Hadron production in photon-photon processes and BSM signatures with small mass differences update

ILD Software and Analysis meeting

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Introduction

- Naturalness requires light higgsinos at electroweak scale
  - $$m_Z^2 = 2\frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - 2\mu^2$$
- Light higgsinos studied for two benchmark scenarios by Hale Sert - DESY-THESIS-2016-001 (HS-analysis)

  - $\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0)$ = 770 MeV => dM770
  - $\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0)$ = 1600 MeV => dM1600

- Studied without the inclusion of $\gamma\gamma \rightarrow$low p_T hadron overlay and simulated using SGV fast simulation - perfect particle identification assumed

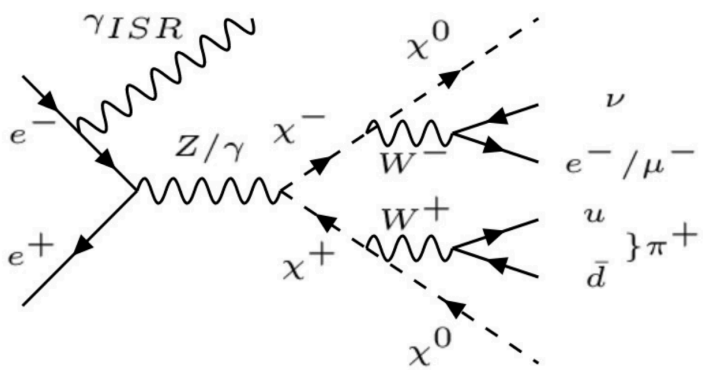
Model Properties for event selection

Production process and decay modes

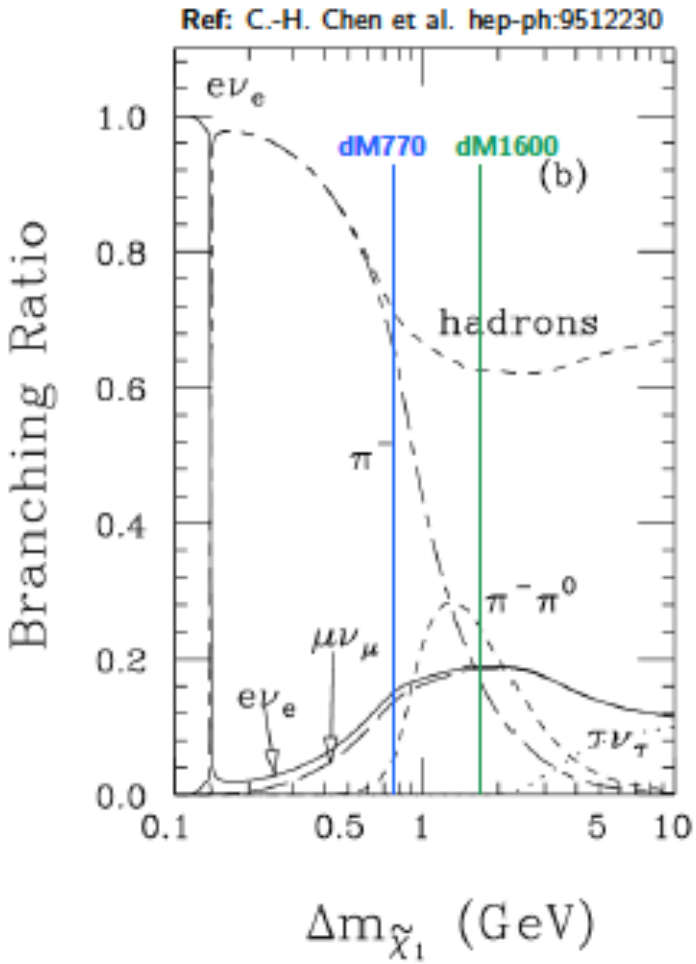
- The charginos are produced as
  $e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$

- The exclusive decay mode:
  $\tilde{\chi}_1^+ \tilde{\chi}_1^- \to 2\tilde{\chi}_1^0 \; \pi^+(\pi^+\pi^0) \; \mu\nu_\mu(e\nu_e)$

  - semi-leptonic final state (30.5%, 35%)
    $\Rightarrow$ to suppress neutralinos



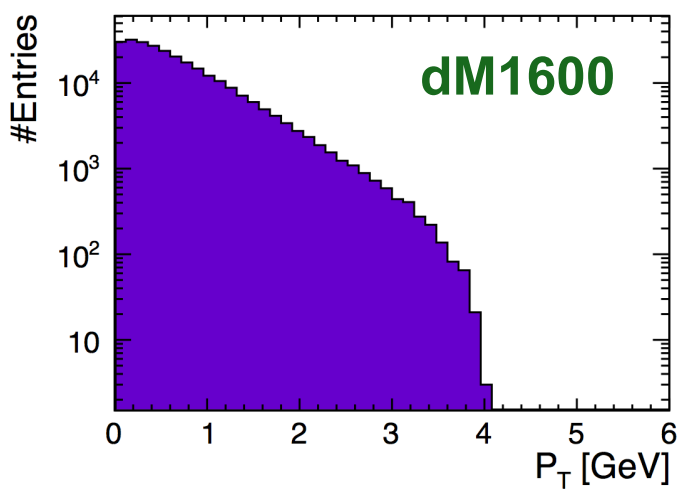
Pic Courtesy: U. Einhaus

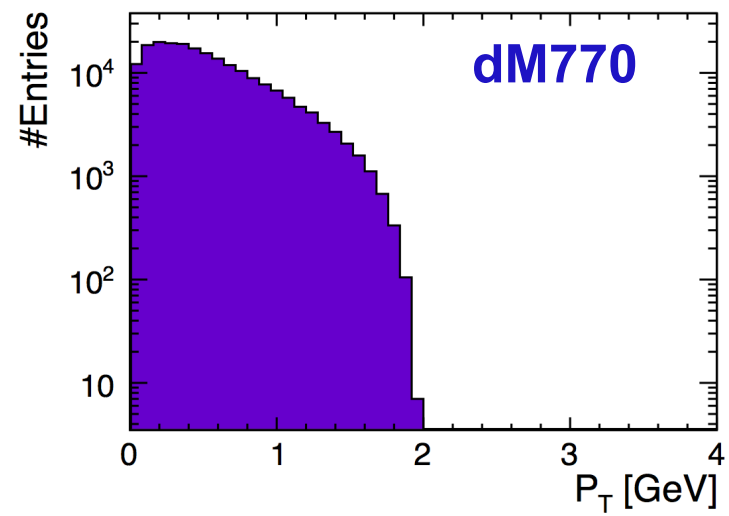


Model Properties for event selection

Signature of Light higgsinos

- Small mass splittings $\Rightarrow$ a few soft visible particles
- Small transverse momentum (2 - 4 GeV)
- Invisible LSPs $\Rightarrow$ a large missing energy

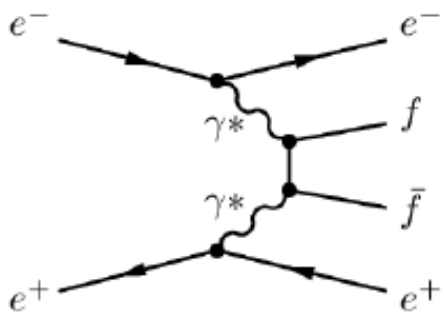


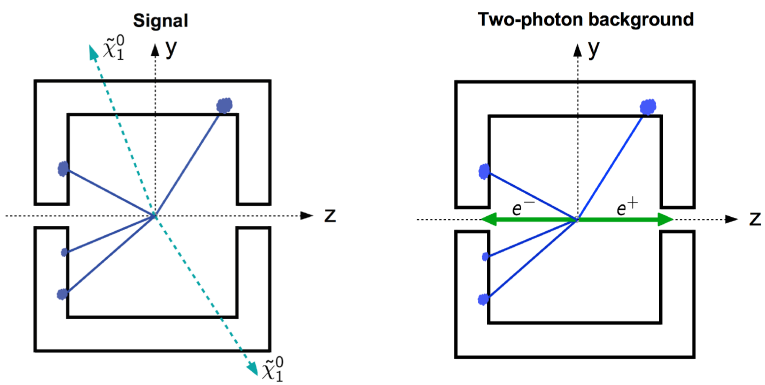


Model Properties for event selection

Standard Model background

- The $\gamma\gamma \to 2f$ background has same signature as the signal





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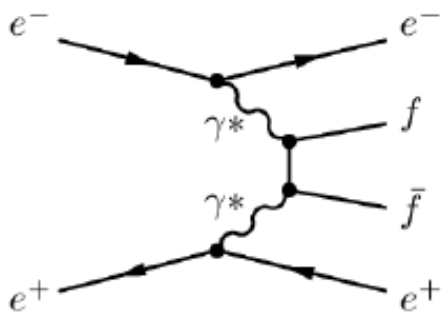
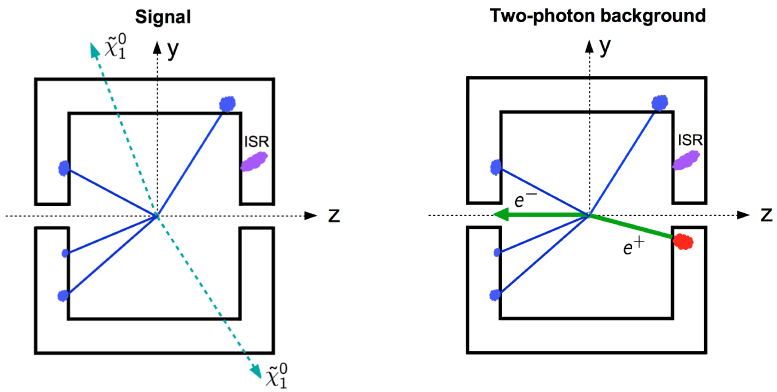
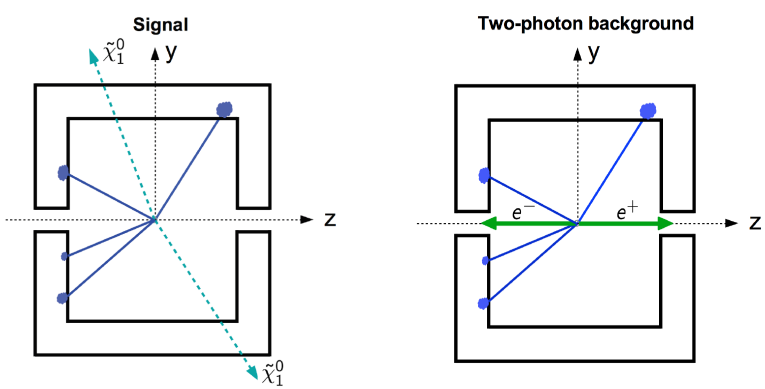


- A hard ISR photon is required to suppress this type background

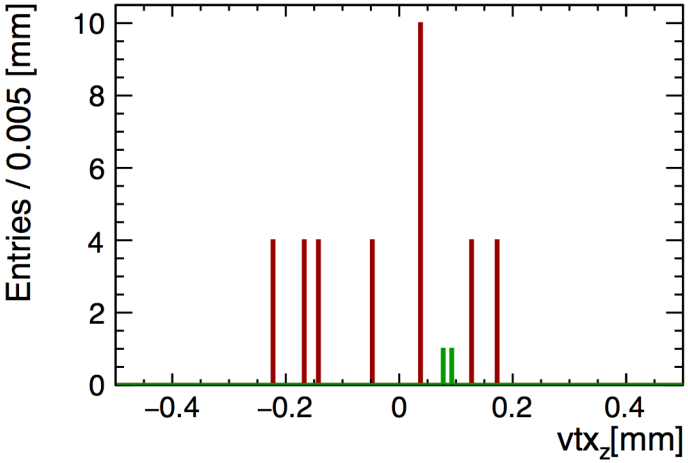




- In the final state: $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$
- A few soft visible particles
- A large missing energy ($2\tilde{\chi}_1^0$)
- A hard ISR photon

Study of $\gamma\gamma$ overlay

- In this study, the two higgsino benchmarks studied with inclusion of $\gamma\gamma \rightarrow$ low p_T hadron overlay
- Detailed study on $\gamma\gamma$ modeling performed and samples taken from the improved generator version to overlay
- Details about the generator study found in ILD meeting talk here
- Signal and $\gamma\gamma \rightarrow$ low p_T hadron vertices are displaced
- Often only single tracks => no classic vertexing possible



Track grouping Algorithm

- A track grouping algorithm developed to group tracks based on their z_0 value
- Aiming to separate signal and overlay tracks => further away on z-axis due to displaced vertices
- Only 16-18 % of the groups have mixed tracks
- The algorithm efficiently separates the overlay and signal tracks
- The results from track grouping algorithm mentioned in LCWS 2018 talk
- The groups created by the algorithm used to select semi-leptonic candidates for the signal among the overlay tracks

Modifications in event selection cuts

Hale's event selection cuts

- Events with any BeamCal activity vetoed
- All particles should be 20° away from the beam and should have E < 5 GeV

Modifications in current analysis

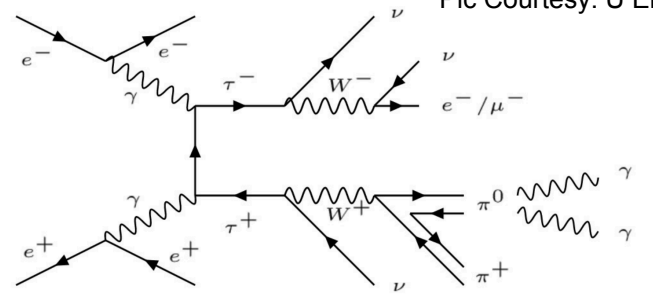
- Events with any BeamCal activity or with particles in BeamCal with energy > 150 GeV vetoed
- Events with semi-lep found: $E_{SL}+E_{neu}$ < 5 GeV & $E_{SL}+E_{othr}$ < 5 GeV and only semi-lep candidates should be 20° away
- Events without semi-lep: for all particles E < 5 GeV & be 20° away
- Details of event selection cuts presented in ILD Sw-Ana talk here

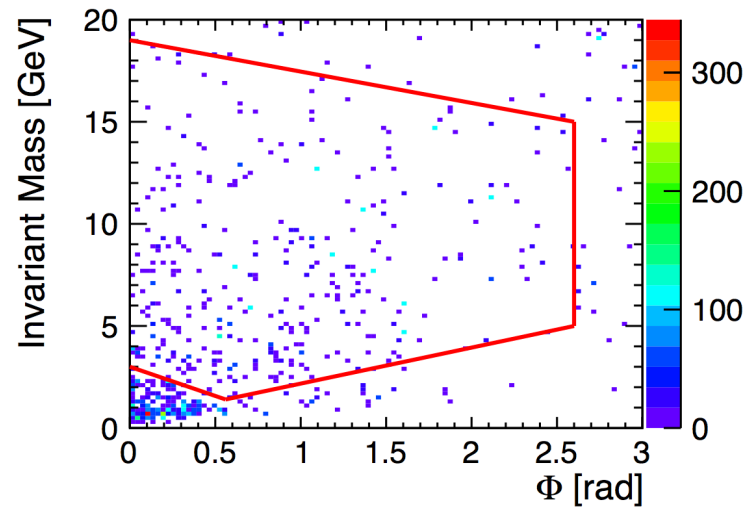
Event selection

New selection cuts

- Any photon with E > 10 GeV & |cos theta| >0.993 qualifies for ISR particularly in tau events
- Angle between ISR candidate and nearest track be larger
- Invariant mass of the ISR candidate and nearest track < M_τ < 1.7 GeV
- Lepton from di-leptonic decay events along with pions from overlay mimic the semi-lep signatures
- Events with oppositely charged extra lepton to the selected candidate, vetoed

Pic Courtesy: U Einhaus





Comparison of survived events

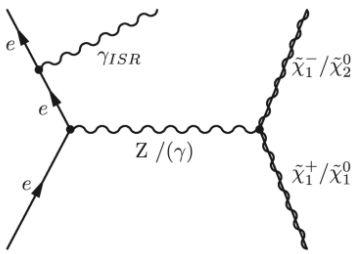
- Comparison of number of events survived after the selection cuts
  - Events with $\gamma\gamma \rightarrow$ low p_T hadron overlay (Swathi)
  - Events without $\gamma\gamma \rightarrow$ low p_T hadron overlay (HS-analysis)

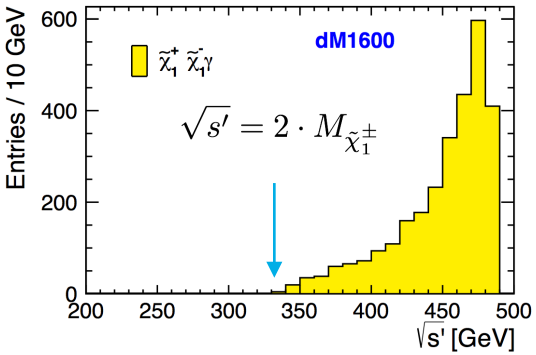
	Swathi dM1600	HS-analysis dM1600	Swathi dM770	HS-analysis dM770
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	2851	3813	2714	4600
$\tilde{\chi}_2^0\tilde{\chi}_1^0$	42	97	78	36
SM	3290	4016	5420	2199

- Presence of overlay makes removal of SM background challenging
- Harsher and new cuts introduced to remove SM background
- Lesser signal events survived wrt HS-analysis

Mass reconstruction of $\tilde{\chi}_1^{\pm}$

- $M_{\tilde{\chi}_1^{\pm}}$ are reconstructed using their recoil mass against the ISR photon



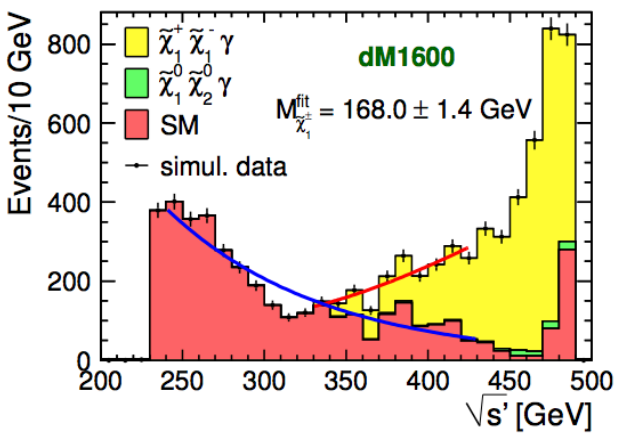


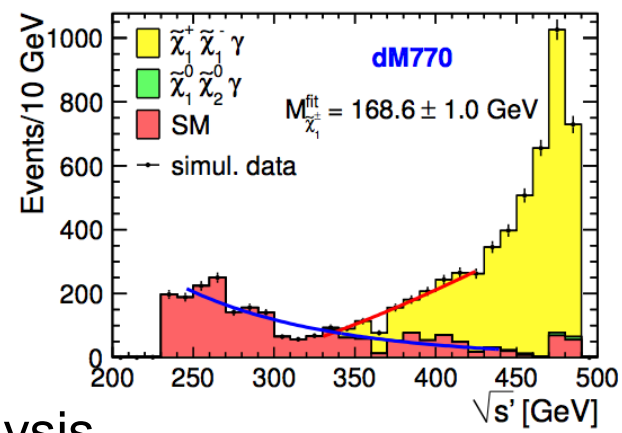
- Reduced CM energy:

$$s' = s - 2\sqrt{s}E_{\gamma}$$

- In rest frame of charginos

$$\sqrt{s'|_{thres}} = 2 \cdot M_{\tilde{\chi}_1^{\pm}}$$

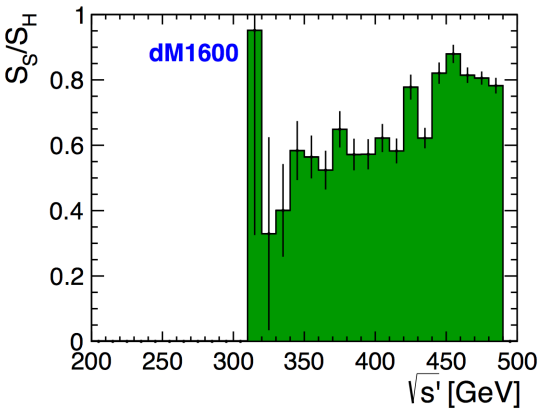


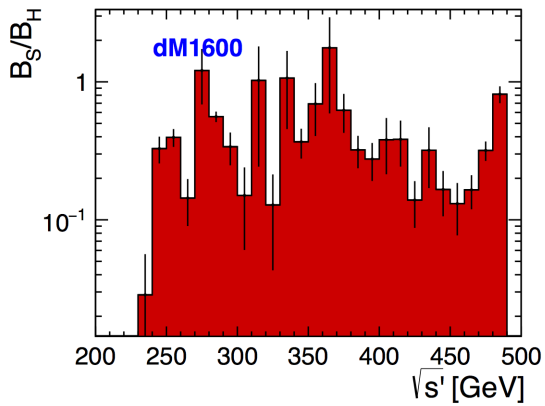


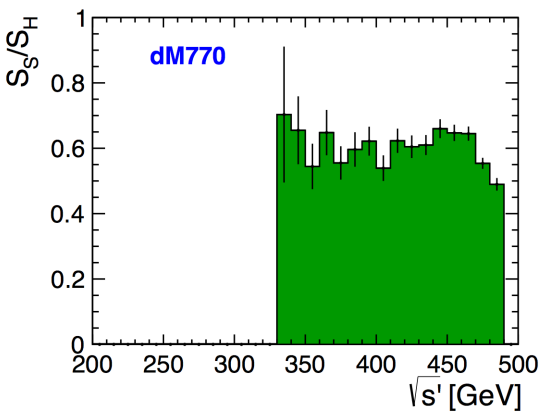
HS-analysis

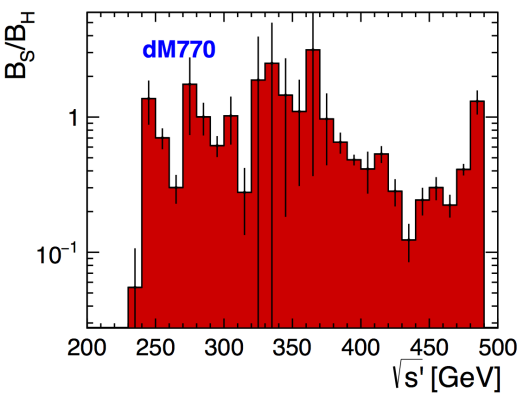
Comparison with HS-analysis

$S_S \Rightarrow$ Swathi's analysis $\qquad$ $S_H \Rightarrow$ Hale's analysis









- Region near end point decisive for mass reconstruction
- Large errors due to lack of statistics at the endpoint
- With the average of first three bins:
  - dM1600 $\Rightarrow$ 40% worse signal, 30% less bkg
  - dM770 $\Rightarrow$ 37% worse, twice more background
- Uncertainties on mass and cross sections depend on amount of background in the same region

Uncertainty expectations

- Assuming similar background and ~half the signal wrt HS-analysis, the uncertainty in dM1600 expected ~40%
- Background is 30% less and signal more than half => uncertainty smaller than 40%

	Swathi dM1600	HS-analysis dM1600	Swathi dM770	HS-analysis dM770
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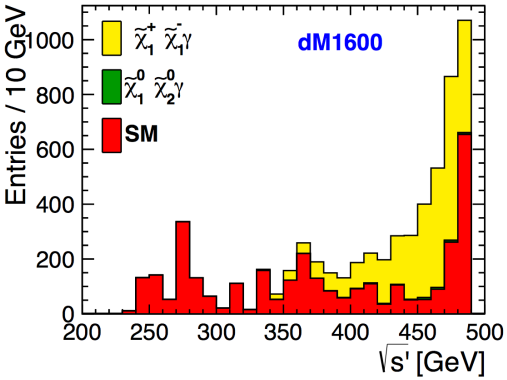
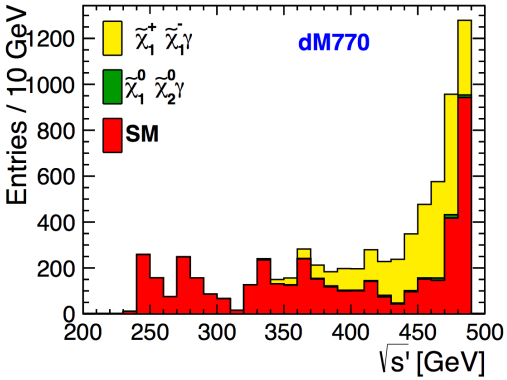
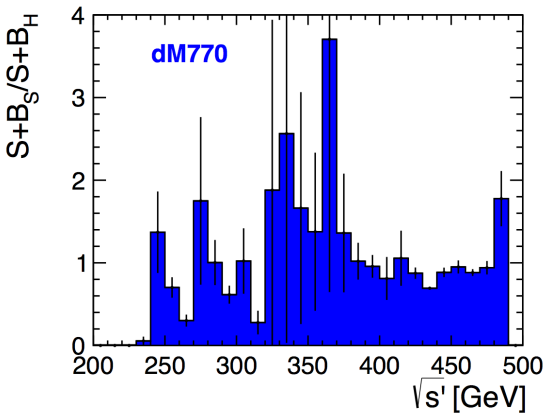
$\tilde{\chi}_2^0\tilde{\chi}_1^0$	42	97	78	36
SM	3290	4016	5420	2199

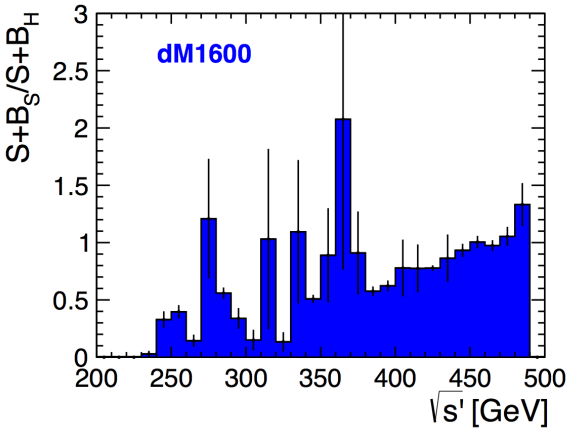
- The number of background and signal event numbers totally different than the HS-analysis for dM770
- Estimation on the uncertainty for this scenario need more inputs

Recoil mass



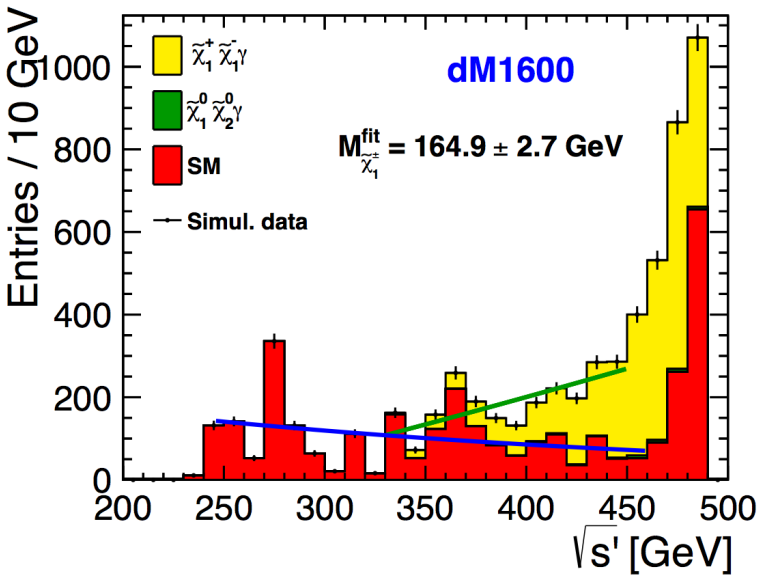


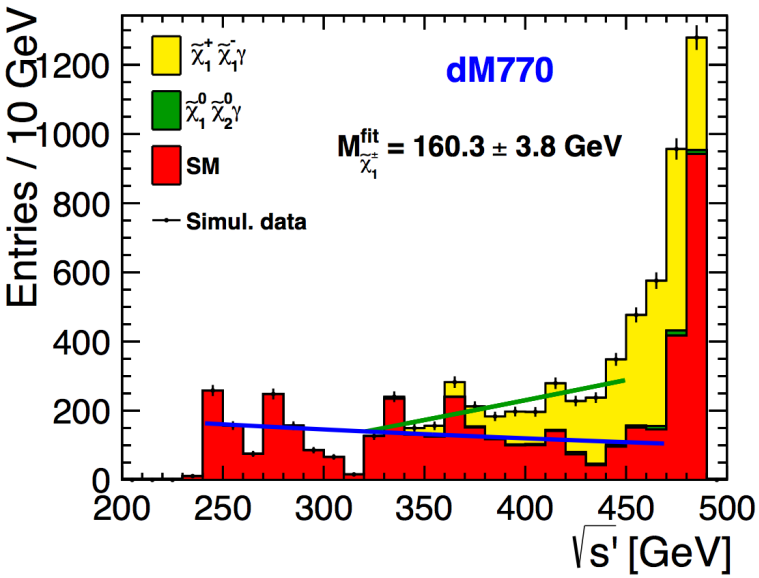




- Shape of recoil mass distribution different than HS-analysis
- Low recoil mass region less populated due to harsher cuts
- Due to lack of MC data, large weights applied on events => spiked around signal end point => large errors => higher uncertainty than expected from bin-to-bin comparison
- No cuts found to reduce background in the high recoil mass region

Fitted recoil mass





- Chargino masses using fitted values:
  - dM1600 : $M_{\tilde{\chi}_1^\pm} = 164.9 \pm 2.7$ GeV
  - dM770 : $M_{\tilde{\chi}_1^\pm} = 160.3 \pm 3.8$ GeV
- Fitted values within 0.3 and 1.8 standard deviations from the input value
- Uncertainty higher than expected from bin-to-bin comparison
- Lack of MC statistics results in large errors => higher uncertainty

Precision determination of Polarized Cross Section

- Statistical precision of polarized cross section $\delta\sigma_{\mathrm{pol}}/\sigma_{\mathrm{pol}}$ is estimated based on efficiency and purity

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

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

	Current Analysis	HS-analysis
dM1600	2.3%	1.9%
dM770	2.9%	1.6%

- Uncertainties on BR depends on the mass difference $\Delta M_{\tilde{\chi}_1^\pm, \tilde{\chi}_1^0}$
- Uncertainties on cross sections obtained as expected from the bin-to-bin comparison

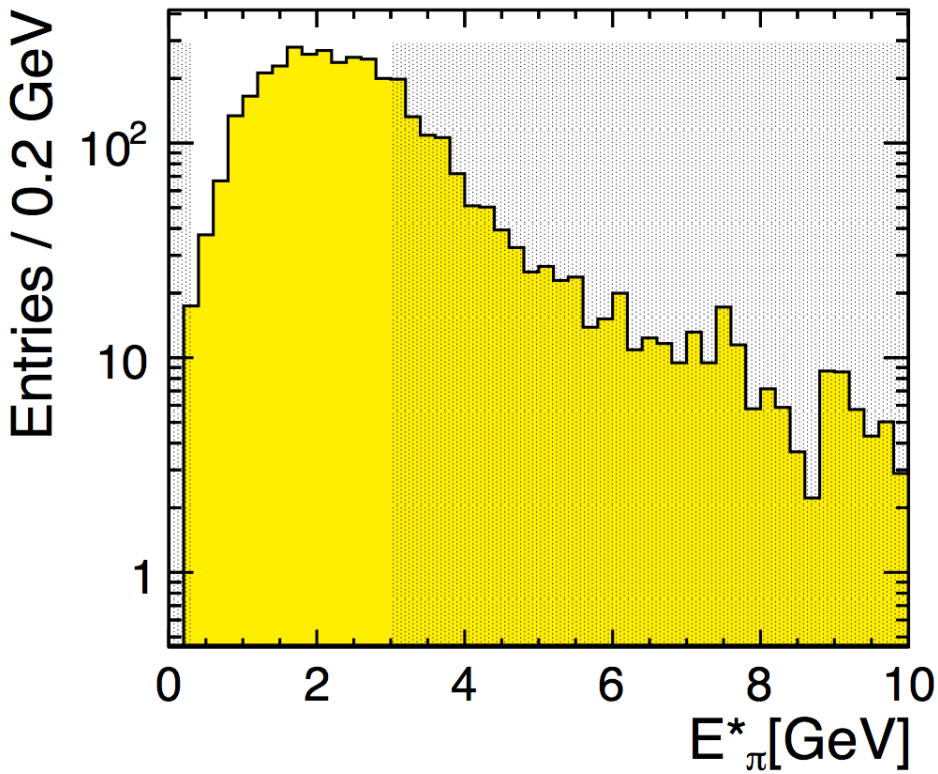
Conclusion

- Light higgsinos can be measured at ILC even in the presence of $\gamma\gamma \rightarrow$ low p_T hadron overlay
- The track grouping algorithm facilitates an effective separation of signal and overlay tracks
- Key observables like the chargino mass and uncertainties on polarized cross section can be measured
- Even with statistical uncertainties worsening due to presence of overlay to about 1-2%, the obtained results are highly precise

Outlook

- Analysis including e^+e^- pair background
- Perfect particle id assumed since PID cheated from MC data - method to separate low momentum pions and muons developed by Hale
- Reconstruction of mass difference $\Delta M_{\tilde{\chi}_1^\pm, \tilde{\chi}_1^0}$
- Further improvements: better tracking for low pT tracks, inclusion of TOF

Mass difference



Thank you