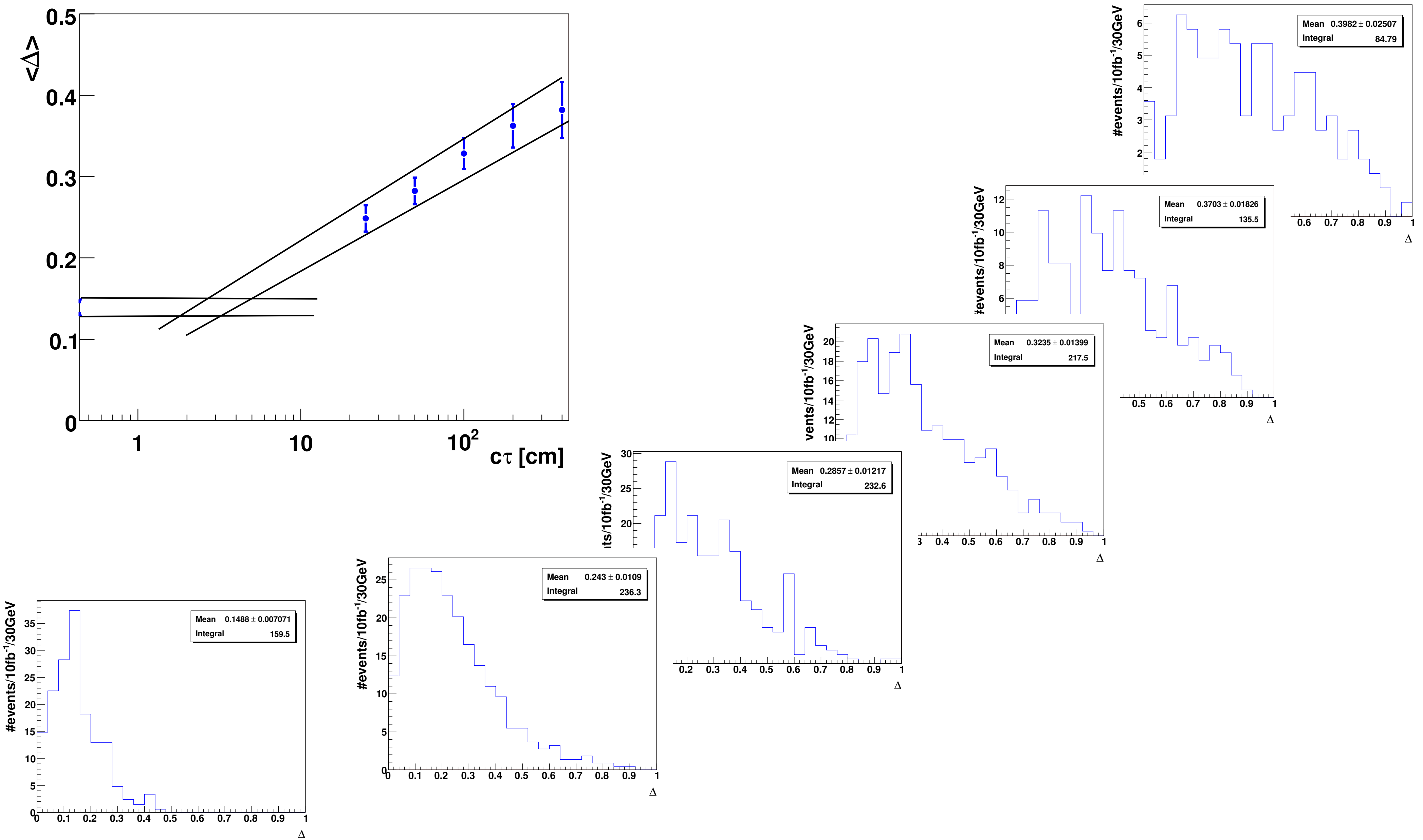
$$S_{c12s} = 2 \cdot \left(\sqrt{s+b} - \sqrt{b}\right) \cdot \frac{b}{b + \Delta b^2}$$

An estimate of a the minimal amount of integrated luminosity needed for 5σ discovery for simulated $c\tau$s is plotted in the Figure.

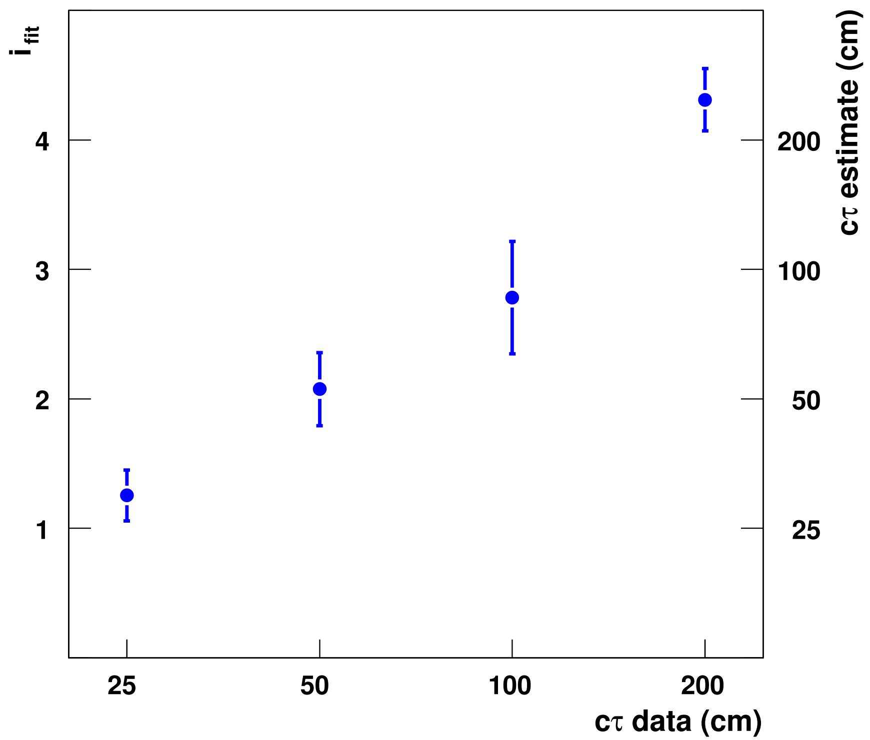
An integrated luminosity $\mathcal{L} = 2/\mathrm{fb}$ is sufficient to claim discovery for $c\tau \leq 100\,\mathrm{cm}$ and $\mathcal{L} = 3.5/\mathrm{fb}$ for $c\tau = 400\,\mathrm{cm}$.



CMS: $\tilde{\chi}_1^0$ NLSP: asymmetry Δ versus $c\tau$



CMS: $\widetilde{\chi}_1^0$ NLSP: lifetime fit



To test CMS ECAL capability to estimate $\widetilde{\chi}_1^0$ lifetime 100 likelihood fits of neighborhood $c\tau$ and background to the given $c\tau$ + background was done. The results are shown in the Figure. The precision of such procedure range from 15% to 40%. It will improve if more $c\tau$ points will be used, but one should remember that it depends on the knowledge of the shapes of distributions of variables used in the fit. These shapes depend (weakly) on other than $c\tau$ parameters of the model.

Conclusions

Gauge-Mediated Supersymmetry Breaking model is a generic framework for long-lived, heavy, charged, weakly interacting particles and decaying in flight heavy (charged or neutral) particles.

During last decade both Atlas and CMS have invented methods to tackle with such signatures, despite the fact that detectors had not been designed for them.

Phenomenological studies are more advanced on the ATLAS side whereas full detector analyses are a bit more advanced on CMS side.

For long lived charged particles both detectors could perform equally well using synergy of specific ionization measurement and TOF method. The ultimate goal before LHC startup should be development of model independent methods which could be tested on cosmics and $Z \rightarrow \mu^+ \mu^-$ candle.

For non-pointing photons signature ATLAS is better equipped than CMS because of good polar angle resolution and possibility of arrival time measurement in ECAL. However, the ultimate resolution for lifetime determination of decaying in flight particles could be obtained only with tracking system. Performance of such methods require full detector simulation with full background turned on.
There is just enough time to do that.