Light Higgsino Scenario at the ILC

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ILD Software and Analysis Meeting

Outline

- Model
- Analysis Strategy
- Results of the Analysis performed using Fast Simulation
- Parameter Determination
- Comparison of Fast and Full Simulation

Light Higgsino Scenario

Motivated by naturalness which requires μ at the electroweak scale

Scenario contains

- 3 light higgsinos: $\tilde{\chi}_1^\pm$ & $\tilde{\chi}_1^0$ & $\tilde{\chi}_2^0$
- Almost mass degenerate: $\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ & $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ $\sim$ a (sub) GeV
- All other supersymmetric particles are heavy up to a few TeV

Two benchmark points are considered:

dm1600

Mass Spectrum	
Particle	Mass (GeV)
h	124
$\tilde{\chi}_1^0$	164.17
$\tilde{\chi}_1^\pm$	165.77
$\tilde{\chi}_2^0$	166.87
H's	$\sim 10^3$
$\tilde{\chi}$'s	$\sim 2-3 \times 10^3$

$\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = 1.59$ GeV

dm770

Mass Spectrum	
Particle	Mass (GeV)
h	127
$\tilde{\chi}_1^0$	166.59
$\tilde{\chi}_1^\pm$	167.36
$\tilde{\chi}_2^0$	167.63
H's	$\sim 10^3$
$\tilde{\chi}$'s	$\sim 2-3 \times 10^3$

$\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = 0.77$ GeV

But also high scale models, for ex.: "Hybrid Gauge-Gravity Mediated Supersymmetry Breaking Models" Ref: F. Brümmer et al. hep-ph/1201.4338

Production Processes & Decay Modes

Production Processes:

- $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$
- $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0$

Decay Modes

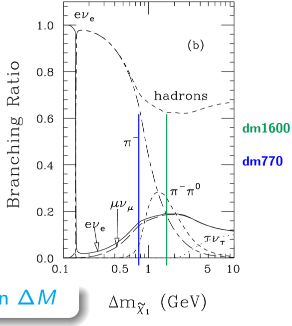
- $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 W^{\pm *}$
- $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^{0*}$
- $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$

Separation of Signal Processes

Exclusive decay modes:

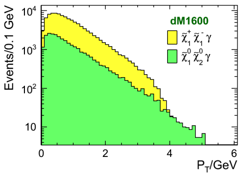
- $\tilde{\chi}_1^+\tilde{\chi}_1^+ \rightarrow 2\tilde{\chi}_1^0\ W^{+*}\ W^{-*}$
  - semileptonic final state (30.5%, 35%)
- $\tilde{\chi}_1^0\tilde{\chi}_2^0 \rightarrow 2\tilde{\chi}_1^0\ Z^{0*}/\gamma$
  - photonic final state (23.6%, 74%)

Ref: C.-H. Chen et al. hep-ph:9512230



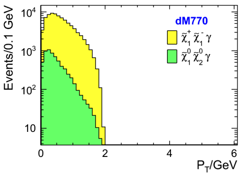
BRs depend crucially on ΔM

Higgsino Signatures and Challenges



In the Final State

- A few soft visible particles
- A lot of missing energy (2 $\tilde{\chi}_1^0$)
- An ISR photon is required
  to avoid similarity of background



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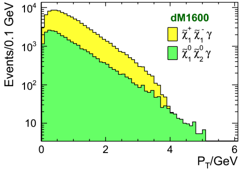

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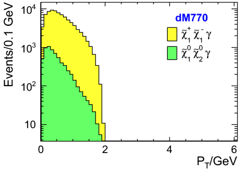
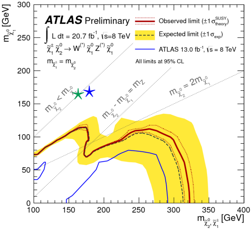
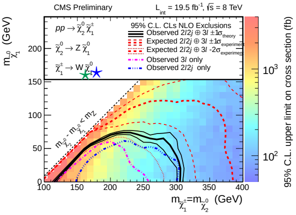


It is extremely challenging for LHC to observe or resolve such low energetic and degenerate particles



Ref: ATLAS-CONF-2013-035



Ref: CMS-PAS-SUS-13-006

Analysis Overview

* So far, analysis has been performed with fast simulation, SGV.
  - $\sqrt{s} = 500$ GeV
  - $\int \mathcal{L} dt = 500$ fb^{-1} for each polarization
  - Polarization:
    - $P_{e^+} = +30\%$, $P_{e^-} = -80\%$
    - $P_{e^+} = -30\%$, $P_{e^-} = +80\%$

Aim of the Study:

To measure

- mass of the $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_2^0$.
- mass difference between $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_1^0$.
- precision on the polarized cross section

To check

- if the measurements are good enough to determine μ, M_1, M_2 and $\tan\beta$

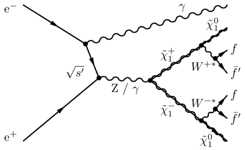
Measurement Strategy

$\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_2^0$ Mass Measurement ($M_{\tilde{\chi}_1^{\pm}}$ & $M_{\tilde{\chi}_2^0}$):

Recoil mass of hard ISR photon is used to measure mass of $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_2^0$

Reduced CM Energy:

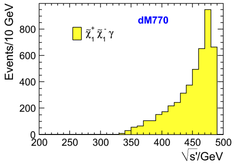
$$s' = s - 2\sqrt{s}E^{\gamma}$$



- $\sqrt{s'} = 2 \times M_{\tilde{\chi}}$ if 2 $\tilde{\chi}$ are produced at rest
- Fitting gives $M_{\tilde{\chi}}$.

However; this method is an approximation, since

- formula is obtained only after some assumptions
- $\sqrt{s}$ is assumed 500 GeV



Hence,

- Calibration is applied to the masses.

Measurement Strategy

Mass Difference Measurement ($\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$):

- Boost decay products to the rest frame of $\tilde{\chi}_1^\pm$

Boosted Energy:

$$E_\pi^* = \frac{(\sqrt{s} - E^\gamma)E^\pi + \mathbf{P}^\pi \cdot \mathbf{P}^\gamma}{2M_{\tilde{\chi}_1^\pm}}$$

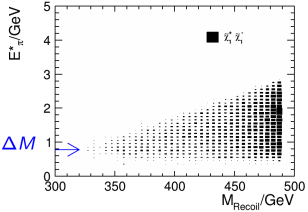
At the rest frame of $\tilde{\chi}_1^\pm$;

- $\tilde{\chi}_1^0$ is produced at rest,

$$E_\pi^* = \frac{(M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0})(M_{\tilde{\chi}_1^\pm} + M_{\tilde{\chi}_1^0}) + m_\pi^2}{2M_{\tilde{\chi}_1^\pm}}$$

$$E_\pi^* = \frac{1}{1/\Delta M + 1/\sum M} + \frac{m_\pi^2}{2M_{\tilde{\chi}_1^\pm}}$$

- $E^*_{decays} = \Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$



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$\tilde{\chi}_1^\pm$ & $\tilde{\chi}_2^0$ Mass Measurement ($M_{\tilde{\chi}_1^\pm}$ & $M_{\tilde{\chi}_2^0}$):

Recoil mass of hard ISR photon is used to measure mass of $\tilde{\chi}_1^+$ & $\tilde{\chi}_2^0$

Reduced CM Energy: $s' = s - 2\sqrt{s}E^\gamma$

Mass Difference Measurement ($\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$):

Boost decay products to the rest frame of $\tilde{\chi}_1^\pm$ ($E^*_{decays} = \Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$)

Boosted Energy: $E^*_\pi = \frac{(\sqrt{s}-E^\gamma)E^\pi + \mathbf{P}^\pi \cdot \mathbf{P}^\gamma}{2M_{\tilde{\chi}_1^\pm}}$

Polarized Cross Section Measurement ($\delta\sigma_{polarized}/\sigma_{polarized}$)

Statistical precision on polarized cross section

$$\frac{<\delta\sigma_{meas}>}{<\sigma_{meas}>} = \frac{1}{\sqrt{\epsilon \cdot \pi \cdot \int \mathcal{L}dt \cdot \sigma_{signal}}}$$

$$\sigma_{meas} = \sigma_{polarized} \times BR(\tilde{\chi}_1^+\tilde{\chi}_1^- \to 2\tilde{\chi}_1^0, \pi, e(\mu))$$

Estimated Precison is based on **efficiency** and **purity**

Result of analysis performed with SGV

For dM770 scenario, it has been obtained that

- $\delta M_{\tilde{\chi}_1^\pm}(M_{\tilde{\chi}_2^0})$ =1.5 GeV
- $\delta\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ =40 MeV
- $\delta(\sigma \times BR)$= 1.6 % for $(P(e^+, e^-) = (+30\%, -80\%))$
- $\delta(\sigma \times BR)$= 3.8 % for $(P(e^+, e^-) = (-30\%, +80\%))$

Parameter Determination:

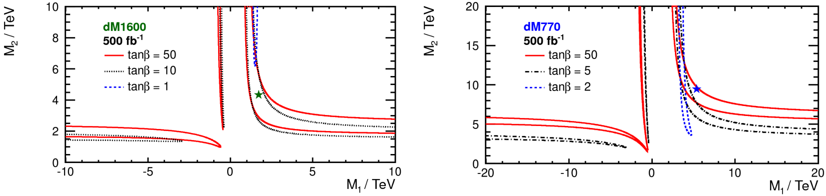
Precision is sufficent

- to determine μ to a few percent
- to constrain M_1, M_2 to narrow band

Results of Parameter Determination

Results

- Lower limits and allowed regions for M_1 and M_2 can be obtained from the correlation between M_1 and M_2
- For $M_1 < 0$, low values of $\tan\beta$ are excluded



- μ parameter can be determined with 6.8(2.5) GeV statistical precision for dM1600(dM770) scenario.

@ 500 fb^{-1}	input	lower	upper
$\|M_1\|$ [TeV]	1.7	$\sim$ 0.8(-0.4)	no
M_2 [TeV]	4.4	$\sim$ 1.5(1.0)	no
μ [GeV]	165.7	165.2	172.5

@ 500 fb^{-1}	input	lower	upper
$\|M_1\|$ [TeV]	5.3	$\sim$ 2(-0.3)	no
M_2 [TeV]	9.5	$\sim$ 3(1.2)	no
μ [GeV]	167.2	164.8	167.8

Does this hold in Full Simulation?

** Do the analysis with full simulation, to check

- reconstruction of ISR photon
- reconstruction and identification of soft $\pi^{\pm}, e^{\pm}, \mu^{\pm}$ (chargino process)
- reconstruction and identification of soft γ (neutralino process)
- effect of low pt $\gamma\gamma \rightarrow$ *hadrons* overlay

Samples:

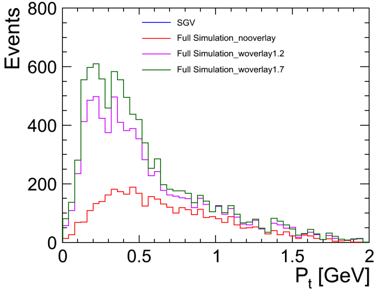
Test signal samples with 2000 events

- chargino process, $e^{+}e^{-} \rightarrow \tilde{\chi}_1^{+}\tilde{\chi}_1^{+}\gamma$
- dm770 scenario
- $P(e^{+}, e^{-}) = (-1, +1)$

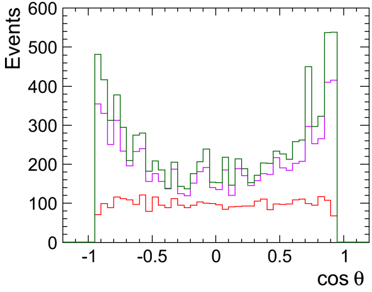
Impact of Overlay

- Signal has low P_t signatures as $\gamma\gamma$ low P_t background
- To remove overlay usual procedure might help, but we might need some special methods

Pt dist. of true charged particles



$\cos\theta$ dist. of true charged particles



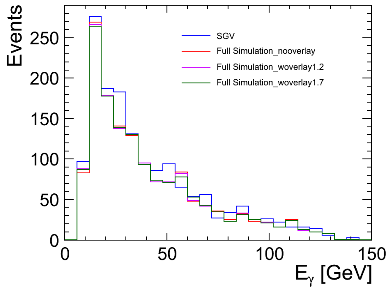
with $|\cos\theta| < 0.9397$

Reconstruction of ISR photon

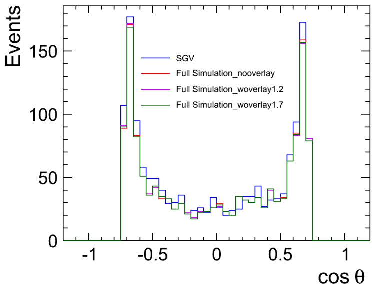
Choose reconstructed ISR photons with

- $E_\gamma > 10$ GeV
- $\cos\theta < 0.993$ (7 degrees)

E dist. of reconstructed ISR photons



$\cos\theta$ dist. of reconstructed ISR photons



- SGV and Full simulation agree with eachother
- Overlay does not harm as expected

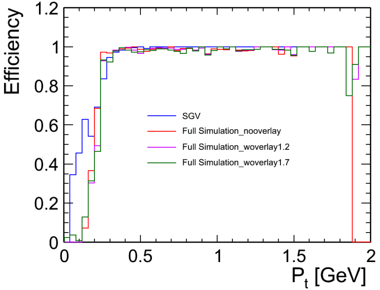
Reconstruction Efficiency of $\tilde{\chi}_1^{\pm}$ decay products

P_t dist. of true charged particles which are stable & within $|\cos\theta| < 0.9397$

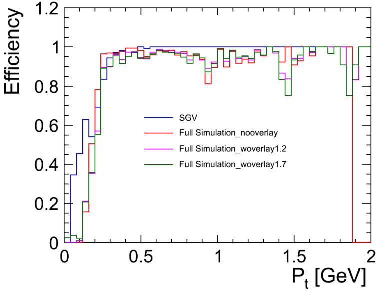
- Tracks found
- Efficiency for $|\cos\theta| < 0.9397$ (20 degrees)

- PFOs found
- Efficiency for $|\cos\theta| < 0.9397$ (20 degrees)

Tracking Efficiency



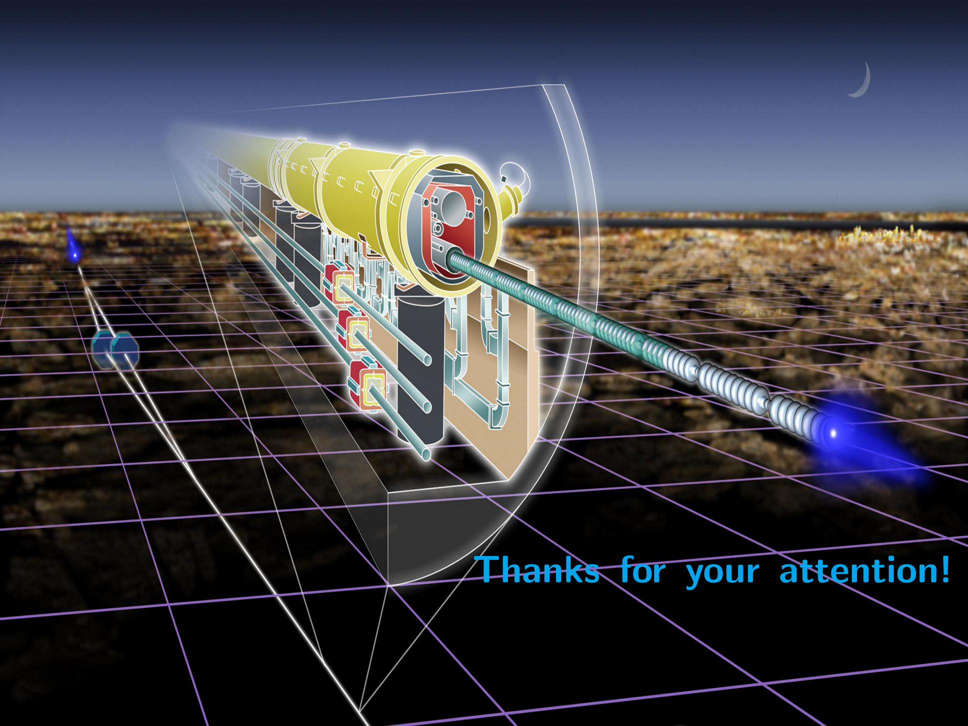
Having PFO Efficiency



- Some tracks are lost in PFO [It is investigating..]

Summary

- Higgsino measurements are promising from SGV
- In full simulation
  - ISR photon reconstruction and identification works
  - Tracking Efficiency works
  - Link to calorimetry information of particle ID needs closer look
- $\gamma\gamma$ overlay
  - ISR photon looks fine
  - For Higgsino decay products it needs special work

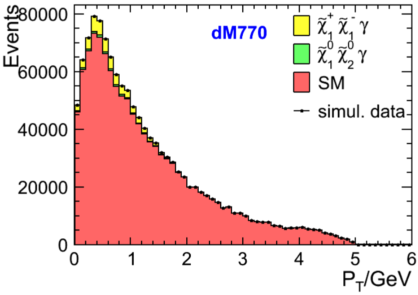

Thanks for your attention!

Backup

Event Selection

Preselection:

- Require 1 photon
  - with $E_\gamma^{max} > 10$ GeV
  - within the acceptance of TPC
- No significant activity in the BeamCal
- Less than 15 reconstructed particles
- $E_{\text{decay products}} < 5$ GeV
- $E_{miss} > 300$ GeV
- Both soft decay products and missing particles are required not to be in the forward region



After PreSelection

Event Selection

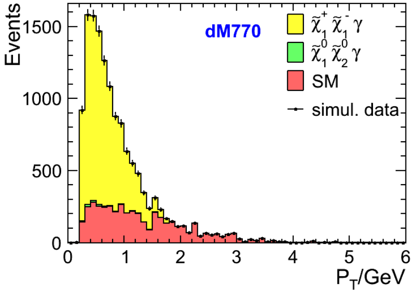
- Preselection is applied to suppress the SM background

Chargino Selection

- Select semi-leptonic decay modes
  - 1 π and (1 e or 1 μ)
- $E_{\pi}^{*} < 3$ GeV
- $\Phi_{acop} < 2$ or $\sqrt{s'} < 480$ GeV

Neutralino Selection

- Select photon decay modes
  - Only photons
- $|\cos\theta_{\gamma soft}| < 0.85$
- $E_{\gamma_{soft}}^{*} > 0.5$ GeV



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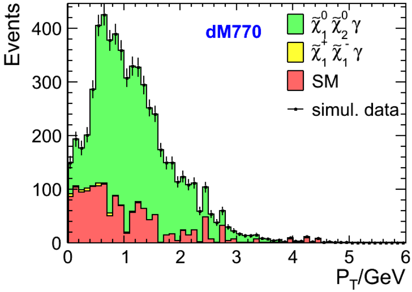
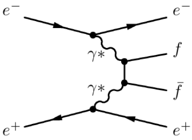


After Neutralino Selection

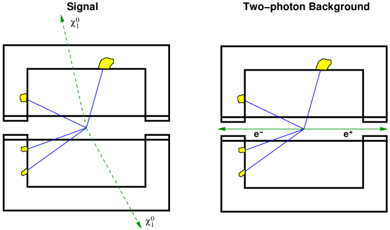
Standard Model Backgrounds

$\gamma\gamma \rightarrow 2f$



In the final state:

- 2 fermions with low energy, which is very similar to the signal



Ref: PhD thesis of C. Hensel

Standard Model Backgrounds

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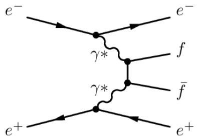

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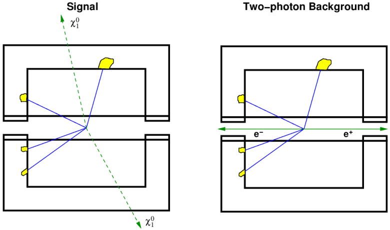

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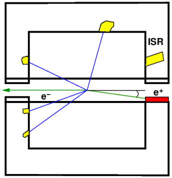
- We have required hard ISR photon,

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$$

$$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0\gamma$$

to avoid this similarity of the final states.

- Additional γ makes the beam electron visible in the detector.



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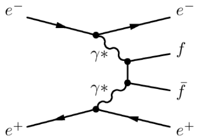

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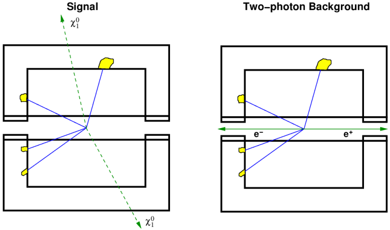

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to avoid this similarity of the final states.

- Additional γ makes the beam electron visible in the detector.

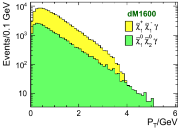
* This method is a well-known trick for $\gamma\gamma \rightarrow 2f$ background

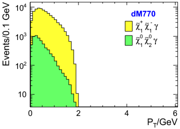
* In this study, it has been observed that this method doesn't work for $e\gamma \rightarrow 3f$ background

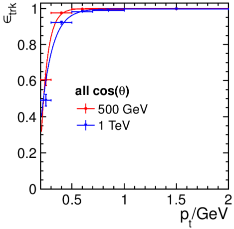
Analysis Overview

Software:

- Signal events are generated with Whizard (ILC-Whizard by generator group) **Ref:** Wolfgang Kilian et al., hep-ph: 0708.4233v2
  - Branching ratios are calculated by Herwig++
    Ref: M. Bahr et.al., *Eur.Phys.J.*, C58:639–707, 2008
- DBD generated samples for SM backgrounds
- Apply fast detector simulation SGV (ILD DBD version of SGV)
  Ref: M. Berggren, physics.ins-det: 1203.0217
- Track efficiency is applied for low P_t
  - Signals
  - Dominating SM backgrounds





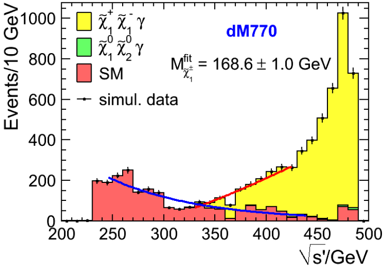


From full simulation including $t\bar{t}$ events and pair background

Mass Measurement Procedure

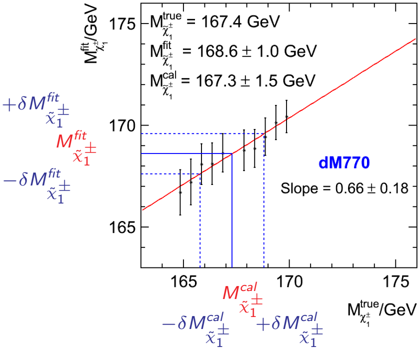
Fitting Procedure

- Fitting is done in the following order:
  - SM background is fitted with an exponential function assuming that we can precisely predict SM background.
  - SM background is fixed.
  - SM background + Signal are fitted using linear function for signal.

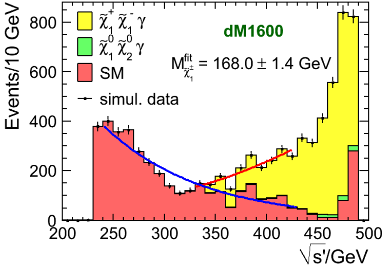


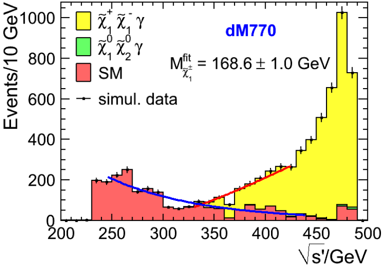
Calibration Procedure

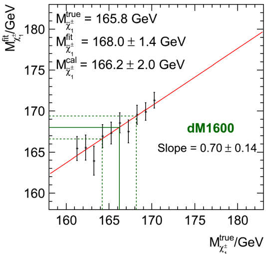
- Choose different true masses (X-axis)
- Apply measurement and get fitted masses (Y-axis)
- Obtain calibration curve

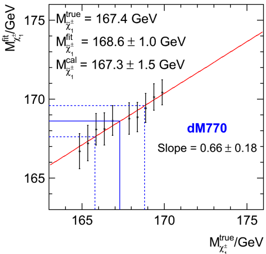


$\tilde{\chi}_1^+$ Mass Measurement & Calibration

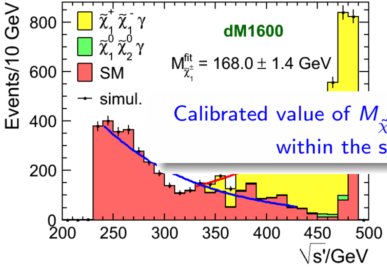


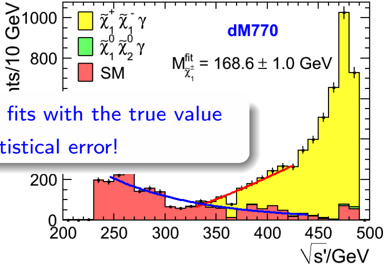




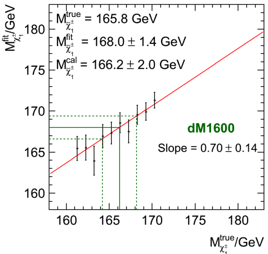


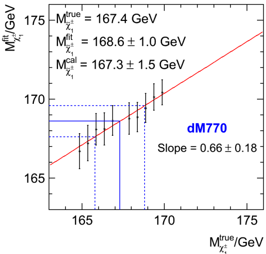
$\tilde{\chi}_1^+$ Mass Measurement & Calibration



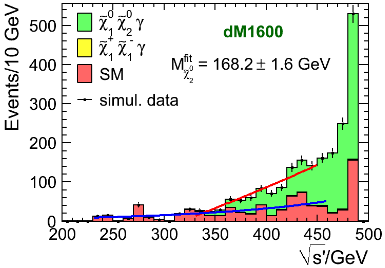


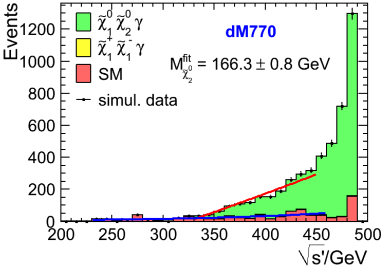
Calibrated value of $M_{\tilde{\chi}_1^\pm}$ fits with the true value within the statistical error!

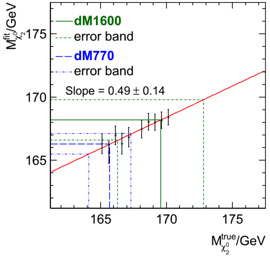




$\tilde{\chi}_2^0$ Mass Measurement & Calibration

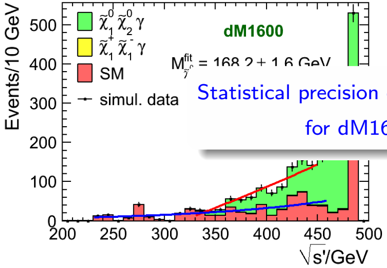


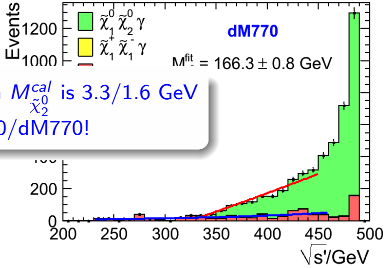




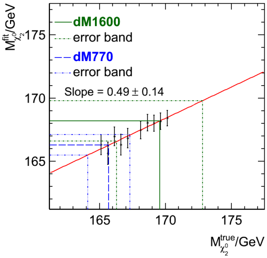
dM1600	dM770
$M^{true}_{\tilde{\chi}_2^0}$ = 166.9 GeV	$M^{true}_{\tilde{\chi}_2^0}$ = 167.6 GeV
$M^{fit}_{\tilde{\chi}_2^0}$ = 168.2 ± 1.6 GeV	$M^{fit}_{\tilde{\chi}_2^0}$ = 166.3 ± 0.8 GeV
$M^{cal}_{\tilde{\chi}_2^0}$ = 169.6 ± 3.3 GeV	$M^{cal}_{\tilde{\chi}_2^0}$ = 165.7 ± 1.6 GeV

$\tilde{\chi}_2^0$ Mass Measurement & Calibration



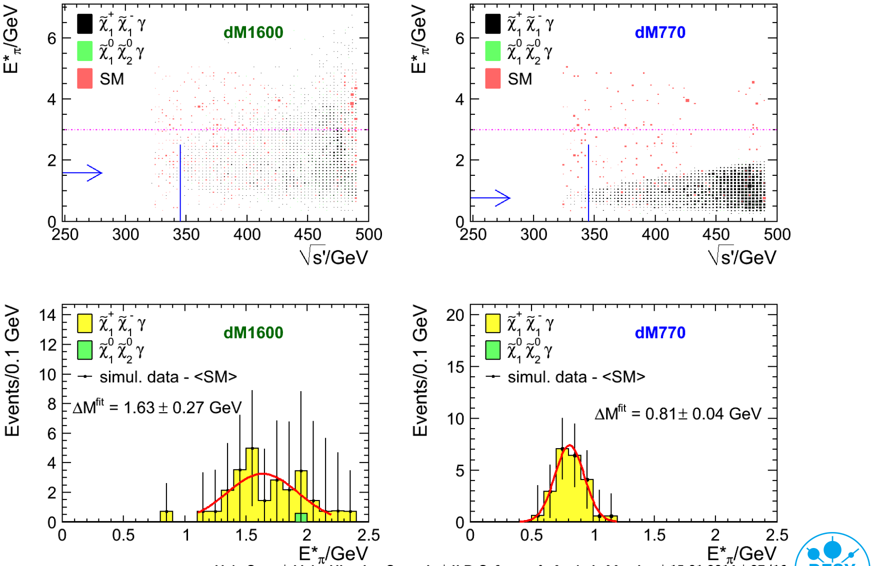


Statistical precision on $M^{cal}_{\tilde{\chi}_2^0}$ is 3.3/1.6 GeV for dM1600/dM770!

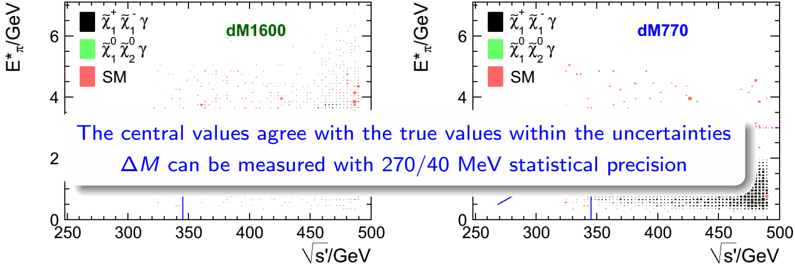


	dM1600	dM770
$M^{true}_{\tilde{\chi}_2^0}$	= 166.9 GeV	= 167.6 GeV
$M^{fit}_{\tilde{\chi}_2^0}$	= 168.2 ± 1.6 GeV	= 166.3 ± 0.8 GeV
$M^{cal}_{\tilde{\chi}_2^0}$	= 169.6 ± 3.3 GeV	= 165.7 ± 1.6 GeV

Mass Difference Measurement

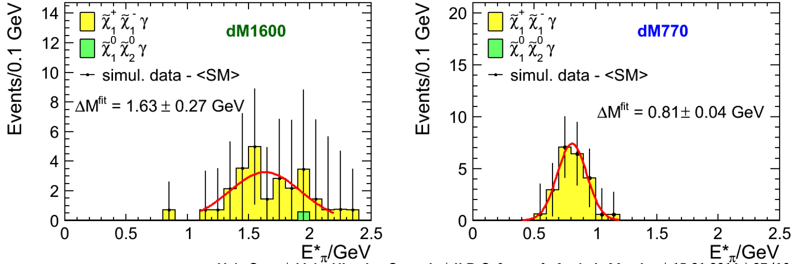


Mass Difference Measurement



The central values agree with the true values within the uncertainties

ΔM can be measured with 270/40 MeV statistical precision



Polarized Cross Section Measurement

Efficiency, Purity and Precison on Polarized Cross Sections:

Polarizations	$P(e^+, e^-) = (+30\%, -80\%)$		$P(e^+, e^-) = (-30\%, +80\%)$	
Processes	$\tilde{\chi}_1^+ \tilde{\chi}_1^- \gamma$	$\tilde{\chi}_2^0 \tilde{\chi}_1^0 \gamma$	$\tilde{\chi}_1^+ \tilde{\chi}_1^- \gamma$	$\tilde{\chi}_2^0 \tilde{\chi}_1^0 \gamma$
dm1600				
BR of selected mode	30.5 %	23.6 %	30.5 %	23.6 %
Efficiency(ϵ)	9.9 %	5.8 %	9.5 %	6.0 %
Purity(π)	70.1%	67.4 %	36.4 %	62.3 %
$\frac{\langle \delta\sigma_{meas} \rangle}{\langle \sigma_{meas} \rangle}$	**1.9 %**	**3.2 %**	**5.3 %**	**3.7 %**
dm770				
BR of selected mode	34.7 %	74.0 %	34.7 %	74.0 %
Efficiency(ϵ)	12.1 %	17.1 %	12.2 %	17.2%
Purity(π)	85.3 %	85.8 %	56.1 %	82.5 %
$\frac{\langle \delta\sigma_{meas} \rangle}{\langle \sigma_{meas} \rangle}$	**1.6 %**	**1.7 %**	**3.8 %**	**1.9 %**

- Efficiencies are almost same for both polarizations
- Huge difference between purities for both polarizations in the chargino processes are due to the strong polarization dependence
- Cross sections can be measured more precisely using the polarisation with $e_R^+ e_L^-$

$$\frac{<\delta\sigma_{meas}>}{<\sigma_{meas}>} = \frac{1}{\sqrt{\epsilon \cdot \pi \cdot \int \mathcal{L}dt \cdot \sigma_{signal}}}$$

$$\sigma_{meas} = \sigma_{polarized} \times BR$$

Parameter Determination

Parameters related to chargino and neutralino sector:

$$M_1, \quad M_2, \quad \mu, \quad \tan\beta$$

Used parameters for the fit

- $M_{\tilde{\chi}_1^\pm}$, $M_{\tilde{\chi}_2^0}$, $\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$
- Statistical precision on the cross sections $(\delta\sigma/\sigma)$

Fit Procedure

- $\tan\beta$ is fixed in the range [1,60]
- Fit the mass parameters; μ, M_1 and M_2.

Parameter determination @ High Luminosity

- Luminosity is increased to $\int Ldt = 2\ ab^{-1}$ for each polarization
- It is assumed that experimental errors would be reduced by a factor 2
- The measurement of the $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ is also included (not measured in this analysis)

Electroweakino parameters & experimental observables

Relation between electroweakino parameters and experimental observables

Tree level masses in the case that M_1 & M_2 are large ($\theta_W \rightarrow$ Weinberg angle)

$$M_{\tilde{\chi}_1^\pm} = |\mu| - \sin 2\beta sign(\mu) \cos^2\theta_W \frac{m_Z^2}{M_2}$$

$$M_{\tilde{\chi}_{1,2}^0} = |\mu| \pm \frac{m_Z^2}{2}(1 \pm \sin 2\beta sign(\mu)) \left(\frac{\sin^2\theta_W}{M_1} + \frac{\cos^2\theta_W}{M_2} \right)$$

- They are **weakly** dependent on $\tan\beta$
- μ determines $M_{\tilde{\chi}_2^0}$ & $M_{\tilde{\chi}_1^\pm}$

$$M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0} = \frac{m_Z^2}{2} \left(\frac{\sin^2\theta_W}{M_1} + \frac{\cos^2\theta_W}{M_2} \right) + \mathcal{O}\left(\frac{\mu}{M_i^2}, \frac{1}{\tan\beta} \right)$$

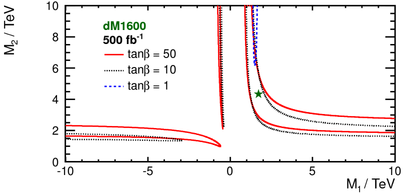
$$M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} = m_Z^2 \left(\frac{\sin^2\theta_W}{M_1} + \frac{\cos^2\theta_W}{M_2} \right) + \mathcal{O}\left(\frac{\mu}{M_i^2} \right)$$

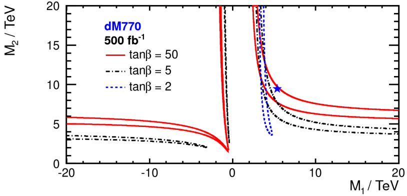
- M_1 & M_2 determine $\Delta M(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ & $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$

Parameter Determination

Results

- Lower limits and allowed regions for M_1 and M_2 can be obtained from the correlation between M_1 and M_2
- For $M_1 < 0$, low values of $\tan\beta$ are excluded
- When M_1 ~-500 GeV, direct production of $\tilde{\chi}_3^0$ could be possible at 1 TeV





- μ parameter can be determined with 6.8(2.5) GeV statistical precision for dM1600(dM770) scenario.

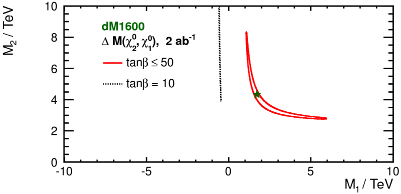
@ 500 fb^{-1}	input	lower	upper
$\lvert M_1 \rvert$ [TeV]	1.7	~ 0.8(-0.4)	no
M_2 [TeV]	4.4	~ 1.5(1.0)	no
μ [GeV]	165.7	165.2	172.5

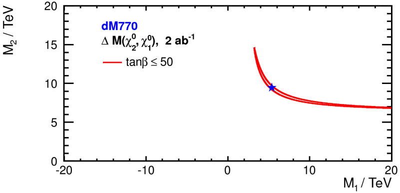
@ 500 fb^{-1}	input	lower	upper
$\lvert M_1 \rvert$ [TeV]	5.3	~ 2(-0.3)	no
M_2 [TeV]	9.5	~ 3(1.2)	no
μ [GeV]	167.2	164.8	167.8

Parameter Determination at High Luminosity

Results:

- Inclusion of $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ breaks the dependency of M_1 & M_2 on the low $\tan\beta$ region
- In dM1600 scenario, if $M_1 < 0$ it gets very small values for moderate $\tan\beta$
- dM770 scenario has valid solutions only for $M_1 > 0$





- Increased luminosity narrows the allowed region for μ parameter

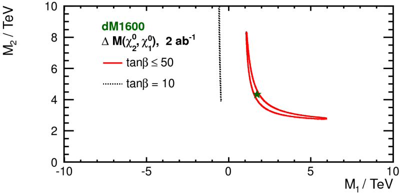
@ 2 ab^{-1}	input	lower	upper
M_1 [TeV]	1.7	~ 1.0 (-0.4)	~ 6.0
M_2 [TeV]	4.4	~ 2.5 (3.5)	~ 8.5
μ [GeV]	165.7	166.2	170.1

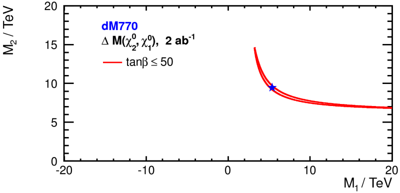
@ 2 ab^{-1}	input	lower	upper
M_1 [TeV]	5.3	~ 3	no
M_2 [TeV]	9.5	~ 7	~ 15
μ [GeV]	167.2	165.2	167.4

Parameter Determination at High Luminosity

Results:

- Inclusion of $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ breaks the dependency of M_1 & M_2 on the low $\tan\beta$ region
- In dM1600 scenario, if $M_1 < 0$ it gets very small values for moderate $\tan\beta$
- dM770 scenario has valid solutions only for $M_1 > 0$





- Increase $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ has an important parameter for the fit! er

@ 2 ab^{-1}	input	lower	upper
M_1 [TeV]	1.7	$\sim$ 1.0 (-0.4)	$\sim$ 6.0
M_2 [TeV]	4.4	$\sim$ 2.5 (3.5)	$\sim$ 8.5
μ [GeV]	165.7	166.2	170.1

@ 2 ab^{-1}	input	lower	upper
M_1 [TeV]	5.3	$\sim$ 3	no
M_2 [TeV]	9.5	$\sim$ 7	$\sim$ 15
μ [GeV]	167.2	165.2	167.4