Light Higgsinos Precision Measurements at the ILC

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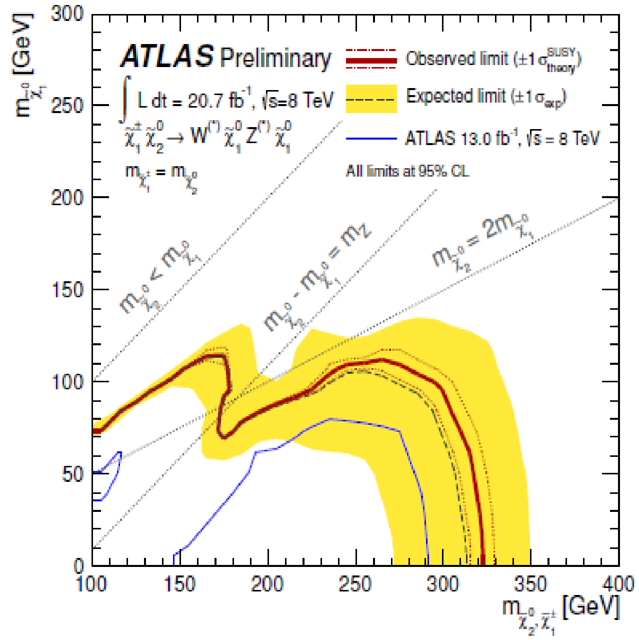
Outline

- Introduction to the scenario
  - Higgsino's production, decay & SM bkg
- Analysis
  - Fast simulation analysis results
  - Going to full sim – challenges
    - Particle identification
    - Beam bkg

Introduction

- SUSY still hasn't be discovered in LHC
  - M (squarks) > 1.7 TeV, M(gluinos) > 1.3 TeV
- Still space left for MSSM with
  - SM like Higgs (m_h=126 GeV)
  - Light EW sector
  - Coloured sector beyond LHC discovery limit
- LHC put limits at the light EW sector
- But..
- When $\mu \ll M_1, M_2$
  - Mass degenerate light states
  - Very challenging for LHC

ATLAS CONF 2013-035



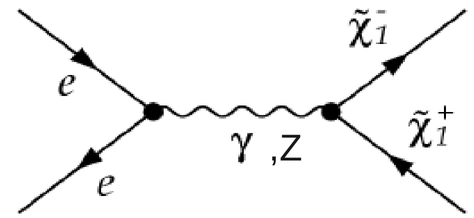
Intro to Light Higgsino's Scenario

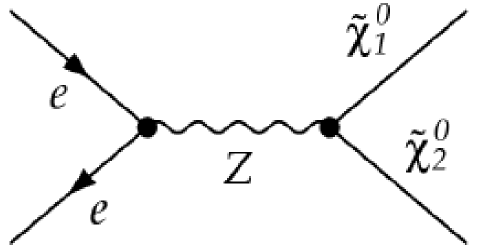
$$m_Z^2 = 2\frac{(m_{H_u}^2 + \Sigma_u^u)\tan^2\beta - m_{H_d}^2 - \Sigma_d^d}{1-\tan^2\beta} - 2|\mu|^2$$

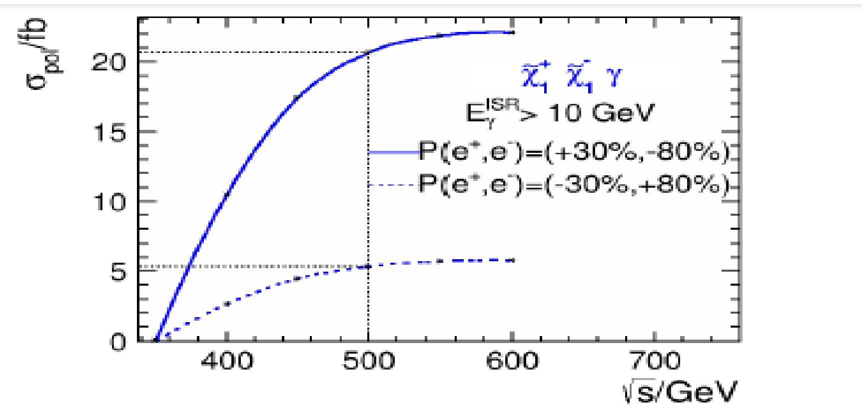
- Naturalness requires μ at the EW scale
- Scenario
  - 3 light higgsinos $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_1^0$ & $\tilde{\chi}_2^0$
  - Almost mass degenerate
  - No other SUSY particles with masses < 1 TeV

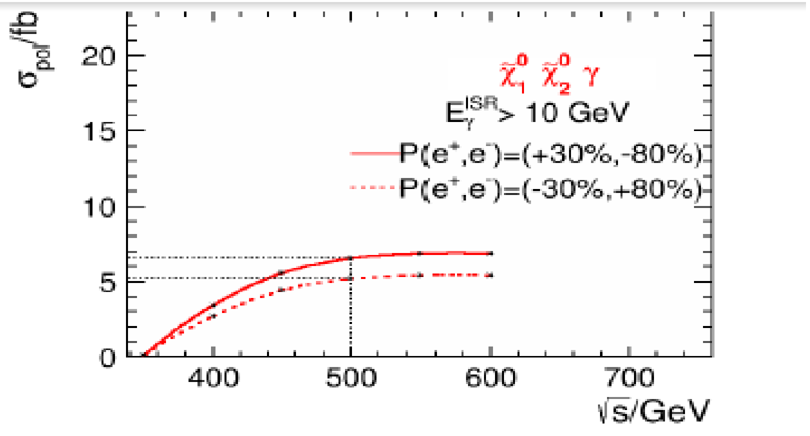
Production

- Via Z, γ exchange in s - channel
- Strong polarisation dependence for charginos, weaker for neutralinos
- t – channel suppressed for both









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

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

← 2 benchmark points, dM1600 & dM770

Decay & SM bkg

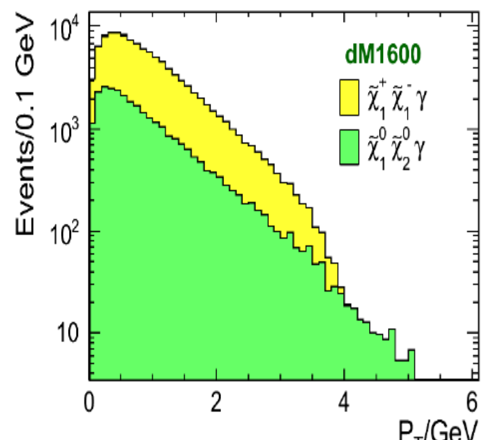
- Chargino & neutralinos decay modes
- Result to few soft particles & missing energy
  - P_T spectrum at generator level

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 W^{\pm *}$$

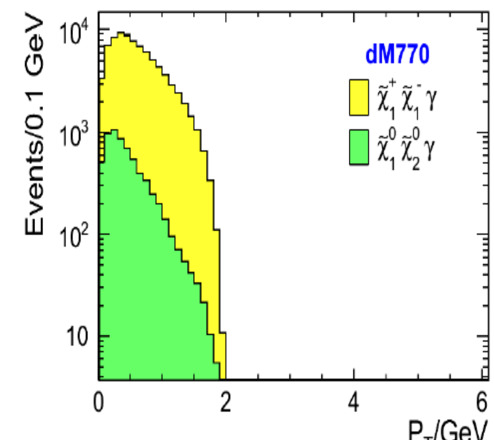
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^{0*}$$

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$$

- Main SM bkg processes
  - $e^+e^- \rightarrow \tau^+\tau^-$
  - $e^+e^- \rightarrow \tau^+\tau^- \nu\nu$
  - $e^+e^- \rightarrow \gamma^* \gamma^* \rightarrow ff$
  - Requirement for a hard ISR photon (E_{ISR}>10 GeV) suppresses bkg
  - eγ→ 3f dominant remaining bgk



$P_T < 5$ GeV



$P_T < 2$ GeV

$m_h = 124$ GeV	$m_h = 127$ GeV
ΔM=1.59 GeV	ΔM=0.77 GeV
$e/\mu + \pi^{\pm}(\pi^0)$	$e/\mu + \pi^{\pm}$
$BR = 30.5\%$	$BR = 35\%$

- Seperation of chargino – neutralino processes
  - Chargino: require semi-leptonic decay
  - Neutralino : require photon

$m_h = 124$ GeV	$m_h = 127$ GeV
$BR(\gamma) = 23.6\%$	$BR(\gamma) = 74.0\%$

Analysis Overview

- Data sample
  - $\sqrt{s}$ 500 GeV, 500 fb^{-1} for each P(e^+,e^-) = (+-30, -+80)
  - Cross sections calculated by Whizard

	m_h = 124 GeV		m_h = 127 GeV	
Processes	$\tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$	$\tilde{\chi}_2^0\tilde{\chi}_1^0\gamma$	$\tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$	$\tilde{\chi}_2^0\tilde{\chi}_1^0\gamma$
$\sigma(e_L^+e_R^- \to \tilde{\chi}\tilde{\chi}\gamma)$	26.83 ± 0.05	61.66 ± 0.10	26.28 ± 0.05	60.92 ± 0.10
$\sigma(e_R^+e_L^- \to \tilde{\chi}\tilde{\chi}\gamma)$	132.99 ± 0.23	80.12 ± 0.13	130.05 ± 0.22	79.16 ± 0.13

  - Fast ILD simulation in SGV
    - See Mikael Berggren, physics.ins-det 1203-0217
    - Tracking efficiency of ILD estimated with full sim., parametrised for 4 polar angle values, has been implemented in SGV
- Goals of the study
  - Mass measurement of chargino & neutralinos
  - Mass difference measurement
  - Statistical precision on polarised cross section
    - The measured uncertainties has been used in a fit to estimate MSSM parameters M_1, M_2, μ

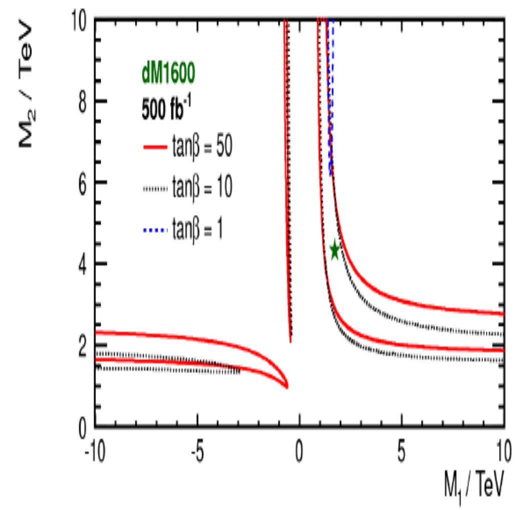
Fast Simulation Results Summary

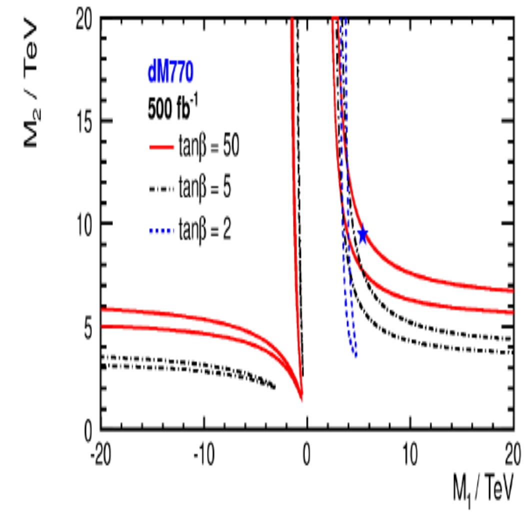
- Chargino mass measurement
  - DM1600: M_{REC} = 166.2$\pm$2.0 GeV (M$_{TRUE}$ = 165.8 GeV)
  - DM770: M_{REC} = 167.3$\pm$1.5 GeV (M$_{TRUE}$ = 167.4 GeV)
- Chargino – LSP mass difference
  - DM1600: ΔM_{REC} = 1630 $\pm$ 270 MeV
  - DM770: ΔM_{REC} = 810 $\pm$ 40 MeV
- Polarised chargino cross – sections precision
  - For $P(e^+,e^-)$ = (+-30, -+80), $\delta\sigma/\sigma$ = 1.9% (1.6%) for dM1600 (dM770)
- Neutralino mass measurement
  - DM1600: M_{REC} = 169.6$\pm$3.3 GeV (M$_{TRUE}$ = 166.9 GeV)
  - DM770: M_{REC} = 165.7$\pm$1.6 GeV (M$_{TRUE}$ = 167.6 GeV)
- Polarised chargino cross – sections precision
  - For $P(e^+,e^-)$ = (+-30, -+80), $\delta\sigma/\sigma$ = 3.2% (1.7%) for dM1600 (dM770)

See [hep-ph] 1307.3566

Parameter Determination

- 4 parameters defining chargino – neutralino sector @ tree level
  - M_1, M_2, μ, tanβ
- Measurements used for extraction
  - Neutralino – chargino masses, mass difference, δσ/σ
  - tanβ can't be constraint – fixed to values in range 1 – 60
- For M_1, M_2 obtain lower limits – allowed region
  - M_1, M_2 strongly correlated
  - μ determination precision
    - ~ 2.5 GeV (dM770), ~ 6.8 GeV (dM1600)
- Expected improvement from high luminosity run
  - Narrows the allowed region for μ by 2-3.5 GeV





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

@ 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

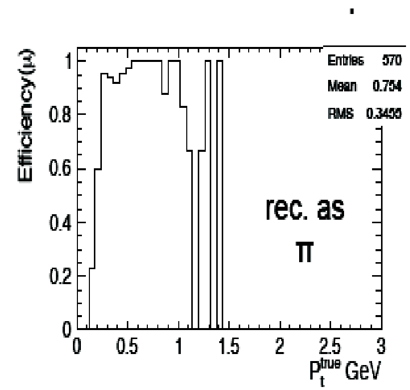
See [hep-ph] 1307.3566

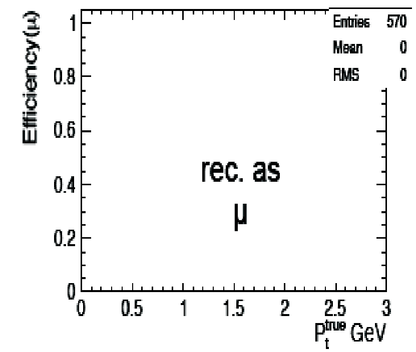
From Fast to Full Sim.

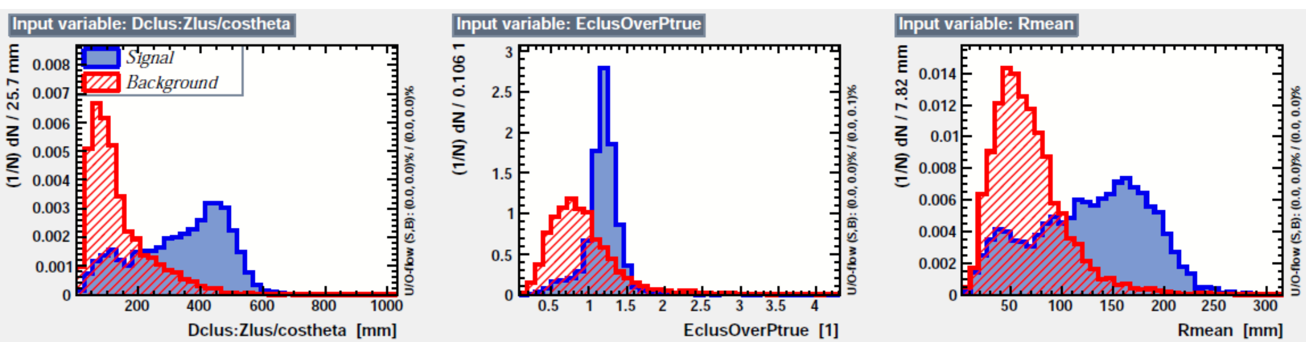
- Fast sim conclusions
  - Light Higgsinos can be resolved in ILC
  - Precision in masses & cross section measurement sufficient to constraint μ, M_1 and M_2
- Going to full simulation
- Open issues:
  - Low P_T particle identification
    - Muons identified as pions
  - Low P_T tracking in the presence of beam bkg
    - Effect of "bad" tracks should be studied
  - $\gamma\gamma \rightarrow$ hadrons overlay

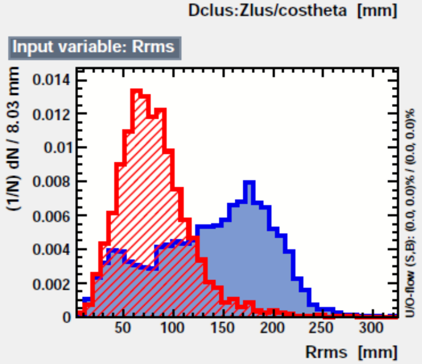
Particle Identification

- Low P_T muons are reconstructed as pions!
- Trying a likelihood methode
- Determine proper discriminating variables & apply TMVA analysis
  - Cluster E / track P
  - Depth of cluster vs incident angle
  - Mean radius of hits
  - RMS of hits radius







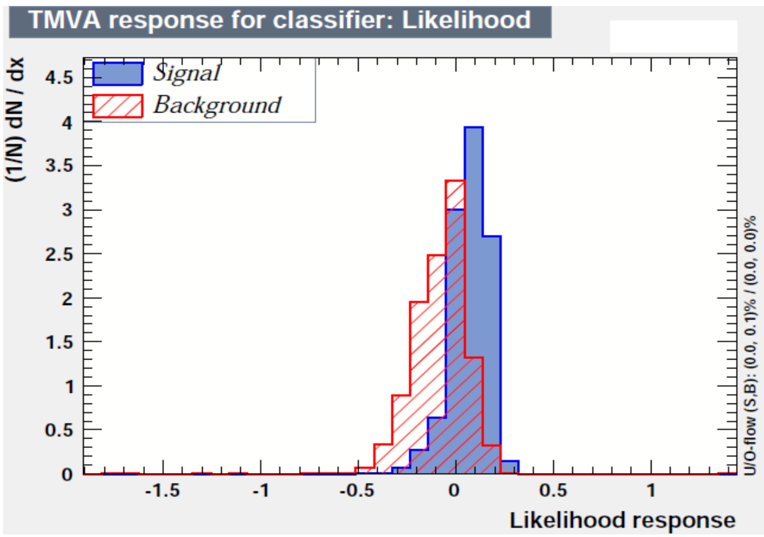


TMVA input variables for 1 GeV

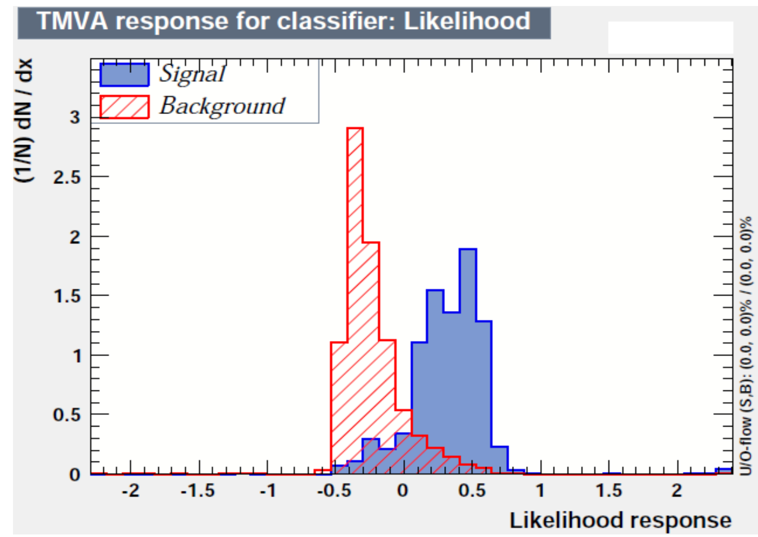
Particle Identification using TMVA

Response for different momenta
Signal: muons, bkg:pions

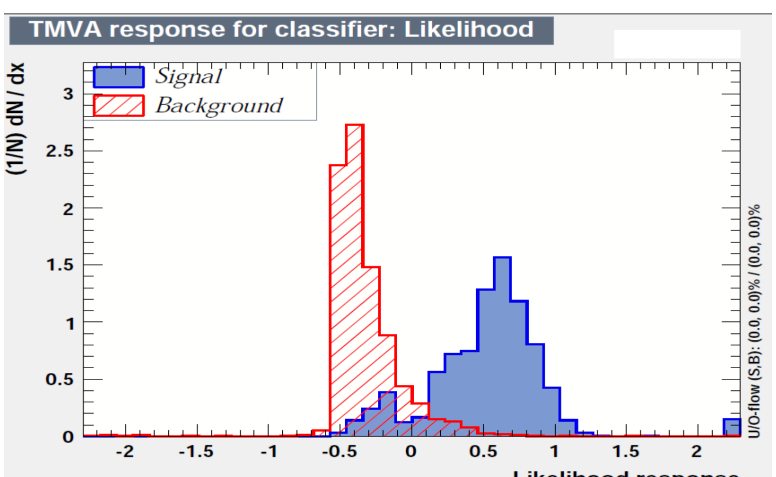
0.5 GeV



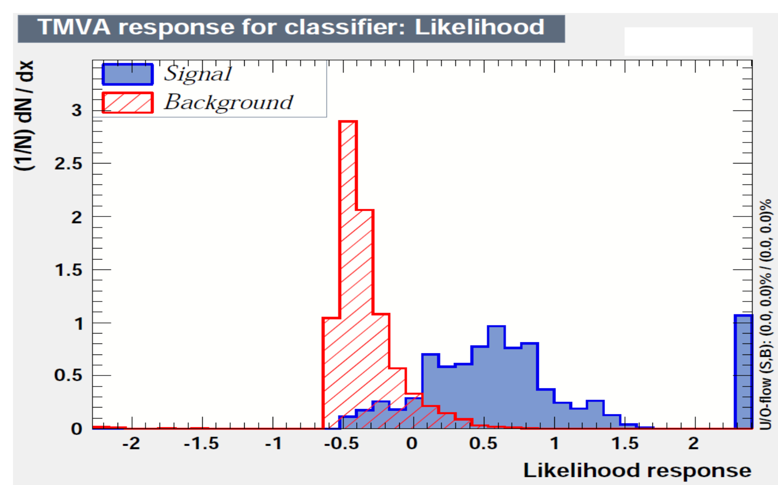
1.0 GeV



1.5 GeV

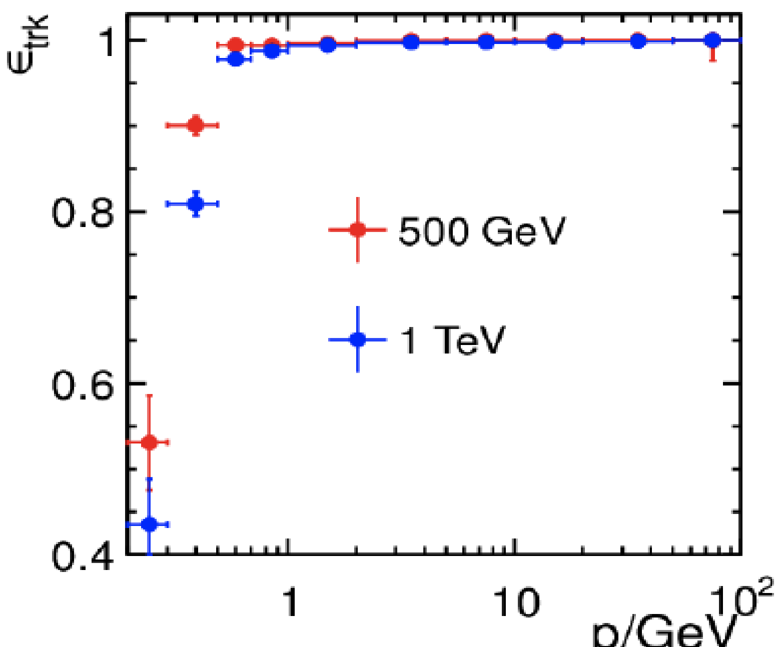


2.0 GeV

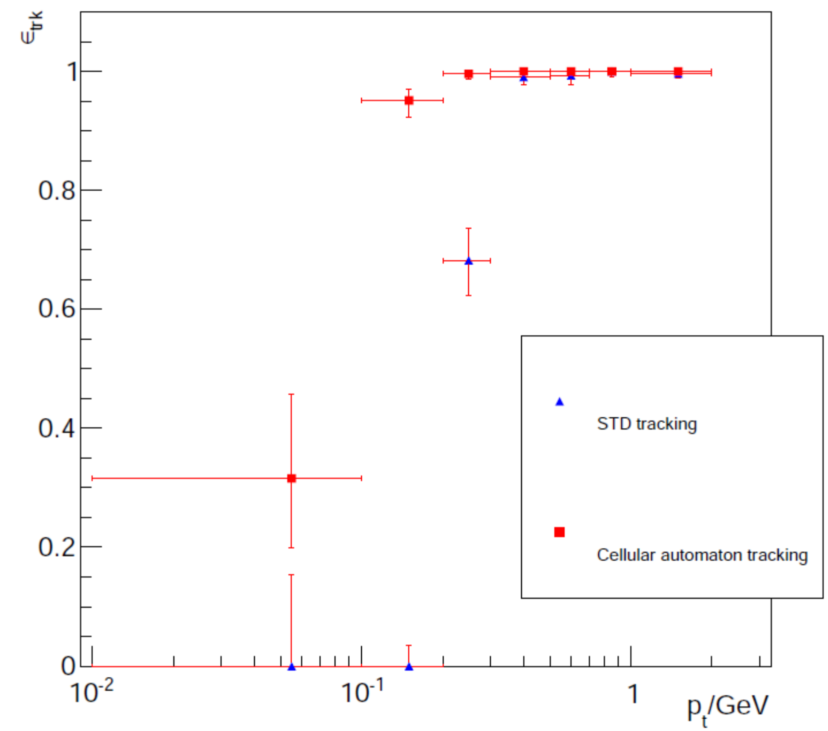


Including beam bkg

- Very soft particles in final state
- Tracking efficiency according to ttbar sample + pair bkg implemented in SGV
  - Despite the relatively low efficiency for low P_T tracks, the analysis is feasible
- New tracking algorithm featuring high efficiency for low P_T tracks in the presence of beam bkg developed



Plots from DBD – ttbar sample, pair bkg included
~ 99.7% eff, P≥ 1 GeV, ≥ 99.8%, cos(θ) < 0.95



Efficiency for higgsino sample + pair bkg for a proposed CMOS VXD, std vs new tracking algo

Including beam bkg - “bad” tracks

- ILD VXD integrates over several Bxs (depending on sensor technology – design parameters)
  - Dominate the occupancy
    - DBD VXD for higgsino sample
      - “physics” hits O(10)
      - Bkg hits $O(10^4)$
- Effect of ghost – pair bkg tracks has not be studied
- Pattern recognition can rule out most of them
  - Still “bad” track rate ≥2
  - Bad track rate strongly correlated with track finding for low P_T particles

Summary – Outlook

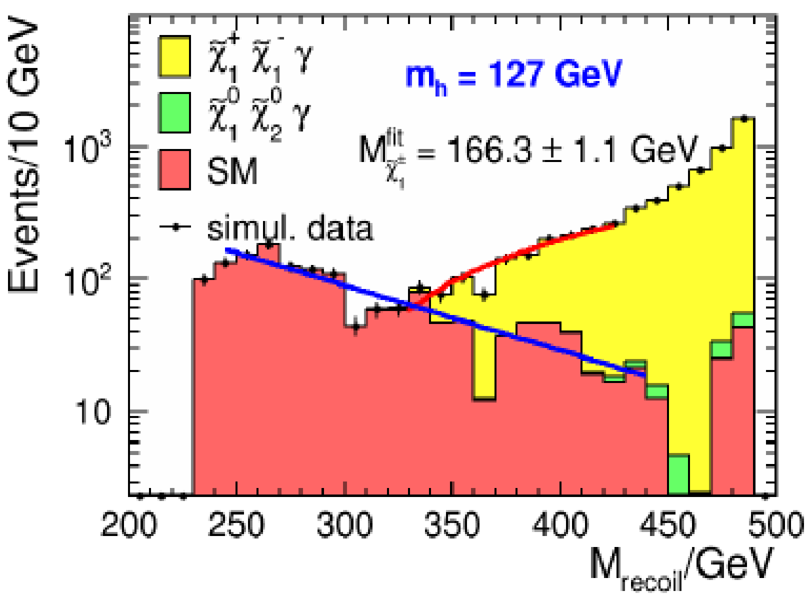
- Naturalness leads to light higgsinos
- The scenario has been studied for ILC in fast sim
  - Determination of μ to few % level
  - M_1, M_2 constraint to a narrow band
- Moving to full simulation studies
  - Work in progress
    - Particle identification for low P_T particles with high efficiency – purity
    - Low P_T tracking in the presence of beam bkg
      - Can we reconstruct signal particles and get rid of the pair bkg particles?
        - Benchmark for VXD specifications

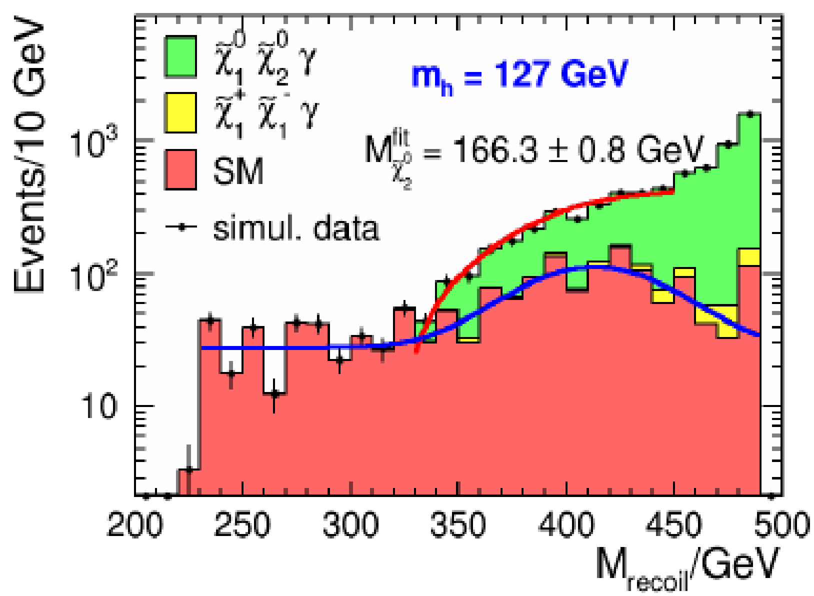
BACKUP

Mass Measurement Procedure

Fitting Procedure

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

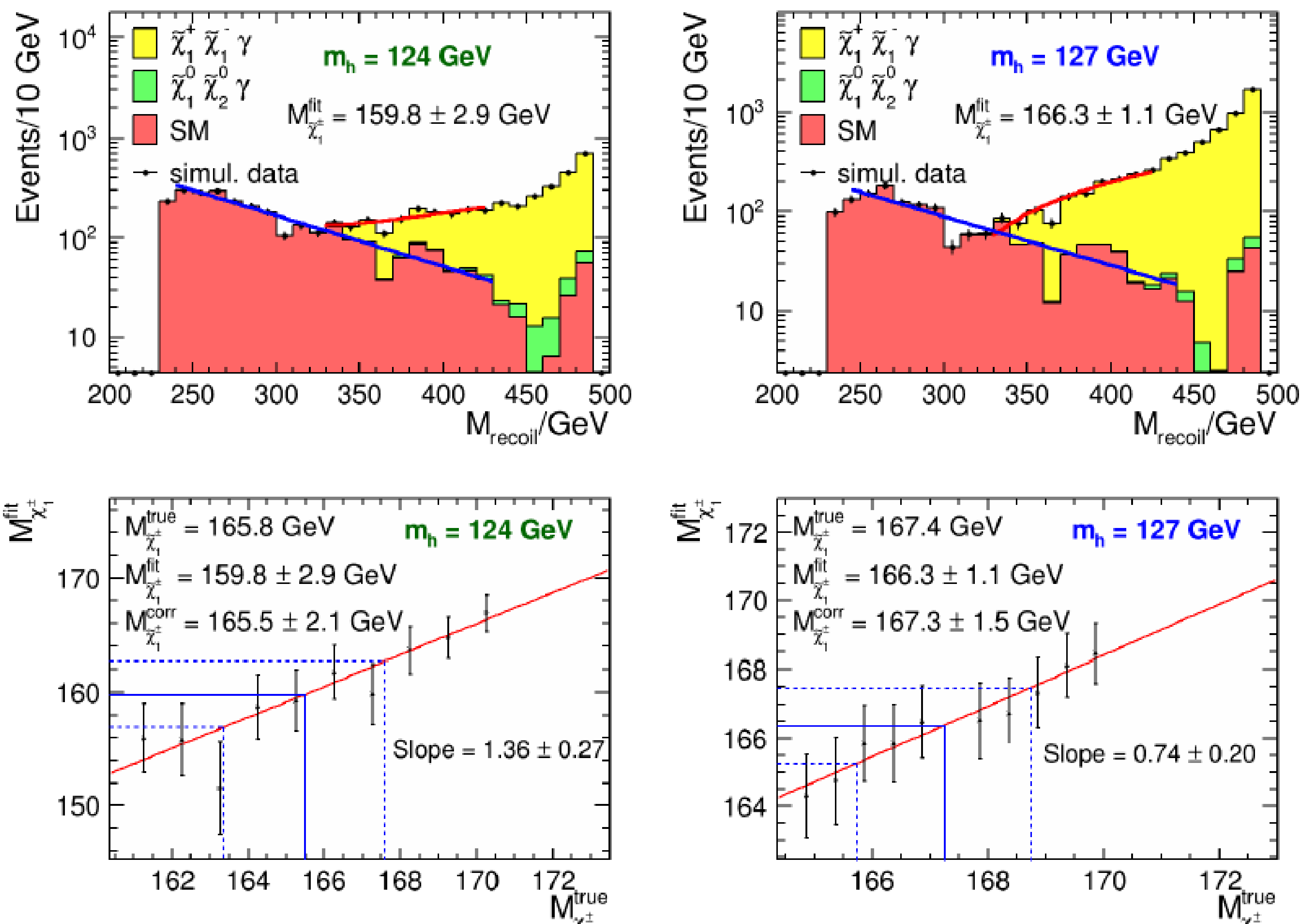




- SM Fit Function: Exponential
- Signal Fit Function: Linear

- SM Fit Function: Linear + Gaussian
- Signal Fit Function: Linear

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



Mass Difference Measurement