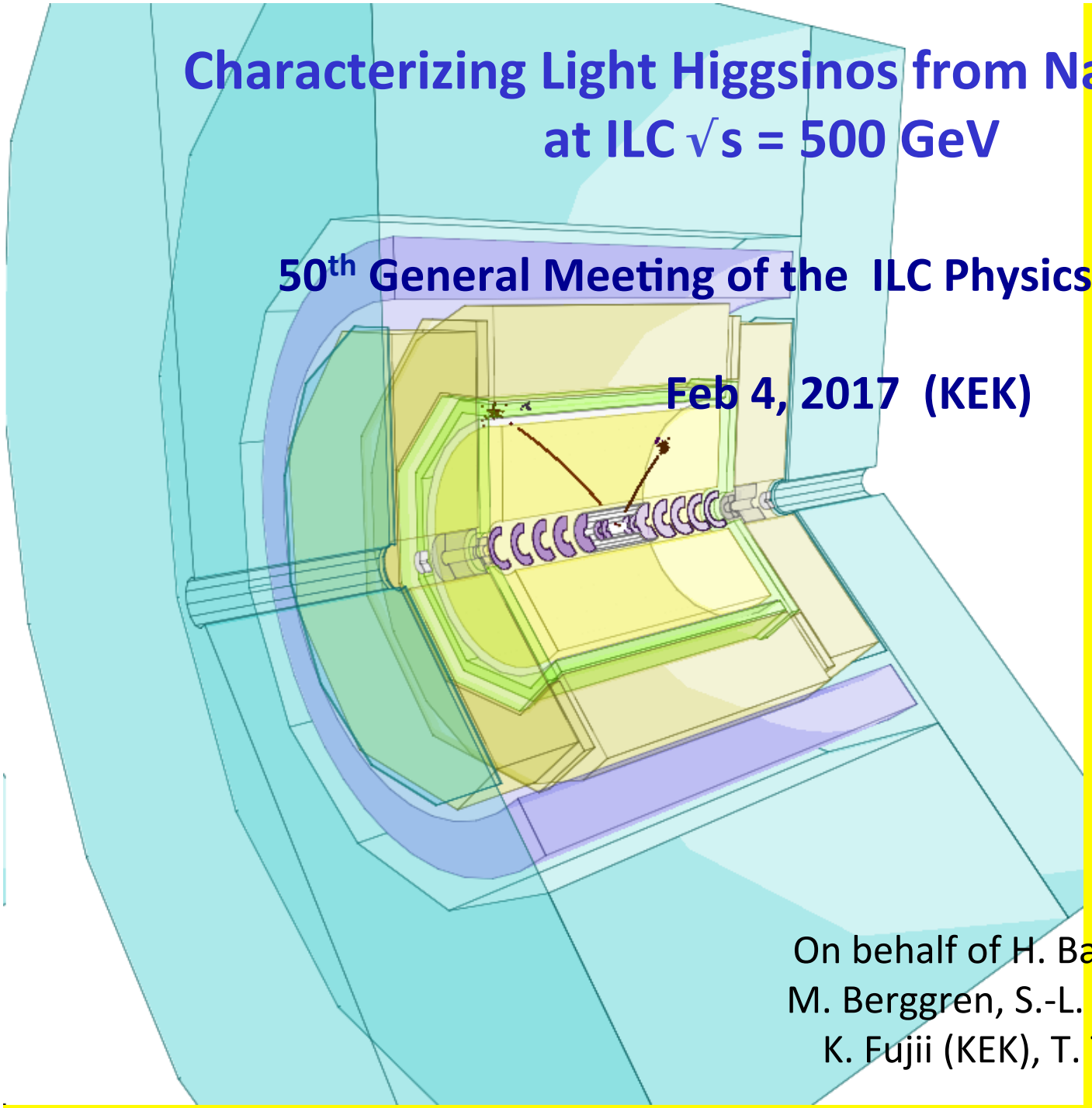
Characterizing Light Higgsinos from Natural SUSY at ILC $\sqrt{s}$ = 500 GeV



50th General Meeting of the ILC Physics Working Group

Feb 4, 2017 (KEK)

Jacqueline Yan (KEK)

On behalf of H. Baer (Univ of Oklahoma),
M. Berggren, S.-L. Lehtinen, J. List (DESY),
K. Fujii (KEK), T. Tanabe (Univ of Tokyo)

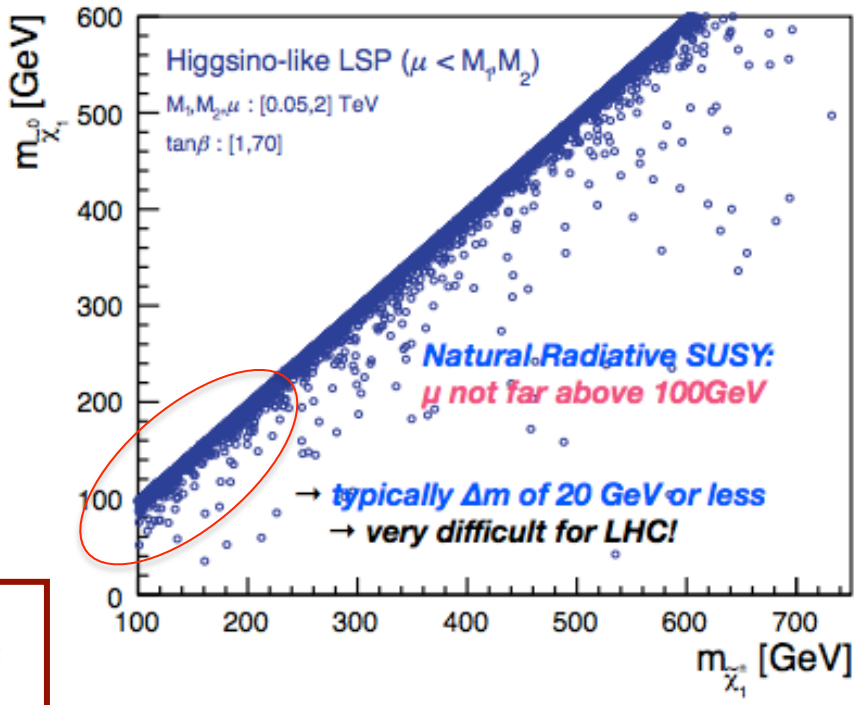
Outline

- Motivation of study
- Analysis method
- Precisions of Higgsino mass and cross section
- Software related issues
- Goals and plans

Motivation for Searching Light Higgsinos with Small ΔM

❖ From experimental point of view:

- LHC already excluded large regions with large ΔM = M(NLSP) – M(LSP)
- Remaining region with compressed spectrum
  very small visible energy release,
  near impossible to probe at LHC
  ➔ **ILC is essential**



❖ From theoretical point of view:

Compressed Higgsino spectra related to naturalness [e.g. arXiv:1212.2655, arXiv:1404.7510]

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

- To maintain **small electroweak fine tuning ΔEW (<∼3%),** all contributions on right-hand-side should be comparable to M(Z) ➔ requires **μ ∼ 100–300 GeV**

  top and bottom squarks in the few TeV regime, gluino mass 2–4 TeV,
  1st, 2nd generation squarks and sleptons in the 5–30 TeV regime

- μ feeds mass to both SM (W, Z, h) and SUSY particles (Higgsinos)
- Higgsino masses not too far from masses of W, Z, h (∼100 GeV)

Goal of Light Higgsino Study

This study

Demonstrate measurement precision of Higgsino masses and production cross sections

Serve as a basis for future discussions of ILC run scenario in the case of new particles being discovered

Results of masses and cross sections (= "observables") as input

S.-L. Lehtinen (DESY) et al

determine SUSY parameters

e.g. M_1, M_2, μ, $\tan\beta$

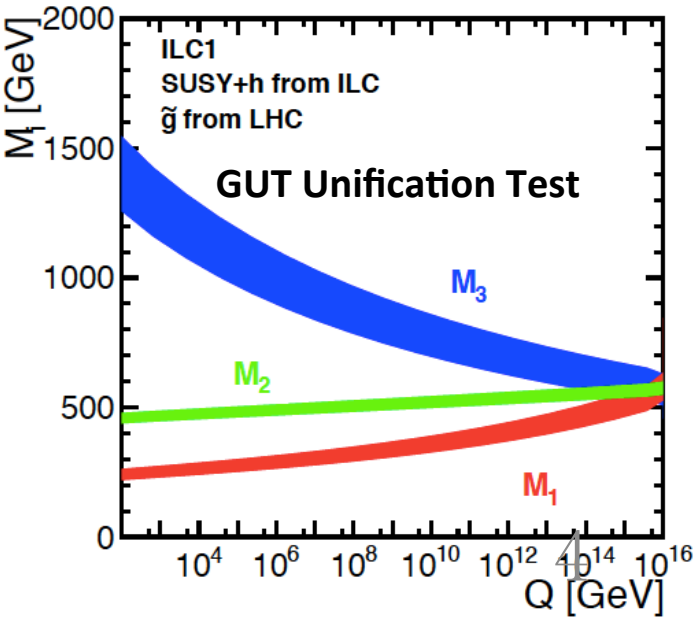
Why?

- **To get info about unobserved sparticles**
- **To test GUT-scale models**

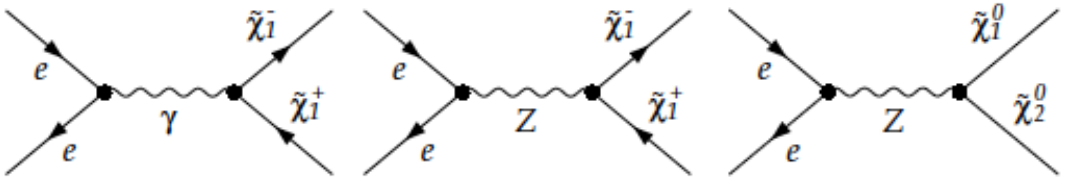
How?

- **Global χ^2 fit of to observables**

Study required input parameters and precisions;
interplay with Higgs precision measurements



Benchmarks in this Study



√s = 500 GeV, full ILD detector simulation

RNS model (Radiatively-driven natural SUSY)

- **4 light Higgsinos:** $\tilde{\chi}_1^0$ (LSP) $\tilde{\chi}_2^0$ $\tilde{\chi}_1^+$ $\tilde{\chi}_1^-$
- **ΔM complies with naturalness** (no need for ISR tag)

Benchmarks with smaller ΔM are drawing attention ,
as ILC1 is (almost) excluded by LHC

- At last general meeting, showed preliminary contents related to **ILC2 (ΔM～10 GeV)**
- Now finishing analysis and reconfirming results , in preparation for publication
- **even more challenging benchmark (nGMM1)** is in progress , with ΔM < 5 GeV (next page)
- Also further optimize ILC1 (to be included in publication)

NUHM2 model parameters **[arXiv:1404.7510]**

Benchmark	ILC1	ILC2
M_0 [GeV]	7025	5000
$M_{1/2}$ [GeV]	568.3	1200
A_0 [GeV]	-10427	-8000
tanβ	10	15
μ [GeV]	115	150
M_A [GeV]	1000	1000
$M(\chi_1^0)$ [GeV]	102.7	148.1
$M(\chi_1^\pm)$ [GeV]	117.3	158.3
$\Delta M(N_2,N_1)$	**21.3**	**9.7**
$M(\chi_2^0)$ [GeV]	124.0	157.8
$\Delta M(C_1,N_1)$	**14.6**	**10.2**

Defined at GUT scale ,
Defined at weak scale **Observables**

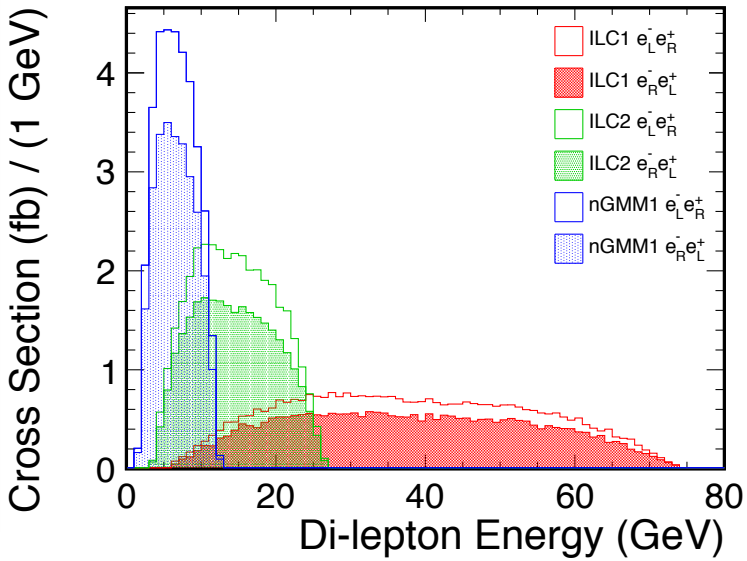
analyzing more challenging benchmarks with smaller ΔM

Despite reduced visible energy, doable without large change in analysis strategies

Higgsino mass precisions ＜～1% (H20) should be achievable

Masses [GeV] from LHA files:

	ILC1	ILC2	nGMM1
M(N1)	102.7	148.1	151.4
M(N2)	124.0	157.8	155.8
ΔM(N2,N1)	**21.3**	**9.7**	**4.4**
M(C1)	117.3	158.3	158.7
ΔM(C1,N1)	**14.6**	**10.2**	**7.3**



Cross sections [fb] for $\sqrt{s}$=500 GeV with TDR beam parameters ,
Event Generator: WHIZARD v1.95, DBD setup)

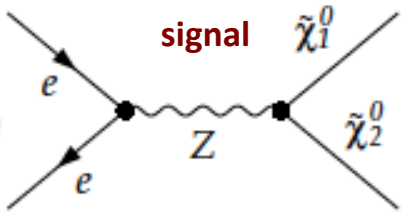
Process (Pe-,Pe+)	ILC1	ILC2	nGMM1
C1C1 (-1,+1)	1799.9	1530.5	1520.6
C1C1 (+1,-1)	334.5	307.2	309.5
N1N2 (-1,+1)	490.9	458.9	463.5
N1N2 (+1,-1)	378.5	353.8	357.3

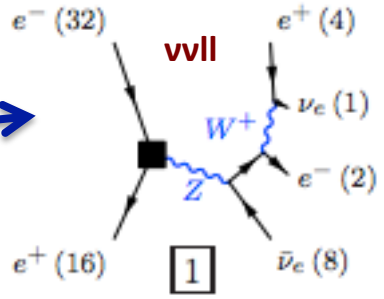
Event Selection

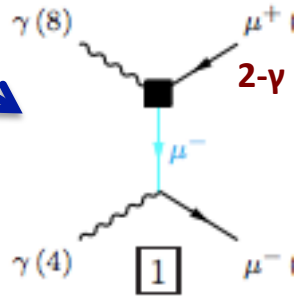
Neutralino mixed production with leptonic decay

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

- Reconstruct **two leptons (ee or μμ) which originate from Z^* emission in decay of χ_2^0 to χ_1^0**
- Major residual bkg. are 4f processes accompanied by large missing energy (vvll)
- 2-γ processes are removed by BeamCal veto, cuts on lepton track p_T, and coplanarity





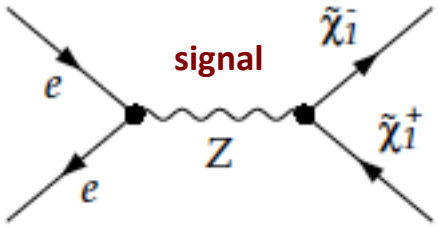


Chargino pair production with semileptonic decay

$$e^+e^- \to \tilde{\chi}_1^+\,\tilde{\chi}_1^- \to \tilde{\chi}_1^0\,\tilde{\chi}_1^0 q q' \ell\nu$$

- Reconstruct **two jets which originate from W^* emission in decay of $\chi_1^\pm$ to χ_1^0**
- Use lepton (e or μ) from the other chargino as tag
- BeamCal veto, cuts on missing p_T, # of tracks, # of leptons, and coplanarity remove almost all bkg.

(signal significance > 100)

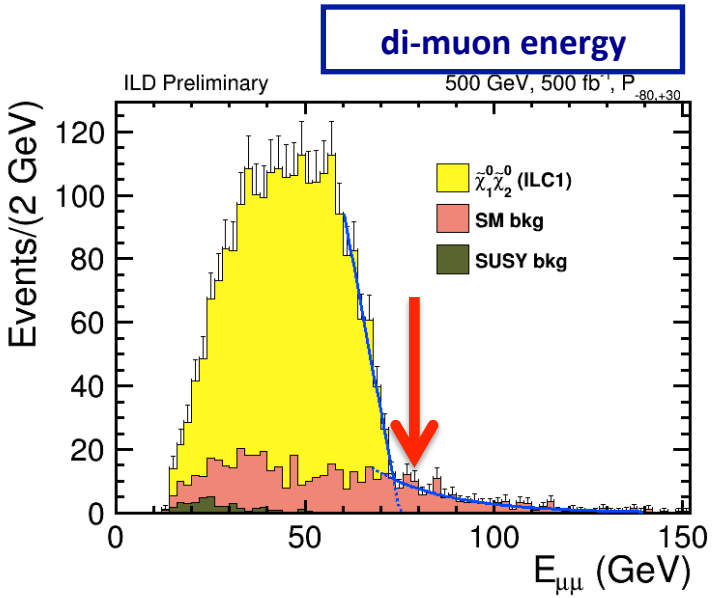


Extraction of Higgsino Mass and Cross Section

Mass :

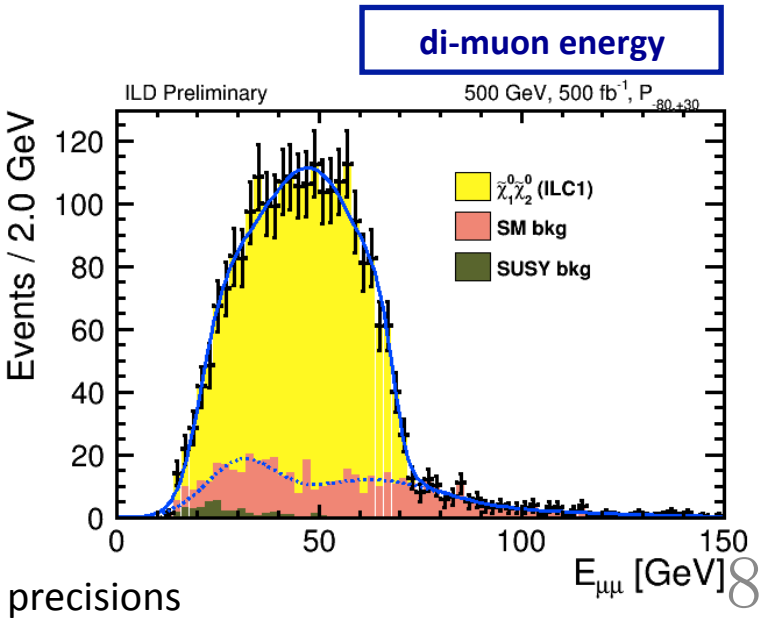
- Kinematic edges of dilepton/dijet energy and invariant mass are functions of $\sqrt{s}$ and Higgsino masses
- **Extract kinematic edges by a fit to distributions ➔ calculate masses**

(requires correction for detector resolution)



Cross section:

Count number of events under dilepton / dijet energy



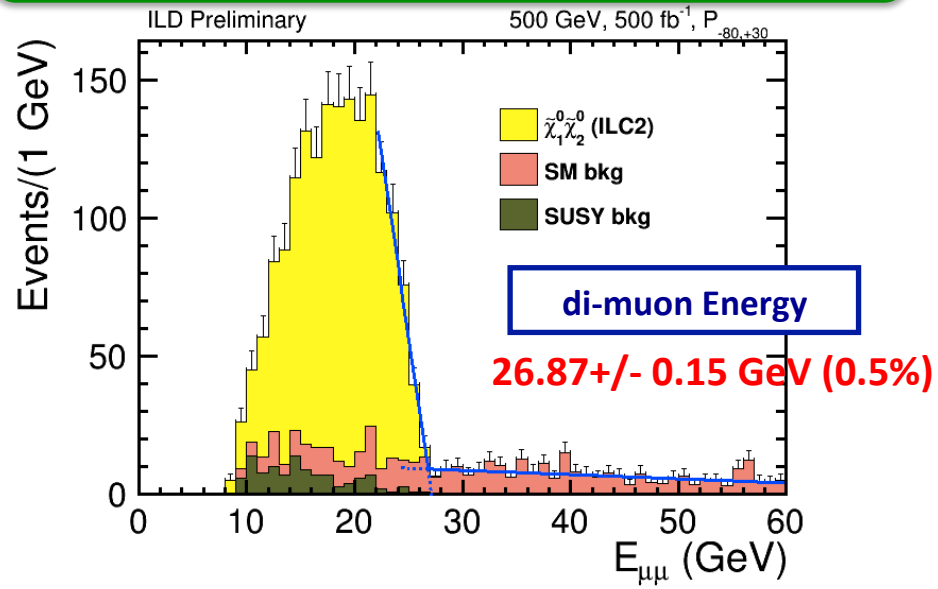
- Use Toy Monte Carlo to obtain mass and cross section precisions

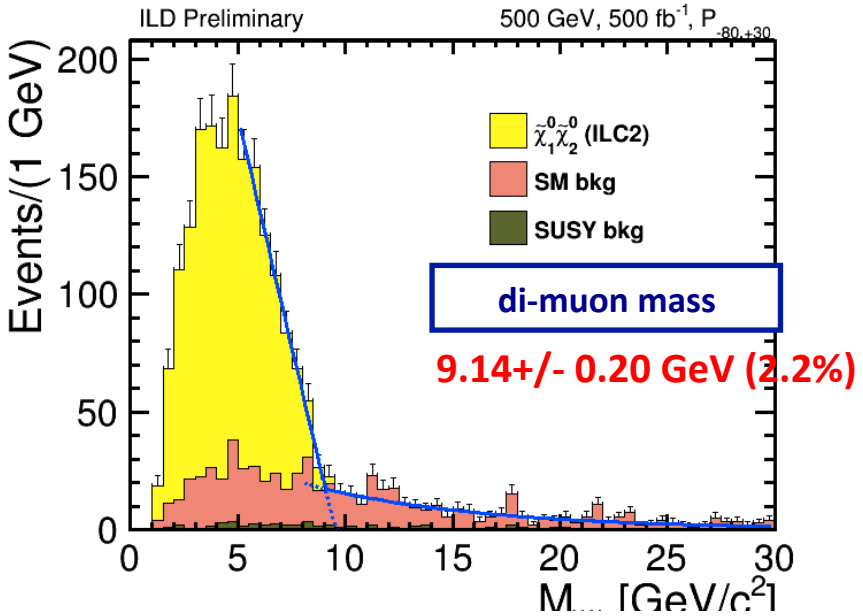
Neutralino mixed production with leptonic decay

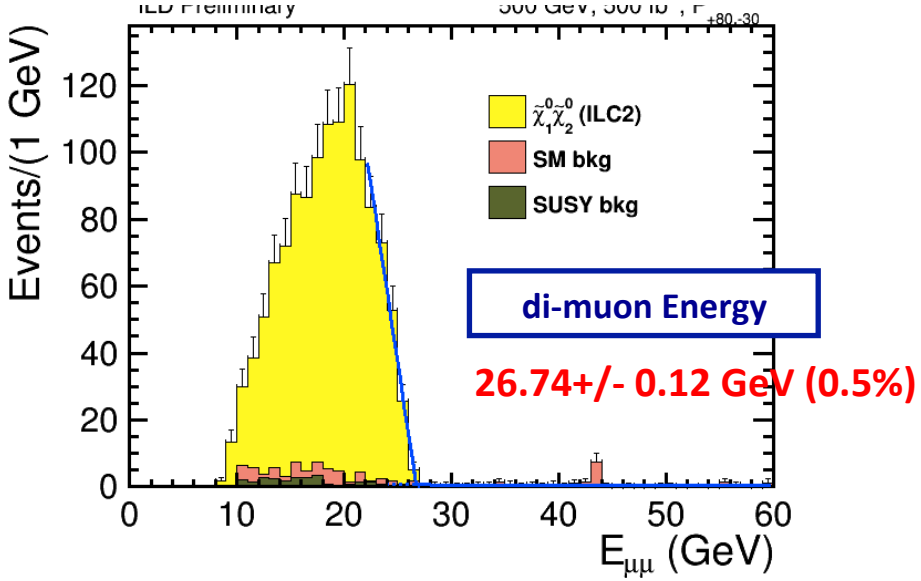
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+\ell^-$$

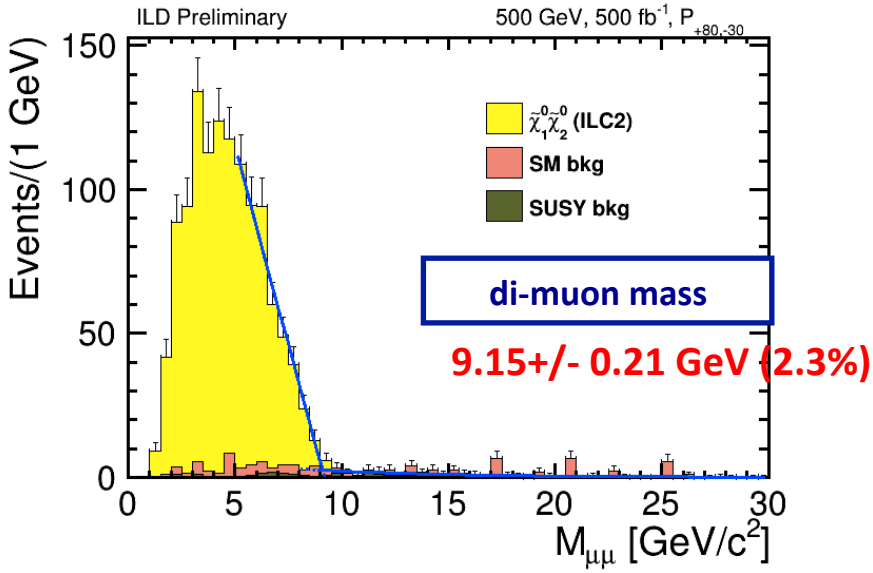
ILC2 mumu, @500fb-1

Edge precisions : 0.5 – 2.5%





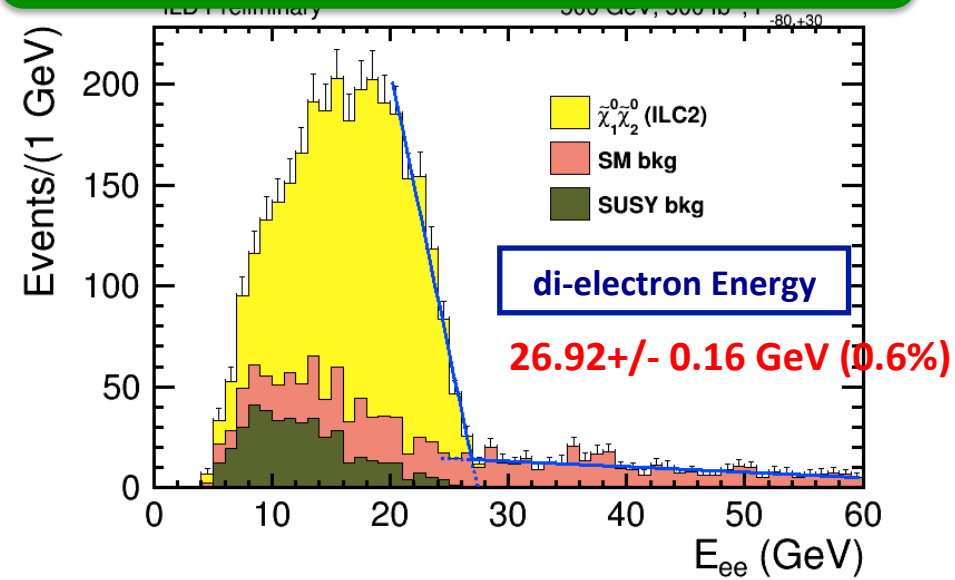




Theoretical values: E_max = 26.9 GeV ΔM = 9.7 GeV

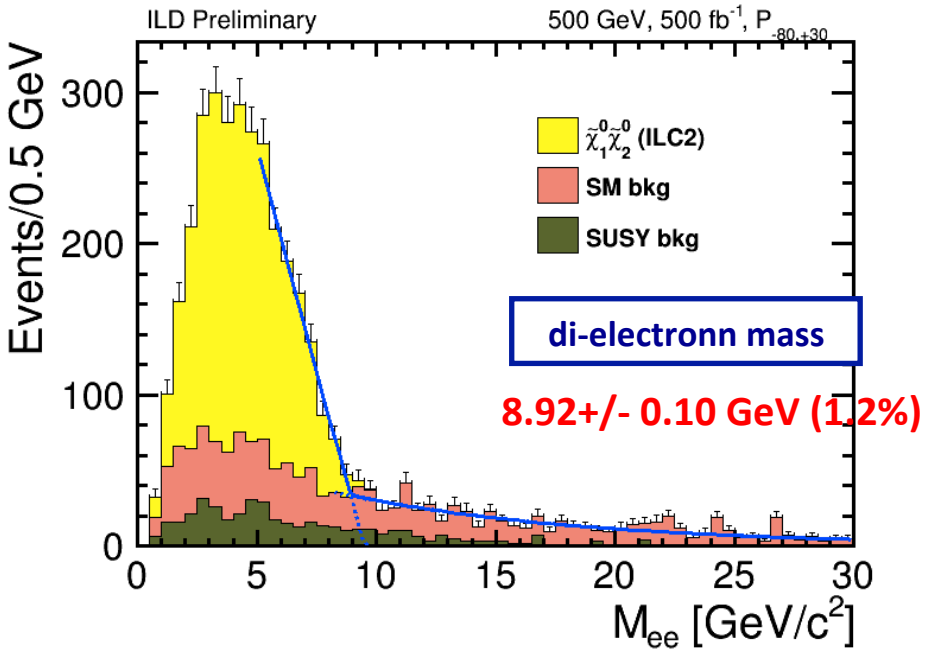
Neutralino mixed production with leptonic decay

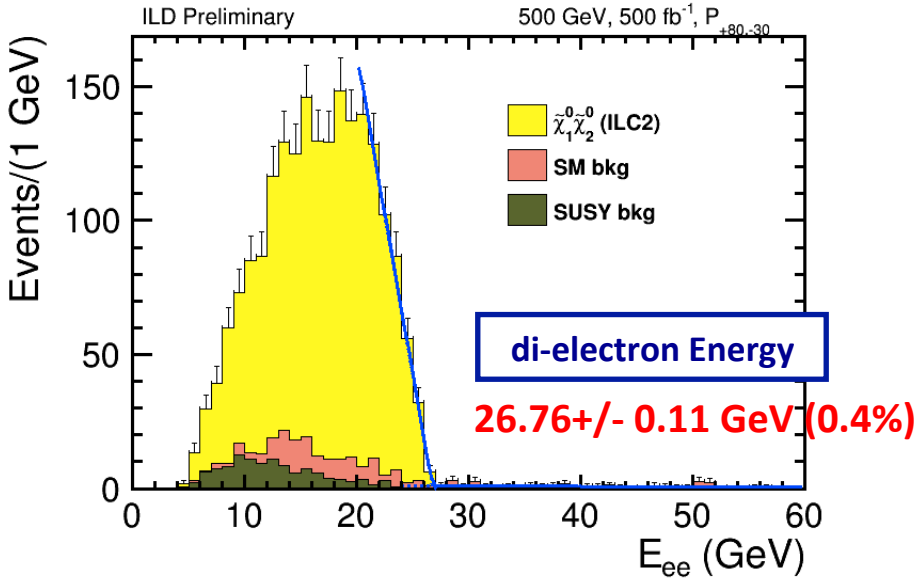
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

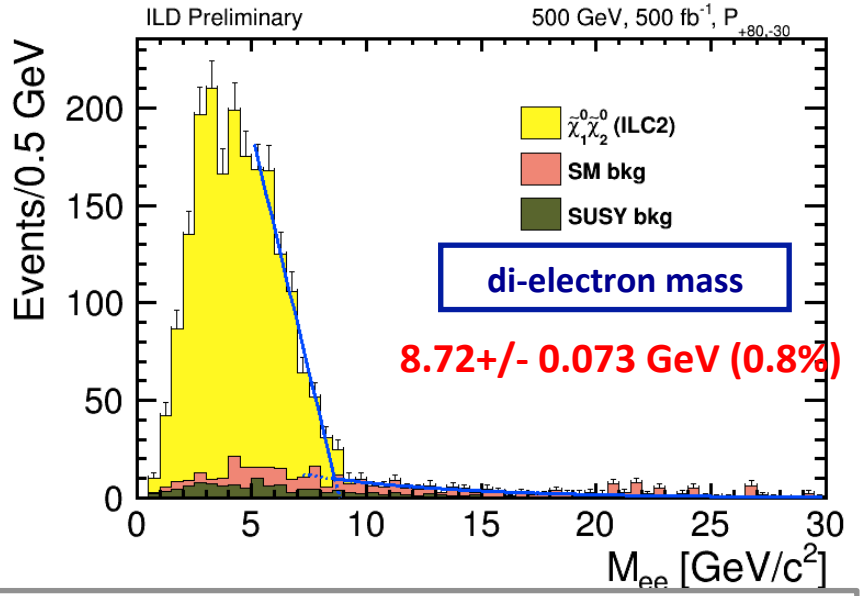


ILC2 ee, @500 fb-1

Edge precisions : 0.5 – 1.5%







Added previously unavailable low M_ee samples

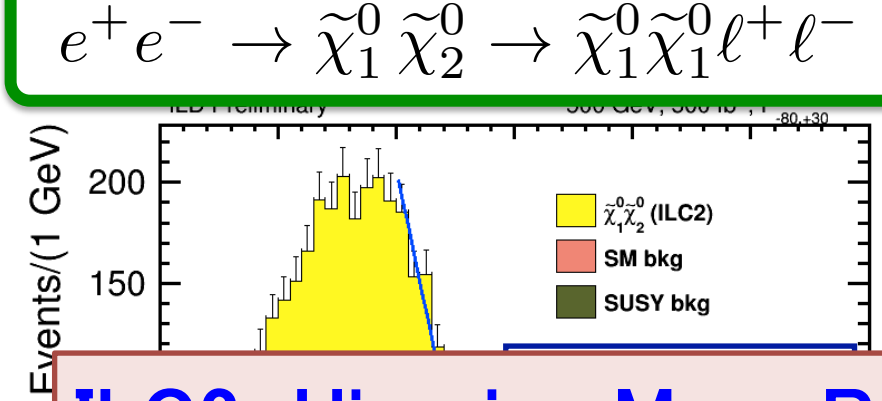
Theoretical values: E_max = 26.9 GeV ΔM = 9.7 GeV

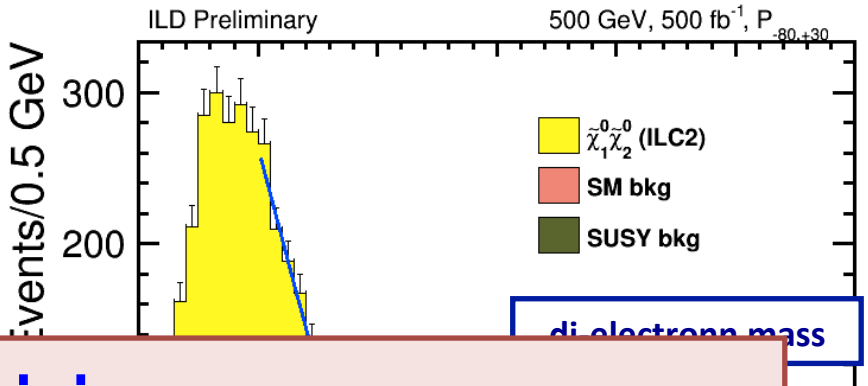
Neutralino mixed production with leptonic decay

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

ILC2 ee, @500 fb-1

Edge precisions : 0.5 – 1.5%





ILC2 Higgsino Mass Precision

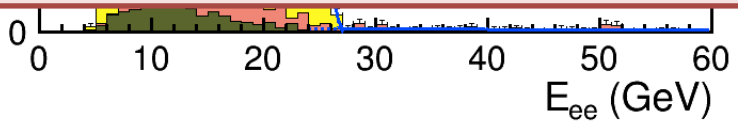
～0.5% (500 fb^{-1}) For each polarization

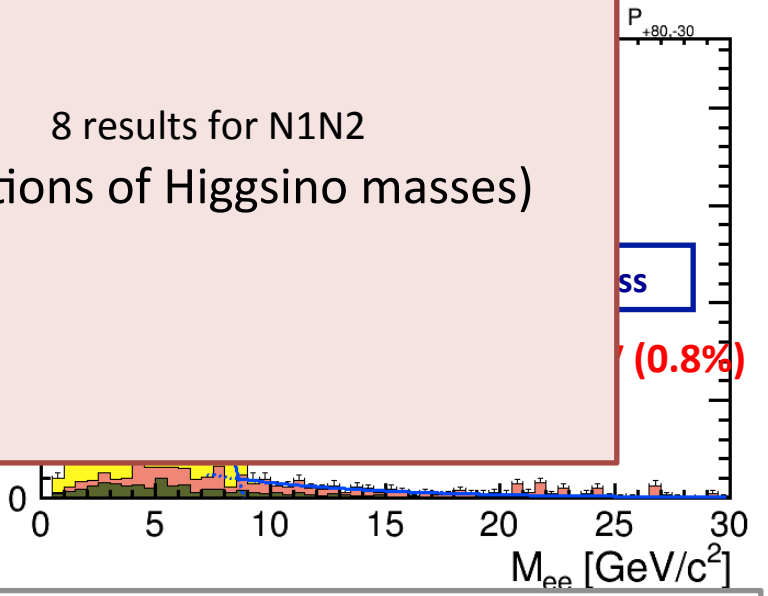
～ 0.3% (H20, 1600 fb^{-1})

apply χ^2 fit to "observables" (kinematic edges) 8 results for N1N2

(Ell_max, Ejj_max, Mll_max, Mjj_max are functions of Higgsino masses)

comparable to ILC1





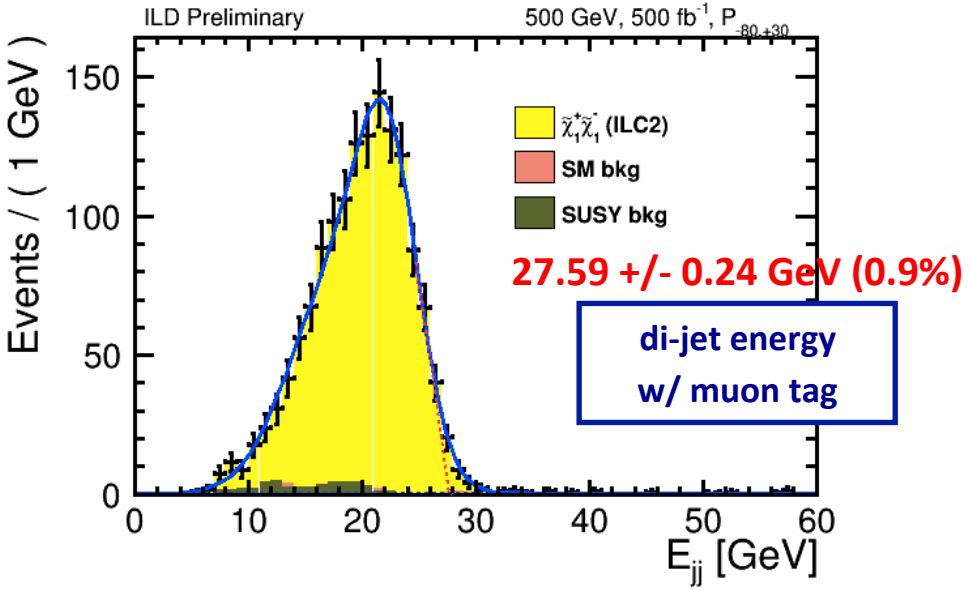
Theoretical values: E_max = 26.9 GeV ΔM = 9.7 GeV

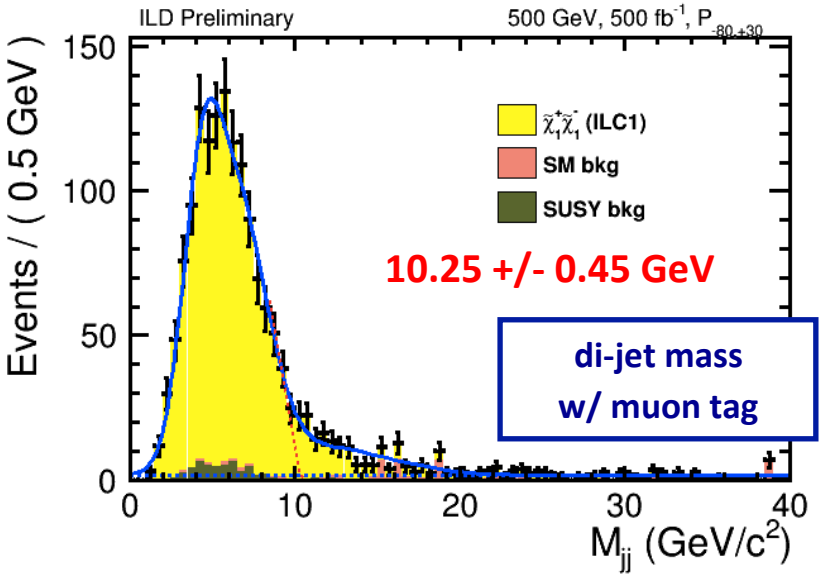
Chargino pair production with semileptonic decay

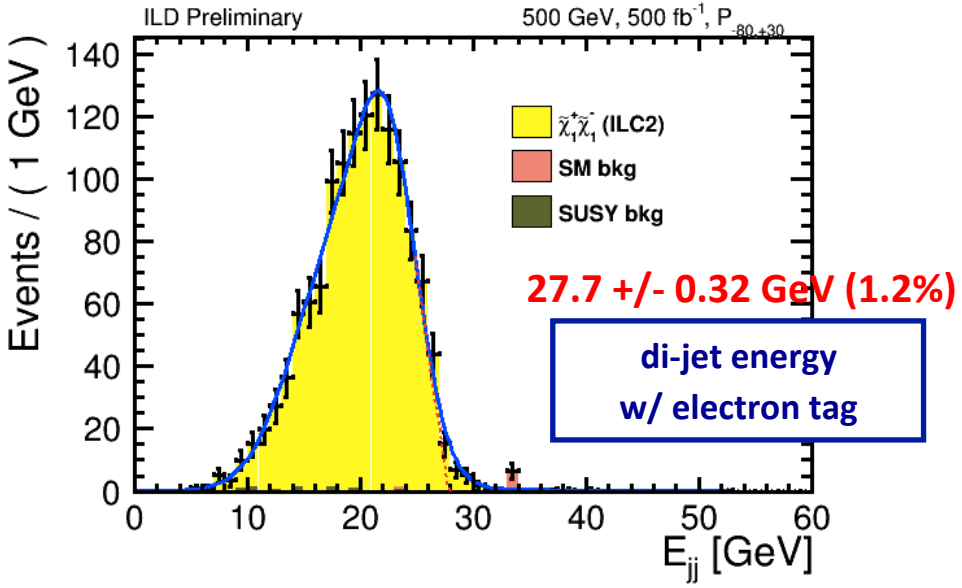
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq'\ell\nu$$

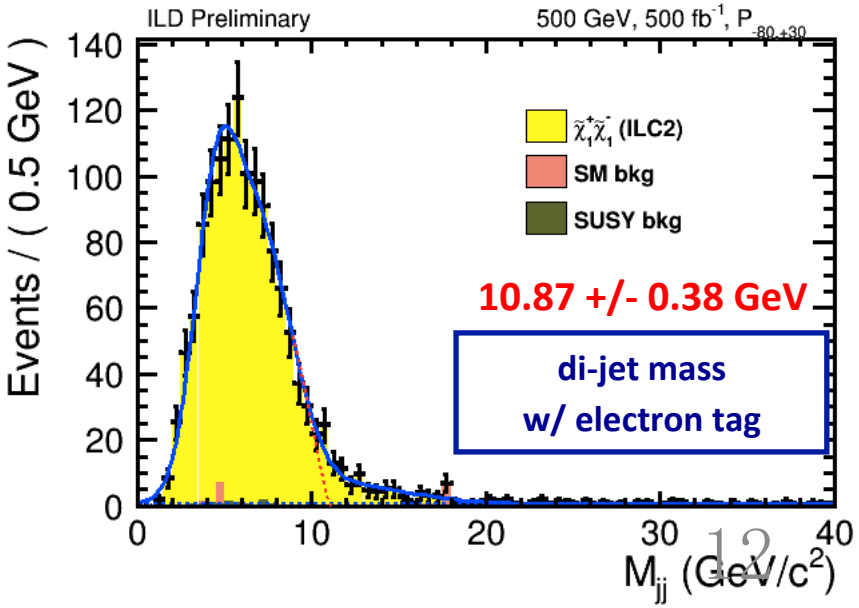
(Pe-,Pe+) = (-0.8, +0.3)
@500 fb-1

Almost all bkg rejected





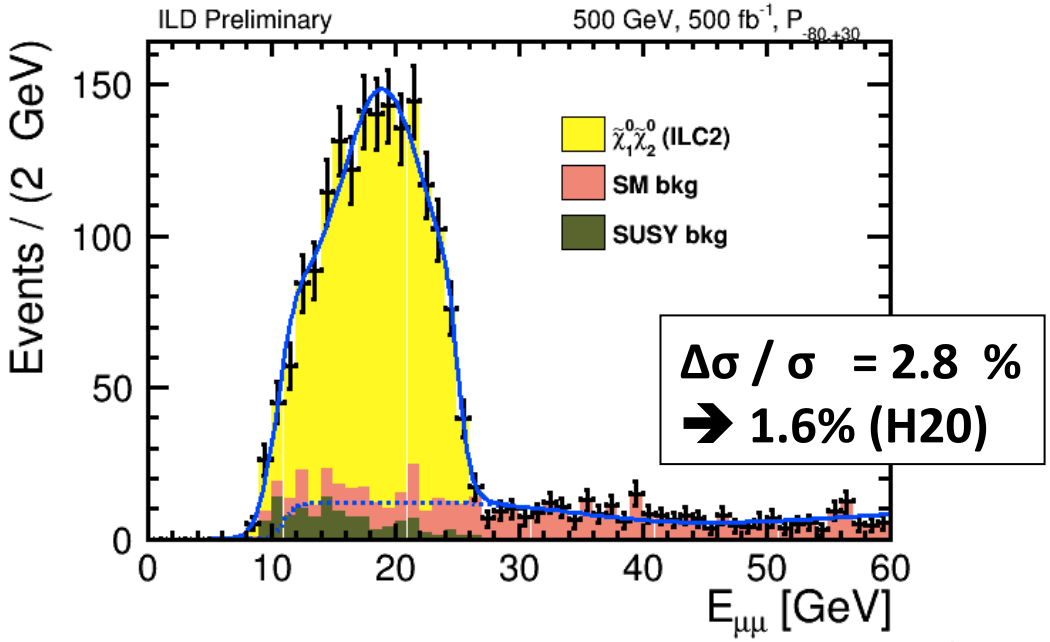




Cross Section Fit

ILC2

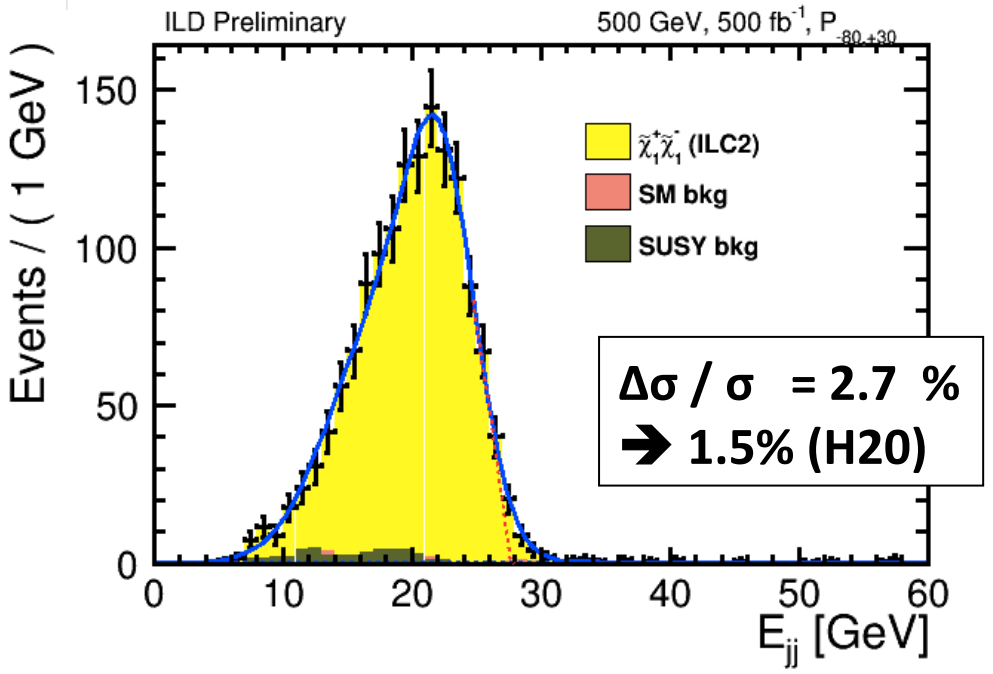
N1N2: di-muon energy



Δσ / σ = 2.8 %
➔ 1.6% (H20)

(Pe-,Pe+) = (-0.8, +0.3)

C1C1: di-jet energy w/ muon tag



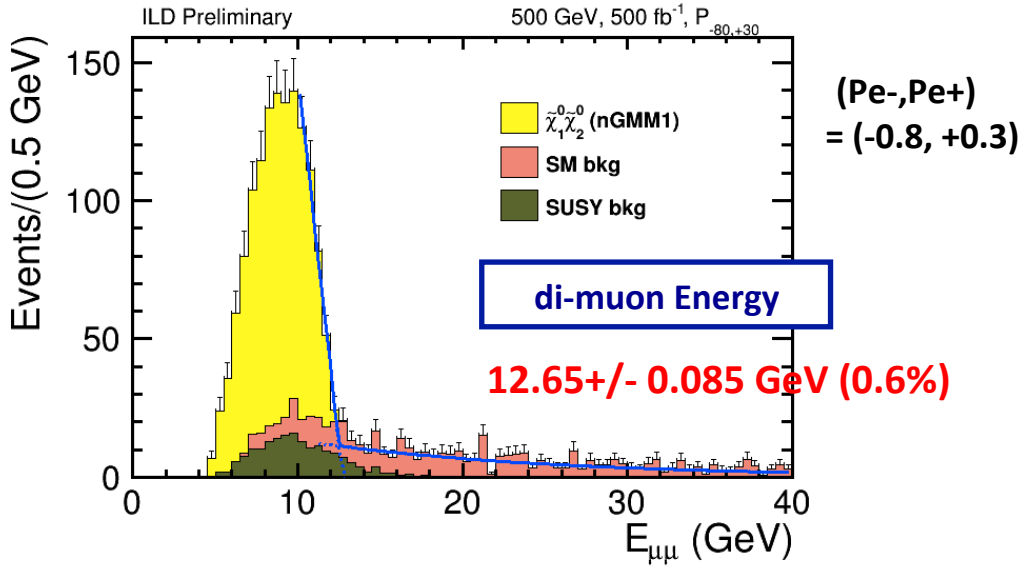
Δσ / σ = 2.7 %
➔ 1.5% (H20)

ILC1 : 1 −1.5% (H20)

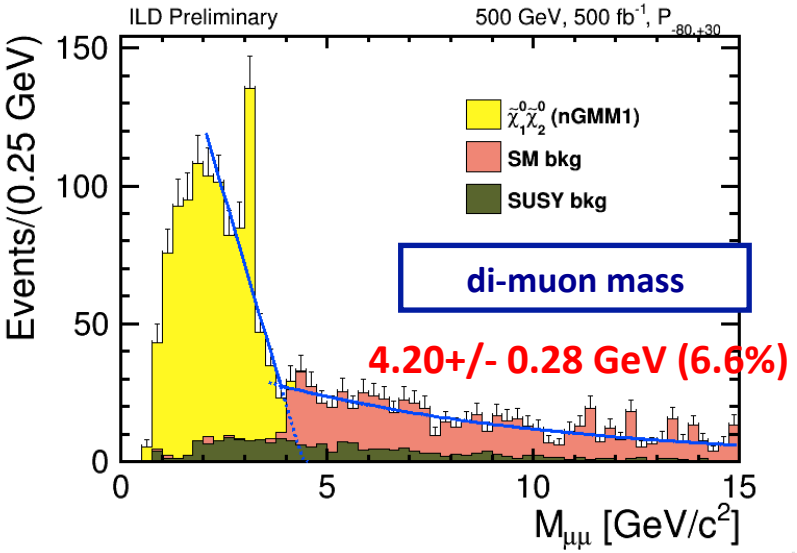
Neutralino mixed production with leptonic decay

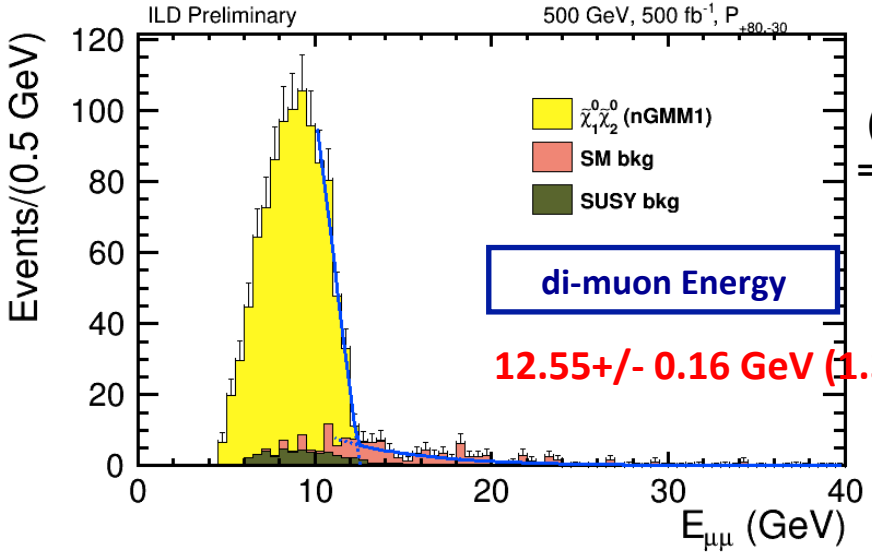
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

Mirage , mumu, @ 500 fb^-1

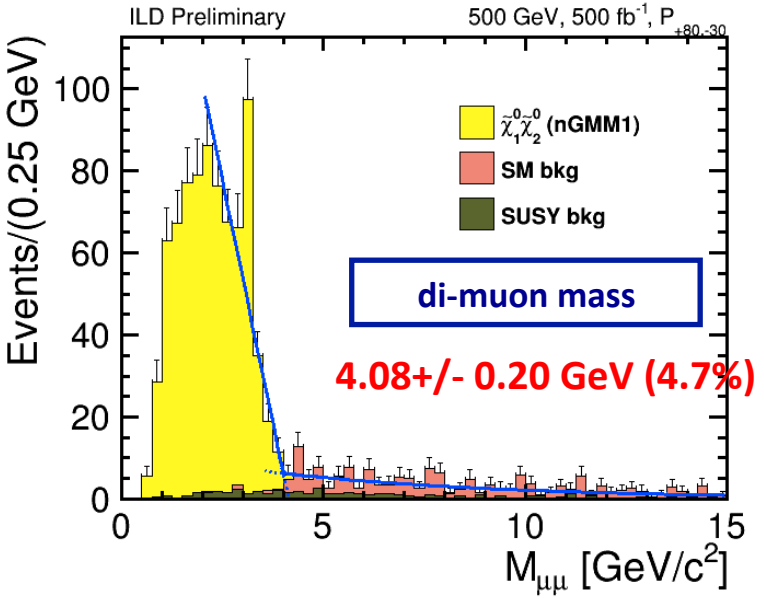


(Pe-,Pe+)
= (-0.8, +0.3)





(Pe-,Pe+)
= (+0.8, -0.3)

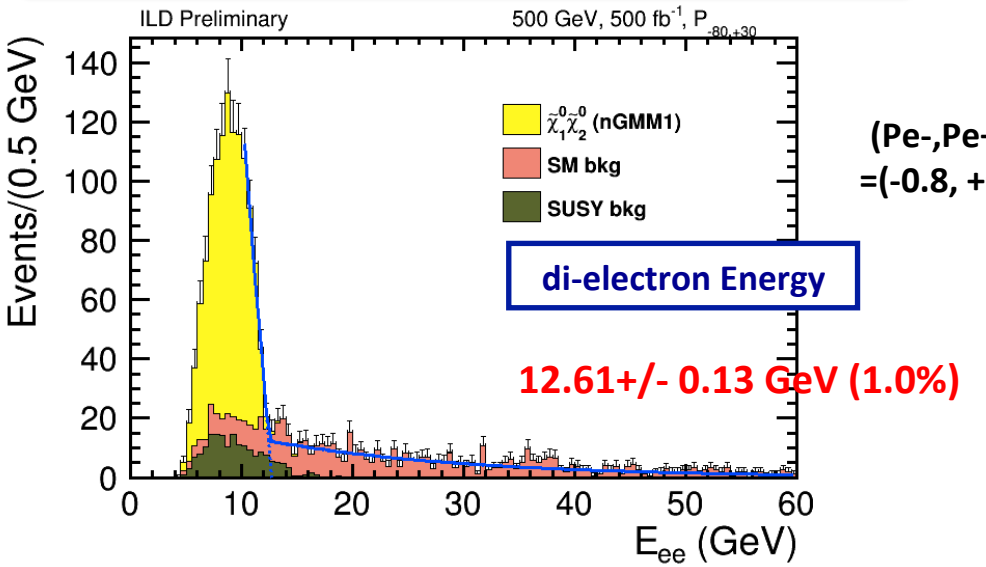


Theoretical values: E_max = 12.5 GeV ΔM = 4.3 GeV

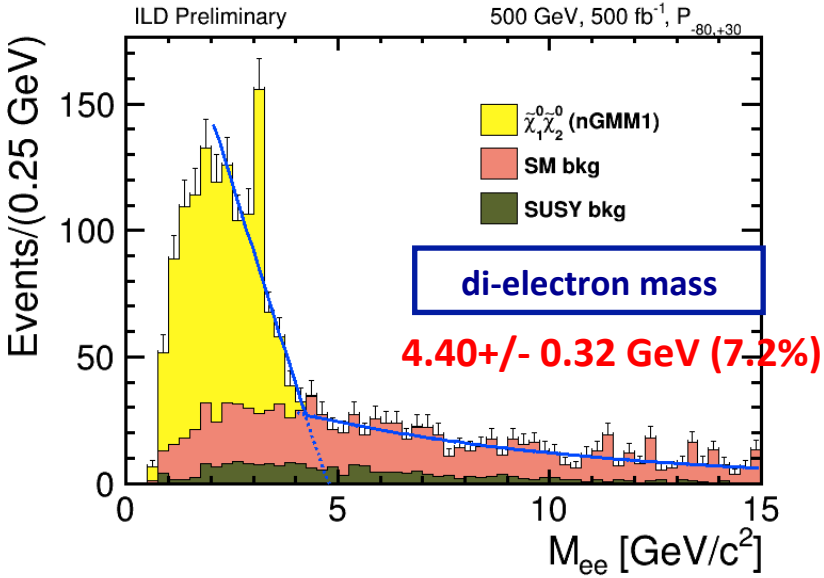
Neutralino mixed production with leptonic decay

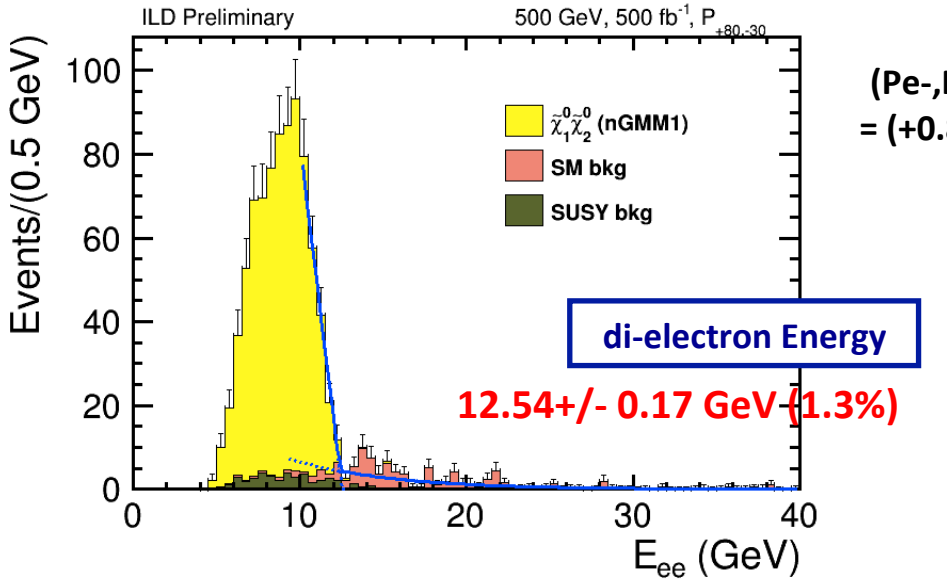
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+\ell^-$$

Mirage , eeu, @ 500 fb^-1

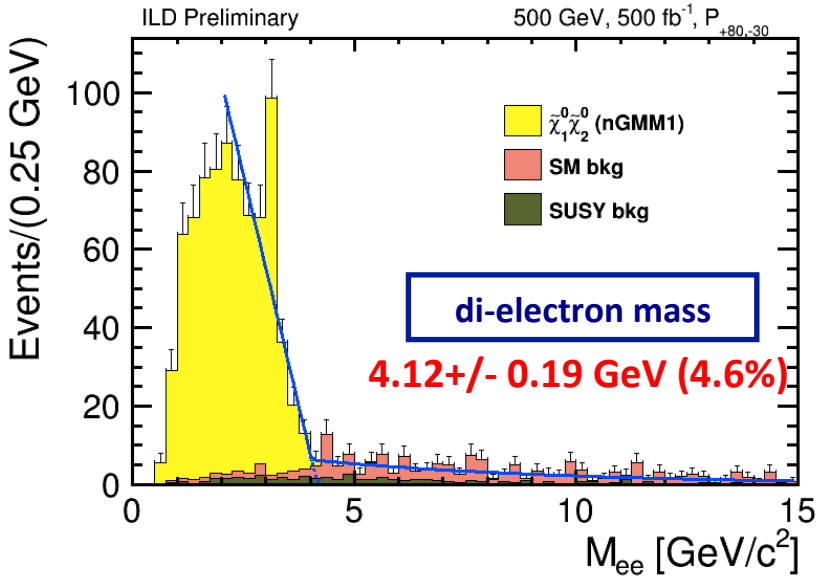


(Pe-,Pe+ =(-0.8, +0.3)





(Pe-,Pe+) = (+0.8, -0.3)



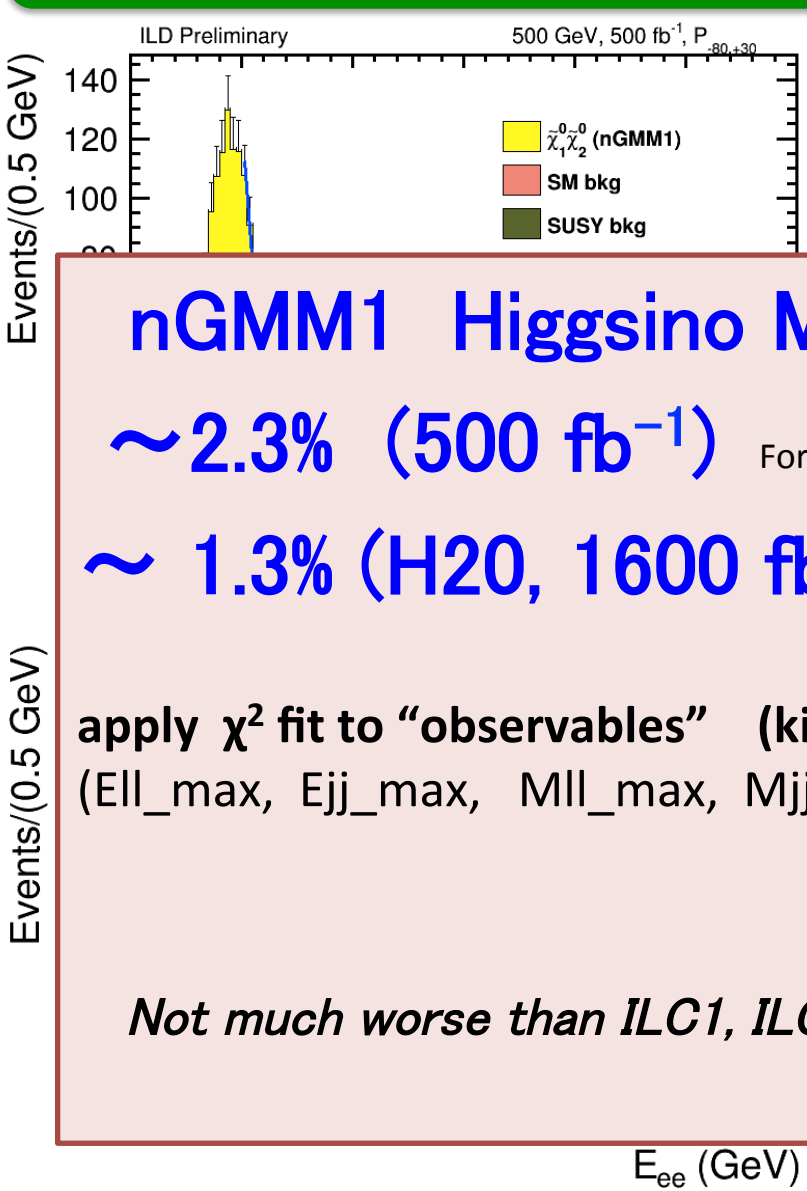
Added previously unavailable low M_ee samples

Theoretical values: E_max = 12.5 GeV ΔM = 4.3 GeV

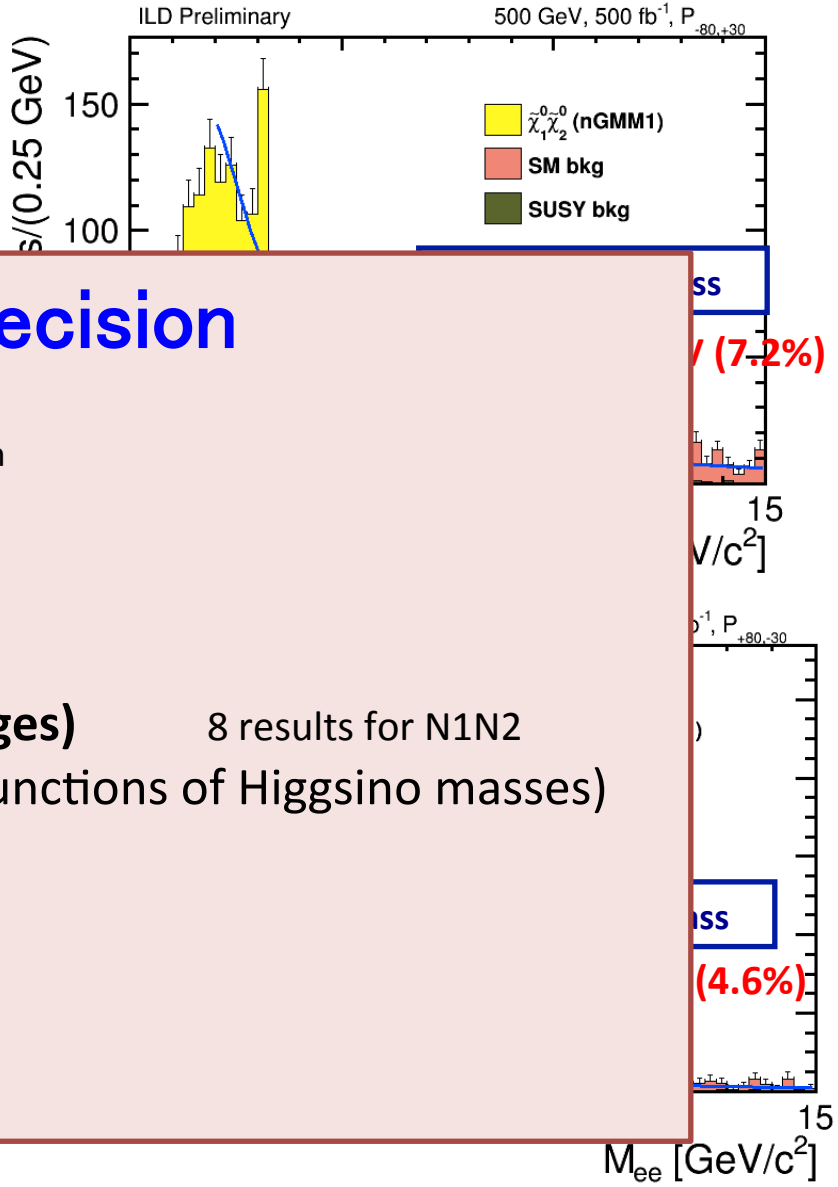
Neutralino mixed production with leptonic decay

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

Mirage , eeu, @ 500 fb^-1



(Pe-,Pe+ =(-0.8, +0.3)



nGMM1 Higgsino Mass Precision

～2.3% (500 fb^{-1}) For each polarization

～ 1.3% (H20, 1600 fb^{-1})

apply χ^2 fit to "observables" (kinematic edges) 8 results for N1N2

(Ell_max, Ejj_max, Mll_max, Mjj_max are functions of Higgsino masses)

Not much worse than ILC1, ILC2

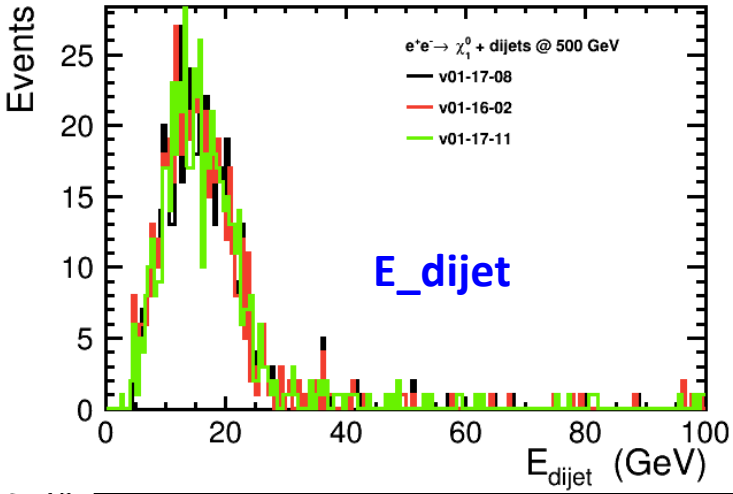
Theoretical values: E_max = 12.5 GeV ΔM = 4.3 GeV

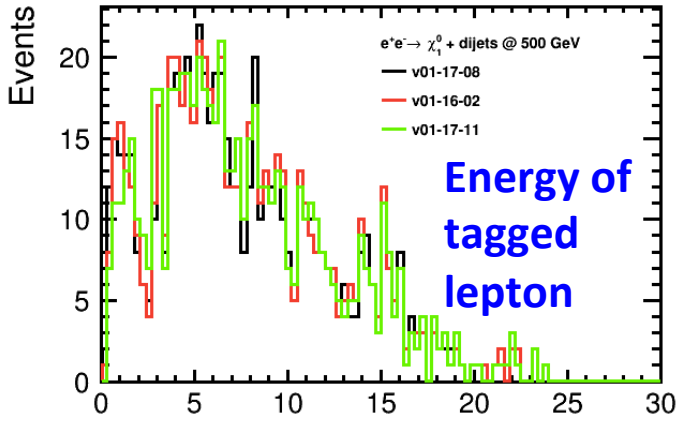
Marlin reconstruction using different ILCSoft Versions (jet variables)

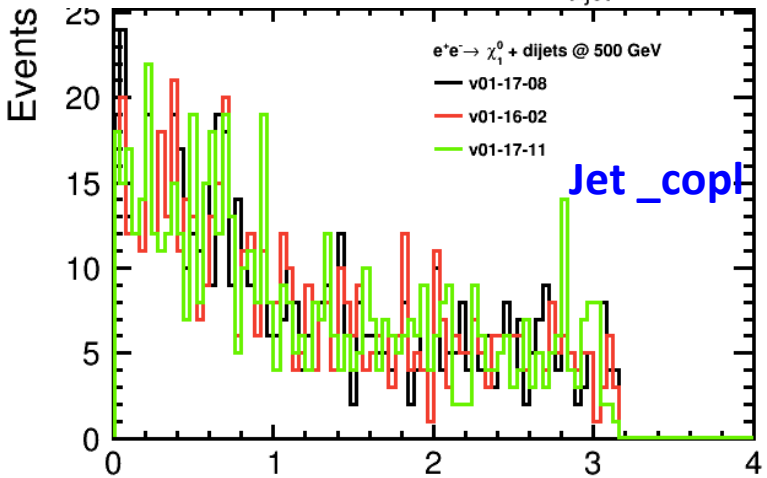
Semileptonic events, μ-tagged

v01-16-02, the original v01-17-08, v01-17-11 no overlay bkg included

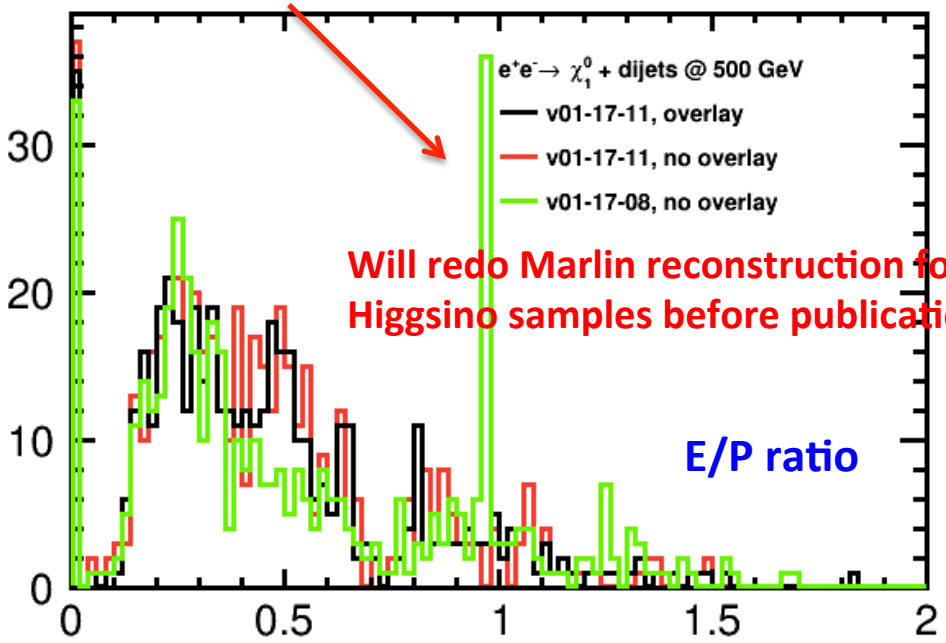
- no huge big difference in variables of jets (e.g. E_dijet, coplanarity) or tagged leptons (E_lepton)







Discovered bug in muon ID of v01-17-08



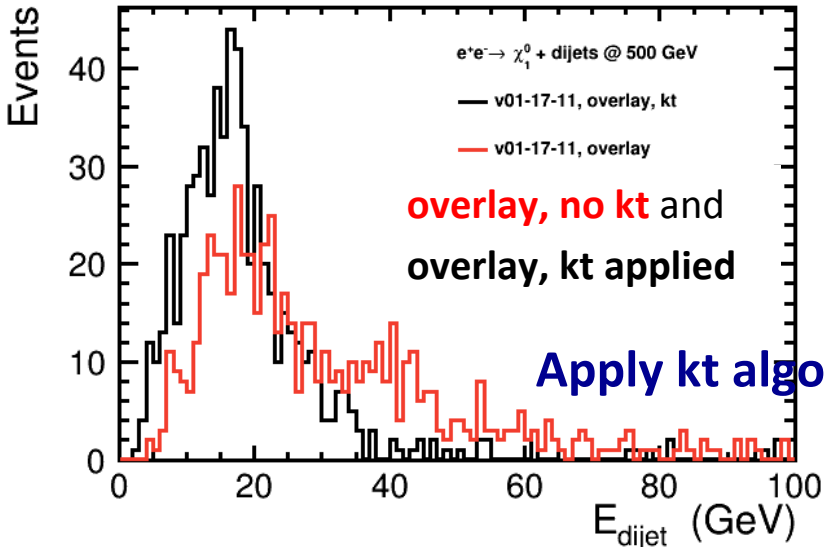
Will redo Marlin reconstruction for all Higgsino samples before publication

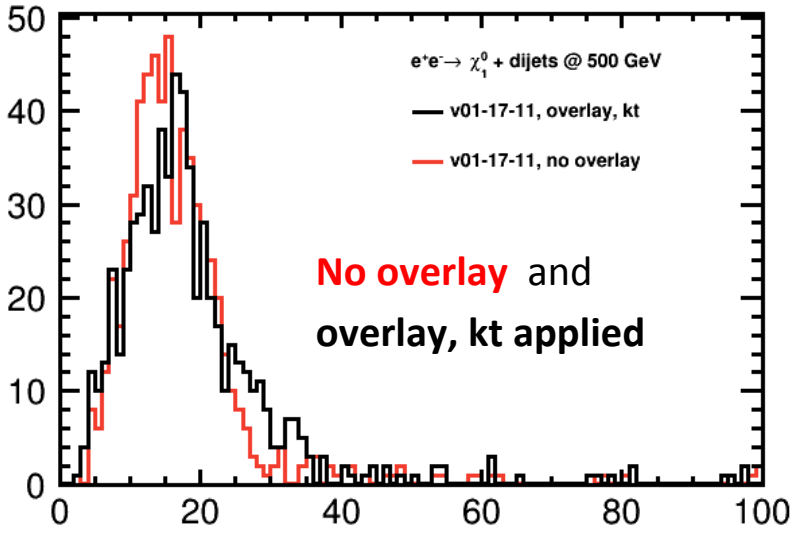
Can expect improved precision in muon channels

Issue of gamma gamma → low Pt hadrons ("overlay BKG")

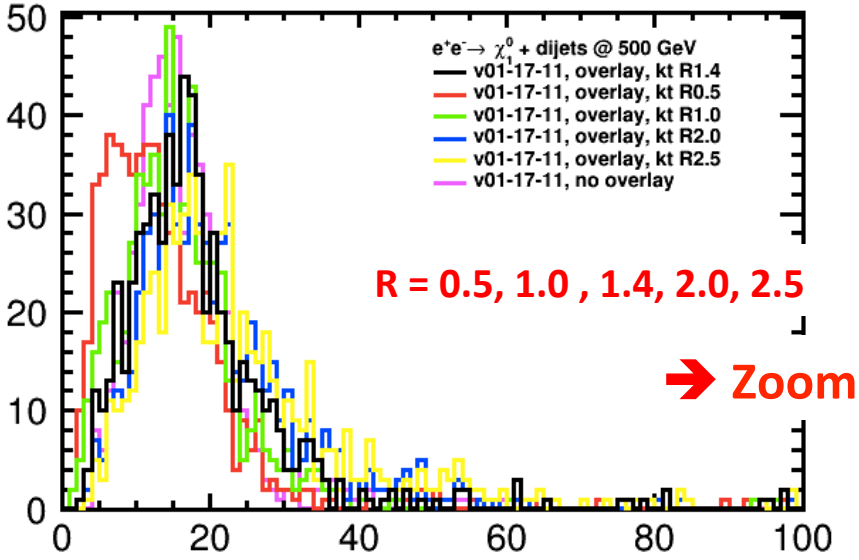
Edijet (mu tagged semileptonic), ILC2
(Marlin Reco with v01-17-11)

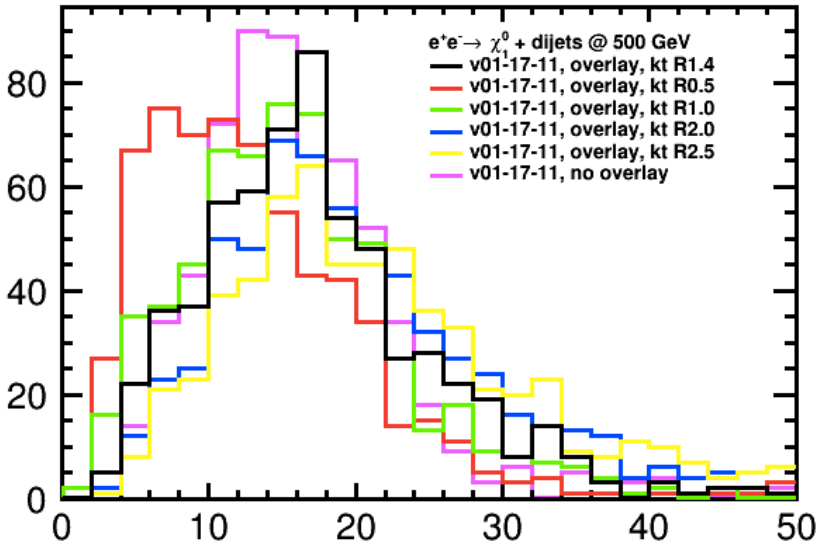
- SM bkg has overlay : eventually, need to investigate if conservative





- **Recovery seems optimistic, R = 1.0 seems to recover peak and higher tail the best**





Summary for Light Higgsino Study

Goal: evaluate measurement precision of masses and cross sections of light Higgsinos with small ΔM (from ～20 GeV down to ～ 5 GeV) at ILC √s = 500 GeV

- Motivated by both experiment (complementary to LHC) and theory (naturalness)

This analysis: **neutralino mixed production ($\chi_1^0\chi_2^0$)** and **chargino pair production ($\chi_1^+\chi_1^-$)**

Full ILD detector simulation, (Pe-, Pe+) = (-0.8,+0.3), (+0.8, -0.3)

- results become **input to SUSY parameter determination**

Since last General Meeting, made **progress in analysis of benchmarks with smaller ΔM**

some channels still in progress

- ILC2 (ΔM～10GeV) : able to obtain similar precisions as ILC1
- nGMM1 (ΔM <～ 5 GeV) : also better than a few %

Currently obtained statistical precisions: **Assuming H20**

- Mass : < ～ 0.5% (ILC1, ILC2) <～1.5% (nGMM1)
- Cross section : 1-1.5% (ILC1, ILC2)

Plans

- redo Marlin Reco (and all analysis) with v01-17-11

- Finish/finalized analysis for all benchmarks
  ➔ move towards publication of a **paper including all 3 benchmarks**
  theory, analysis, and SUSY parameter extraction

- study deviation of central value of Higgsino masses from "truth"
  effect of **jet energy resolution,** possibly identify and remove ISR from jets

- Study potential for treating overlay bkg
- Study low pt tracking tools in new ILCSoft → improve **lepton tagging efficiency**

- **Light Higgsino analysis at lower ECM (250 GeV)**

Thank you for listening