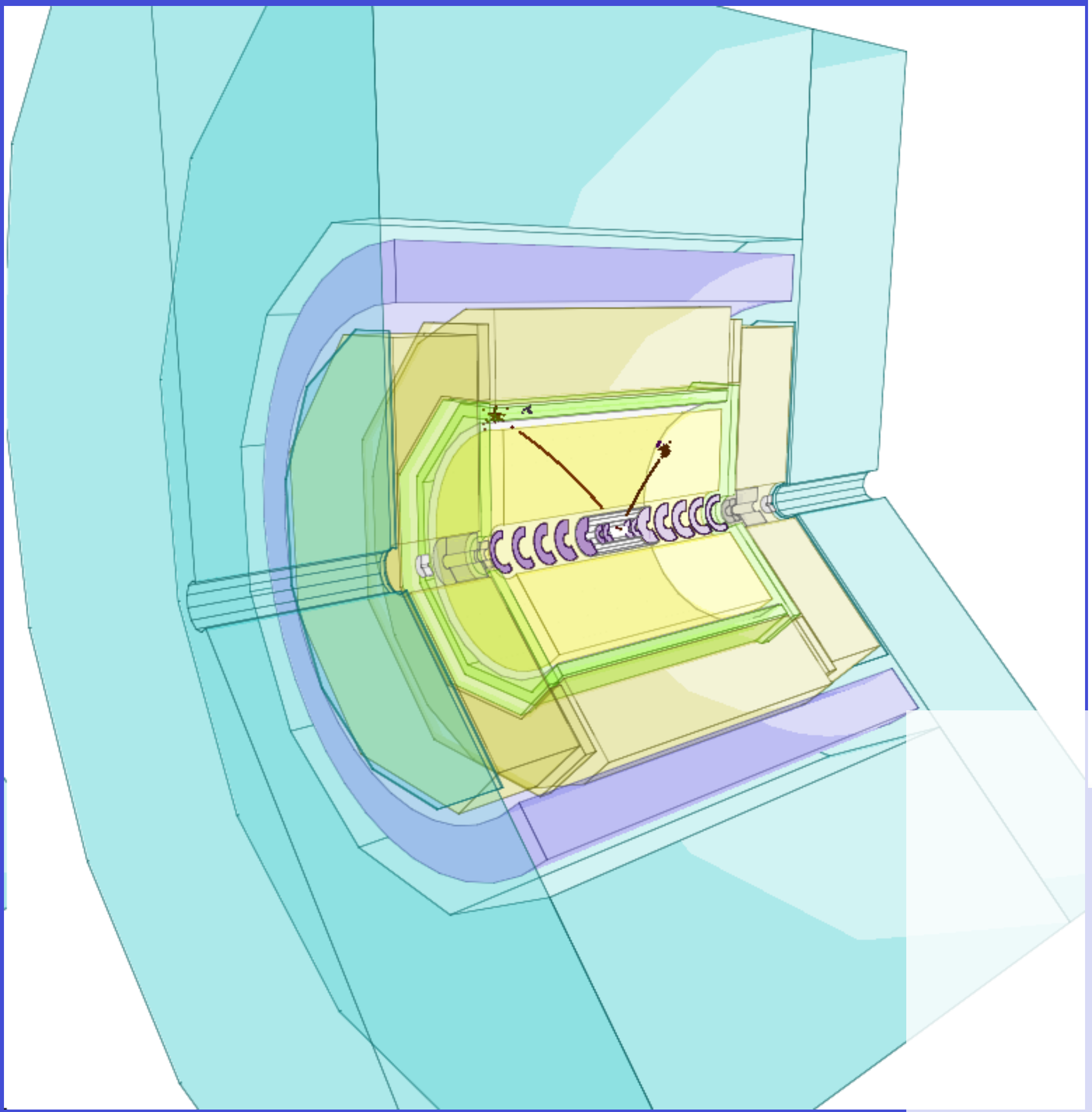
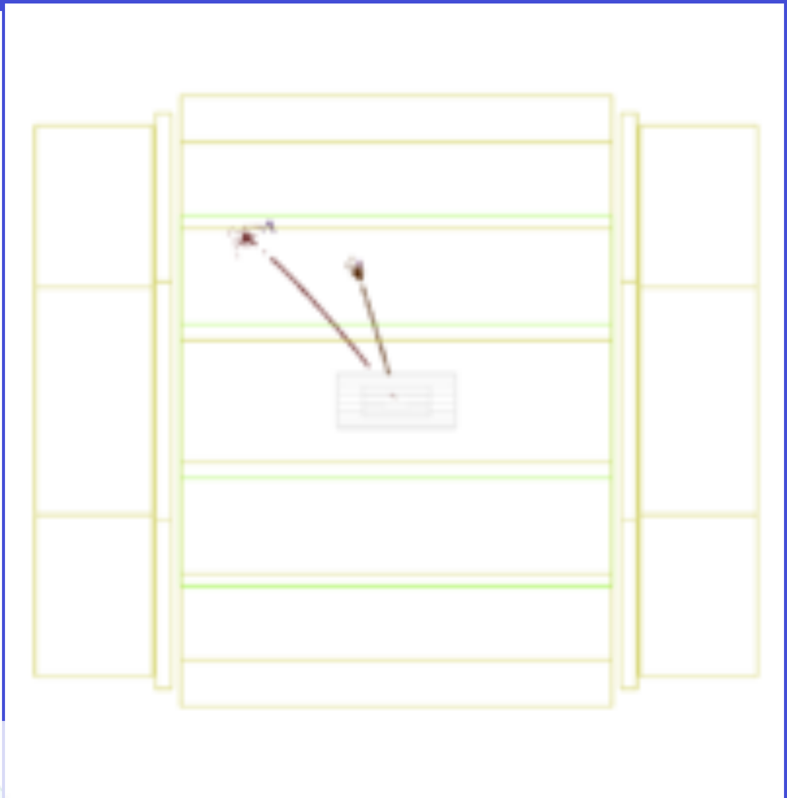
Characterizing Light Higgsinos from Natural SUSY at ILC $\sqrt{s}$ = 500 GeV





Jacqueline Yan (KEK)

Friday Meeting

8/19/2016

Outline

- **Update on edge and xsec extraction**
  - **now using new full sim samples**
  - **Extracted kinematic edge and cross section for just about all channels , both polarizations**
- **calculated propagation of uncertainty of observables to Higgsino mass**
- **Plans**

Extraction of Higgsino Mass

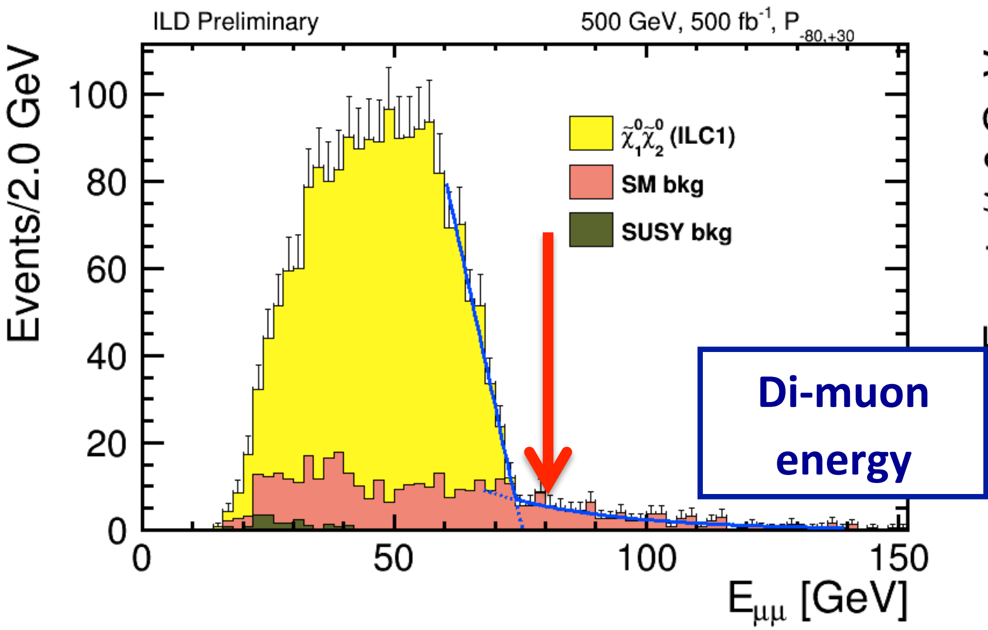
Almost done

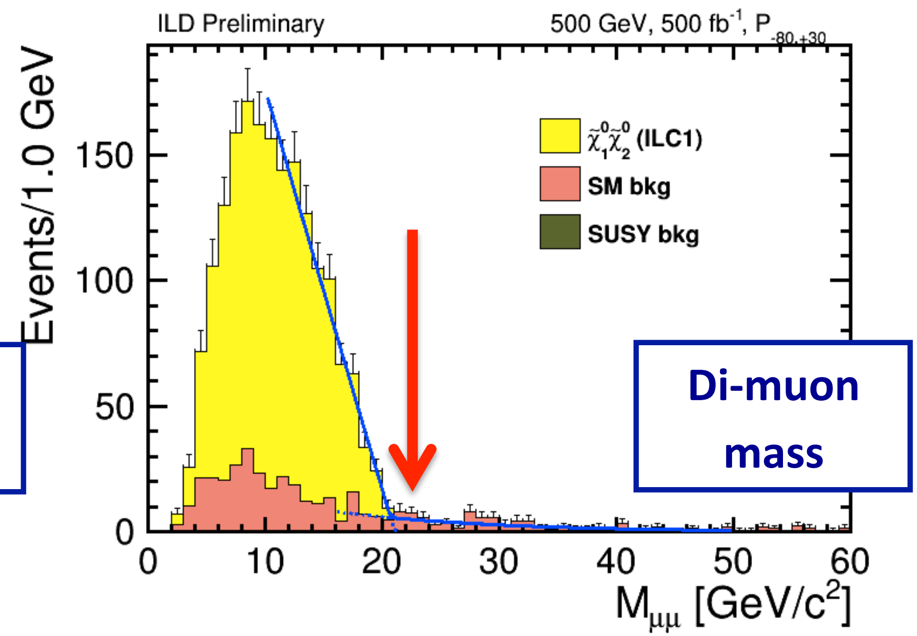
Neutralino mixed production with leptonic decay

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

- The position of the kinematic edges of the dilepton energy (E_{ll}) and invariant mass (M_{ll}) are functions of CM energy and the two neutralino masses.
- The maximum values $E_{ll,max}$ and $M_{ll,max}$ are extracted by a fit to obtain the neutralino masses after correcting for detector/reconstruction effects`

Similar for case of chargino pair production (ll → jj)





Edge precision ∼ 1 %

Cuts have been designed so as not to destroy upper edge

- Use toy MC (generated from MC data fit) to evaluate statistical uncertainty
- Making progress in kinematic edge extraction

Edge extraction

What has been changed since last time (July 13)

Optimized method for extraction of edge and cross section

- **Modeling of complex signal and bkg distributions (energy , invariant mass)**
- **Bin width, fitting range**

Still fine tuning in aim of better precision

e.g. Loosen cuts for edge extraction, tighter cuts for cross section extraction (?)

Now using full simulation bkg samples

(thanks to Miyamoto-san and others in the software group)

Took a while to check the samples and interpret difference between SGV

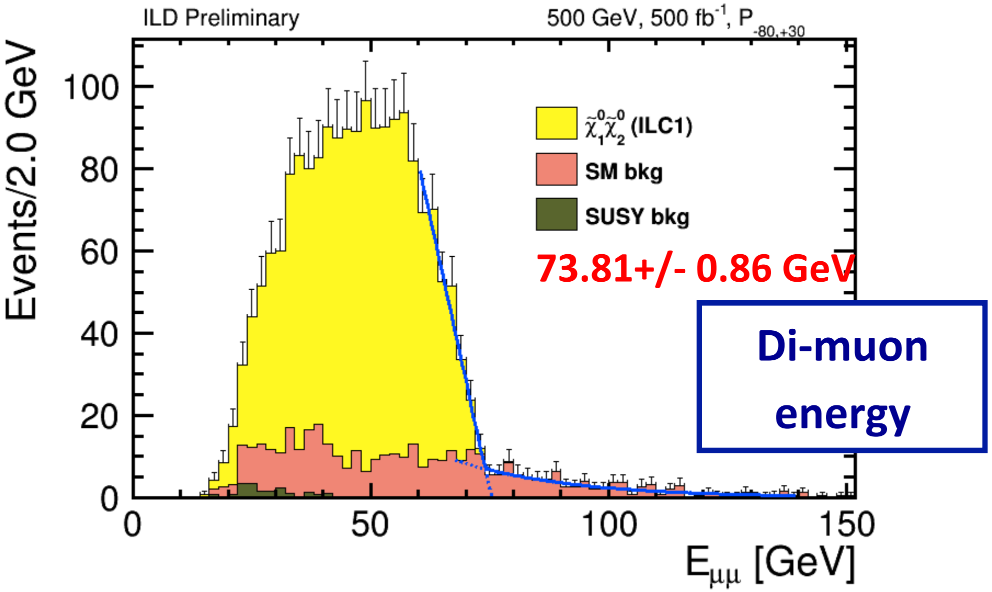
Analysis has been done for right-handed polarization as well.

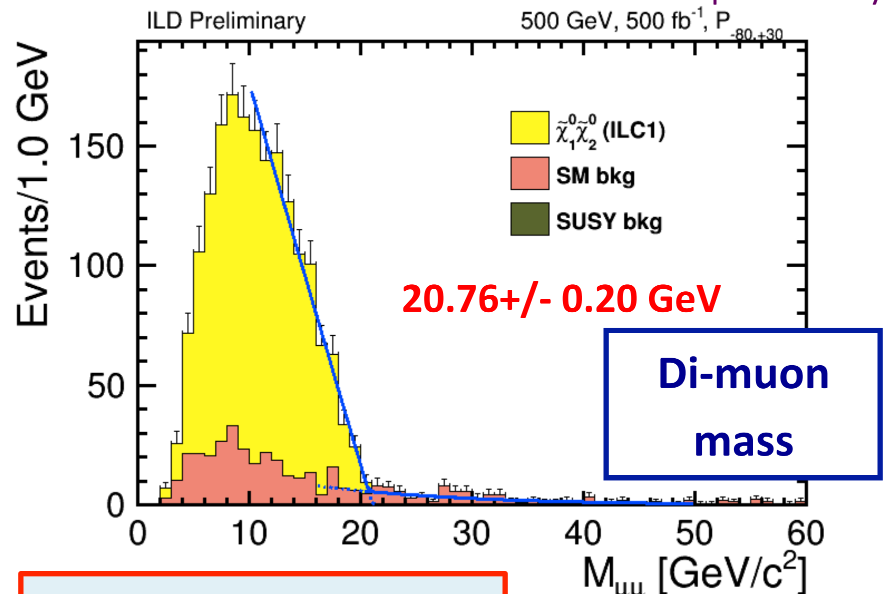
Neutralino mixed production with leptonic decay

$$e^+e^- \rightarrow \widetilde{\chi}_1^0\,\widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0\widetilde{\chi}_1^0\ell^+\ell^-$$

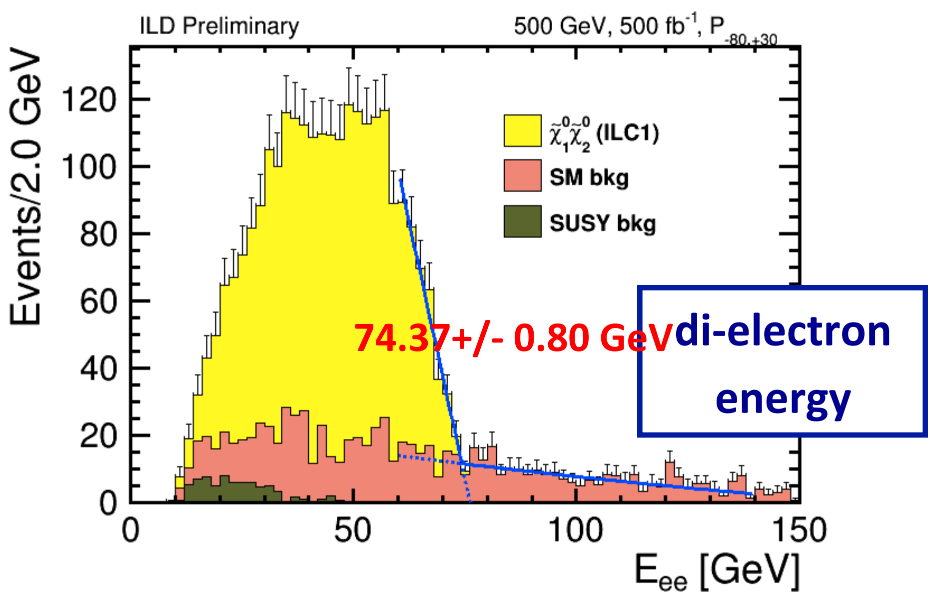
Polarization (Pe-,Pe+) = (-0.8, +0.3)

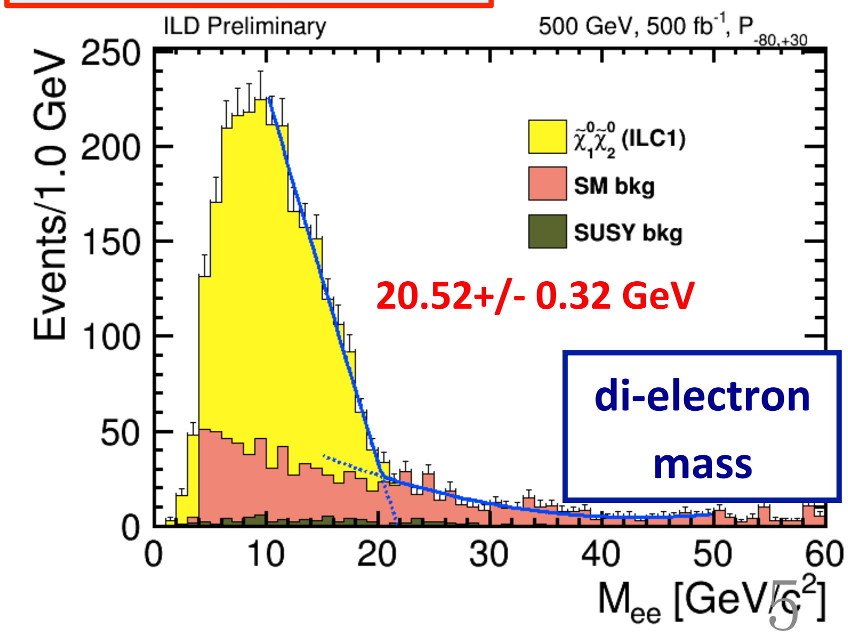
preliminary





Edge precision ～ 1 %



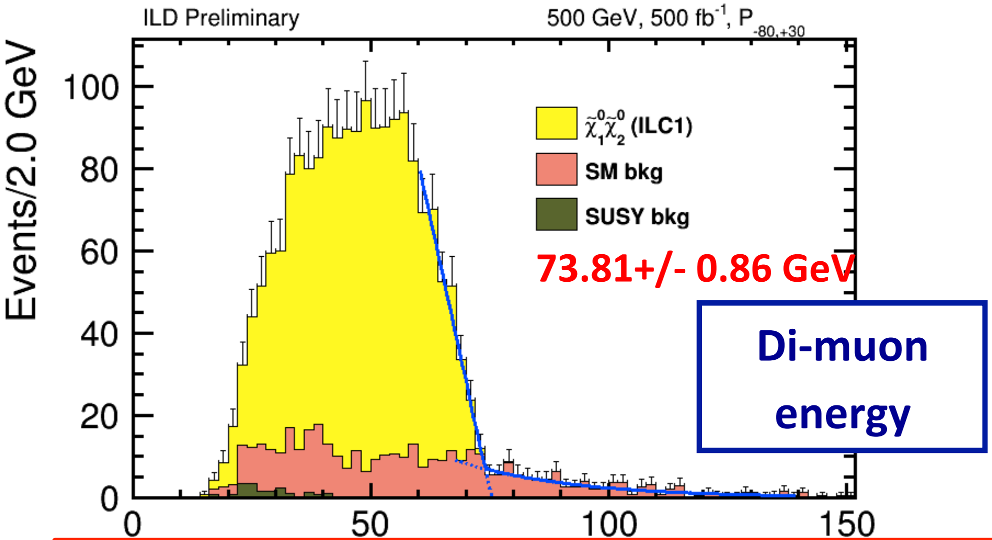


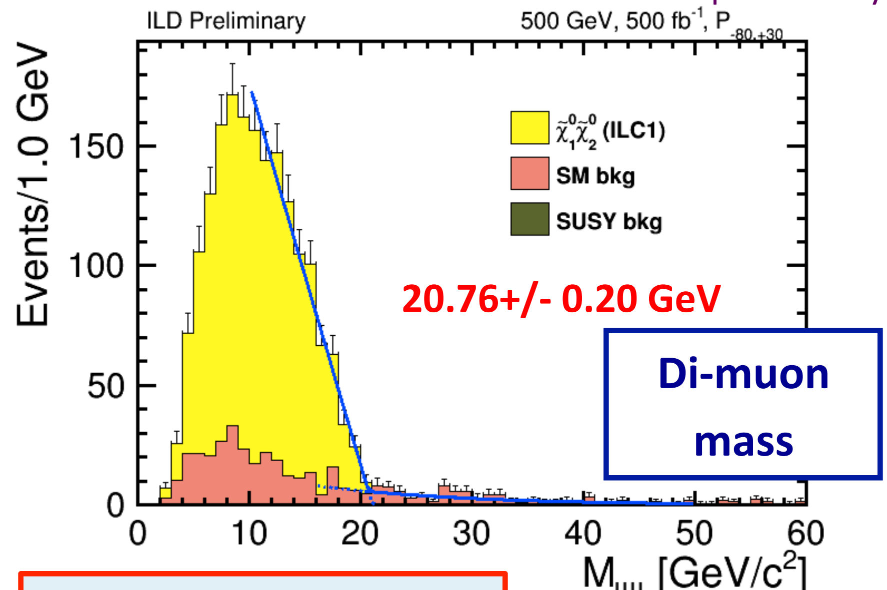
Neutralino mixed production with leptonic decay

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

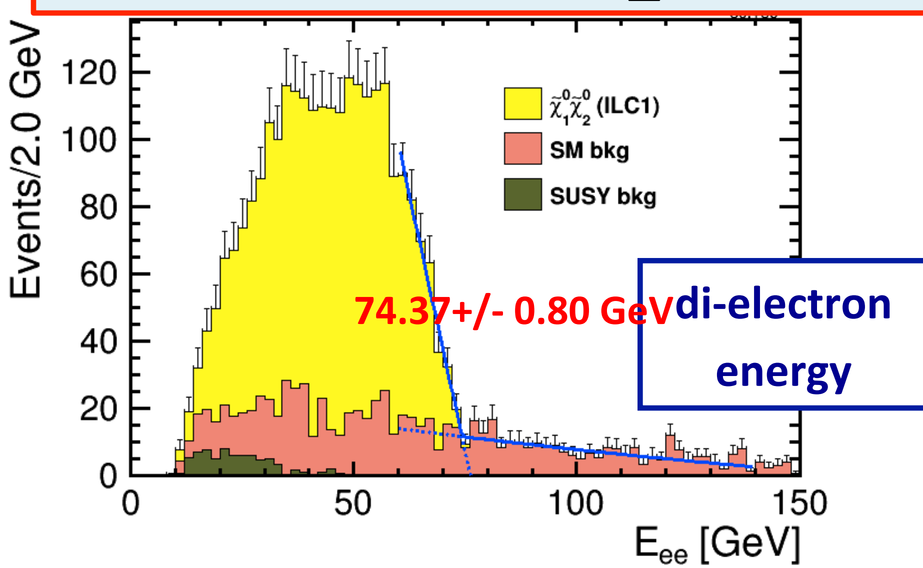
Polarization (Pe-,Pe+) = (-0.8, +0.3)

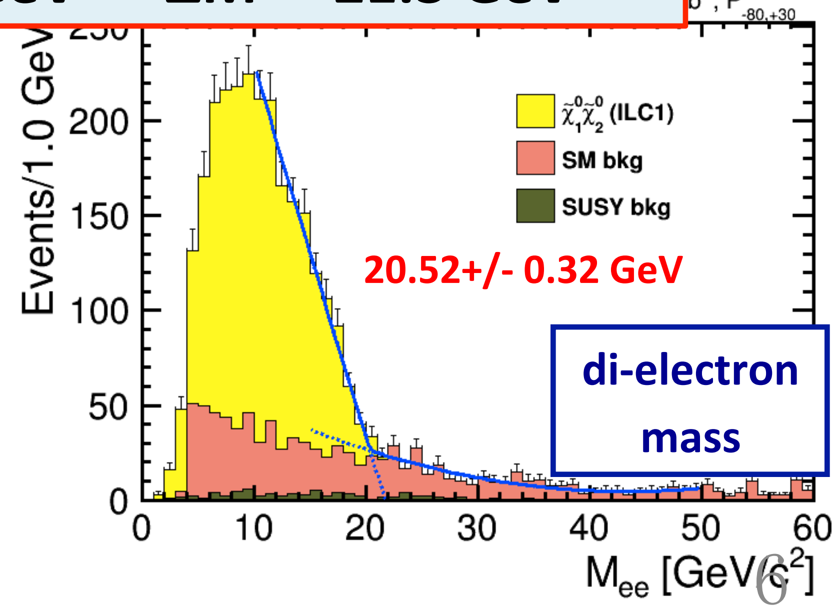
preliminary





Theoretical values: E_max = 74.9 GeV ΔM = 21.3 GeV

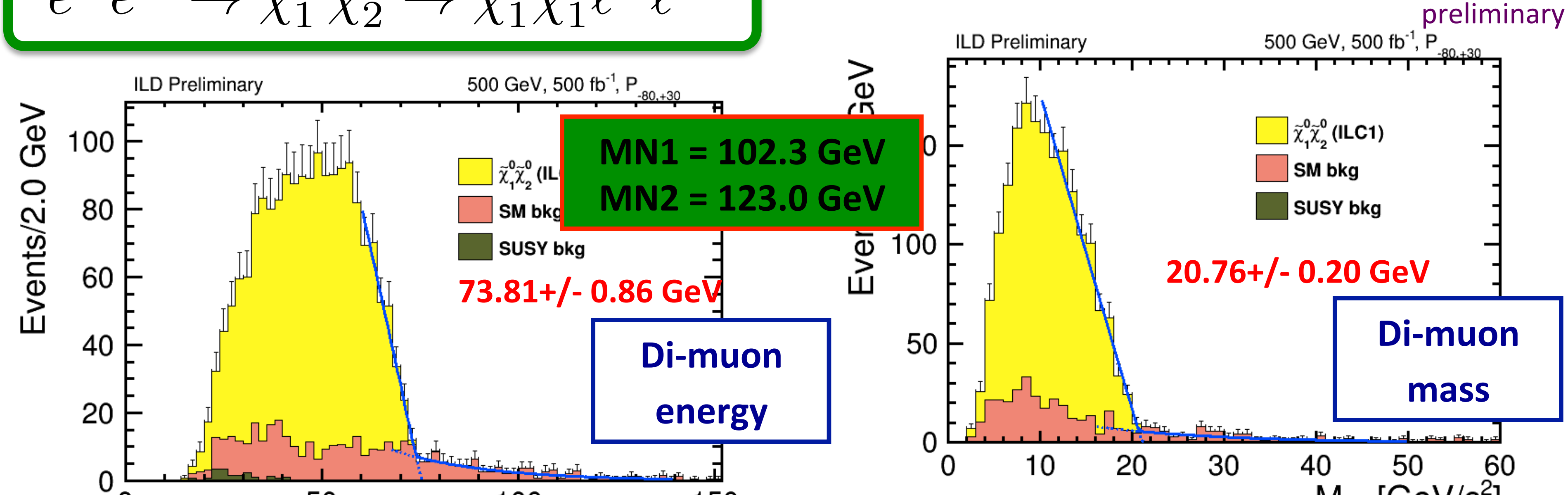




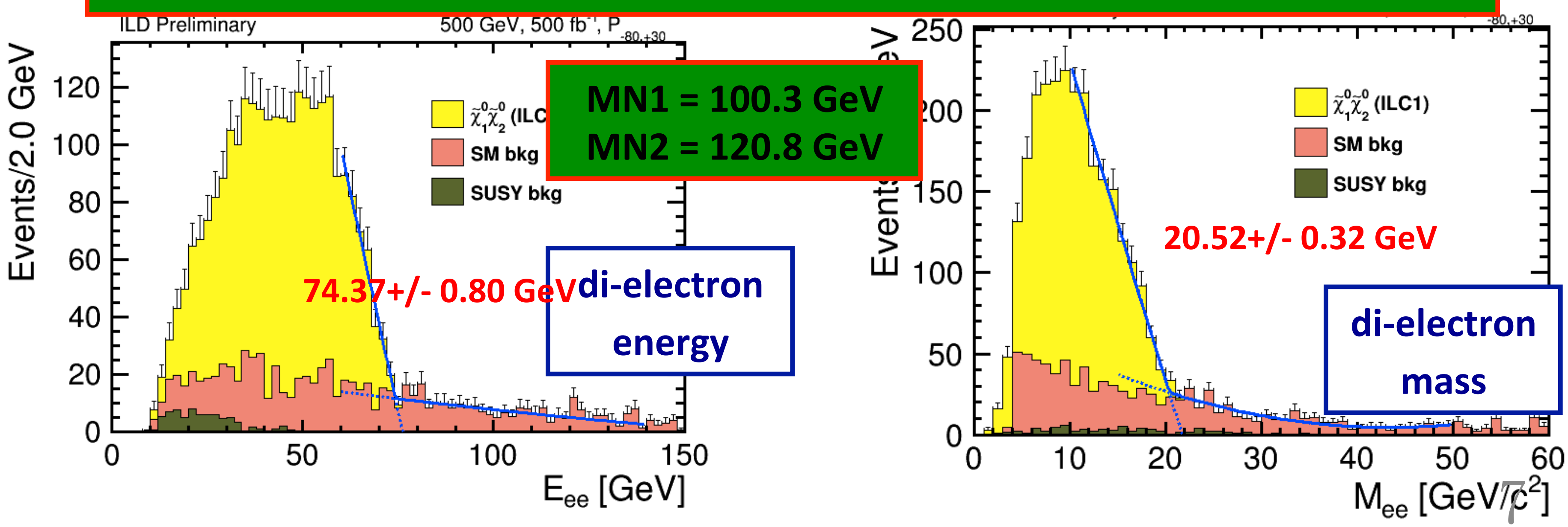
Neutralino mixed production with leptonic decay

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

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



Theoretical values: MN1 = 102.7 GeV MN2 = 124.0 GeV



Neutralino mixed production with leptonic decay

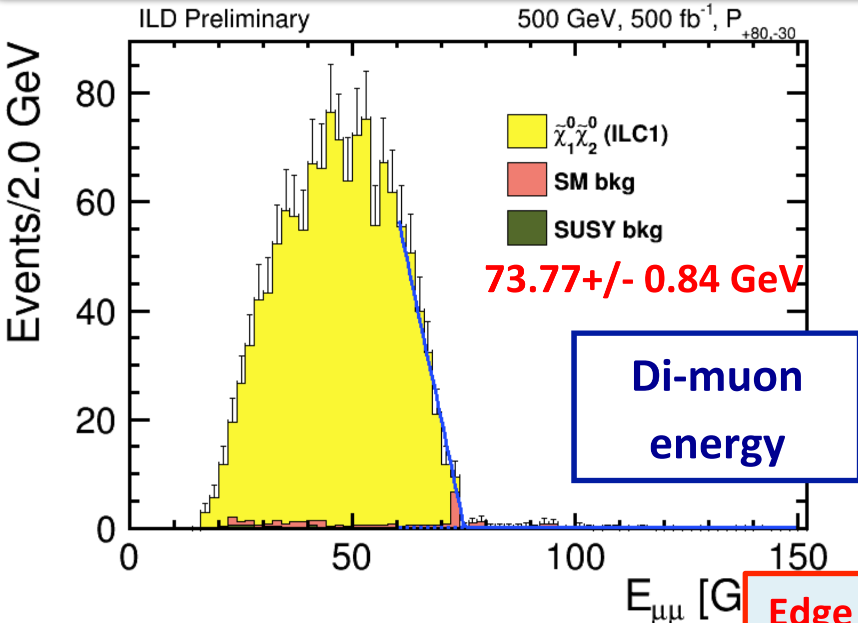
$$e^+e^- \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$$

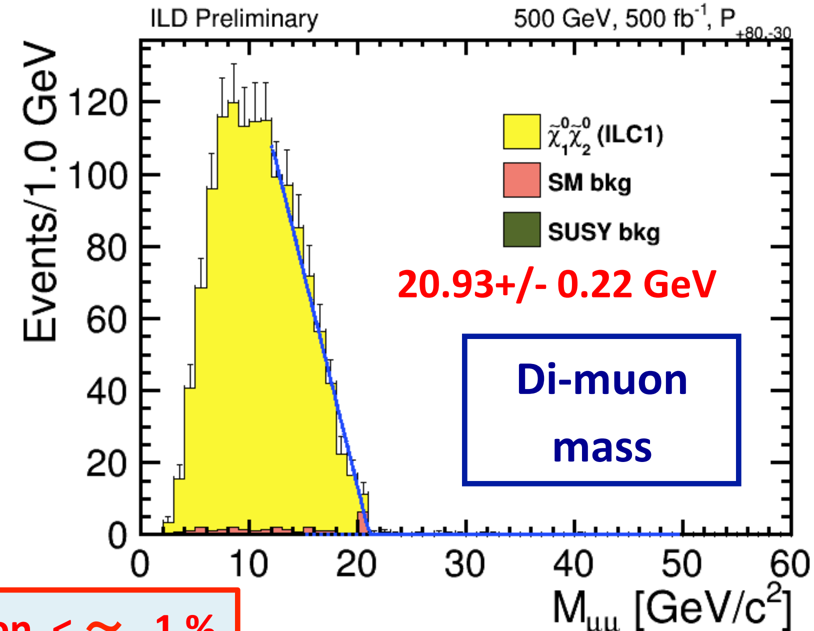
Polarization (Pe-,Pe+) = (+0.8, -0.3)

Much less bkg

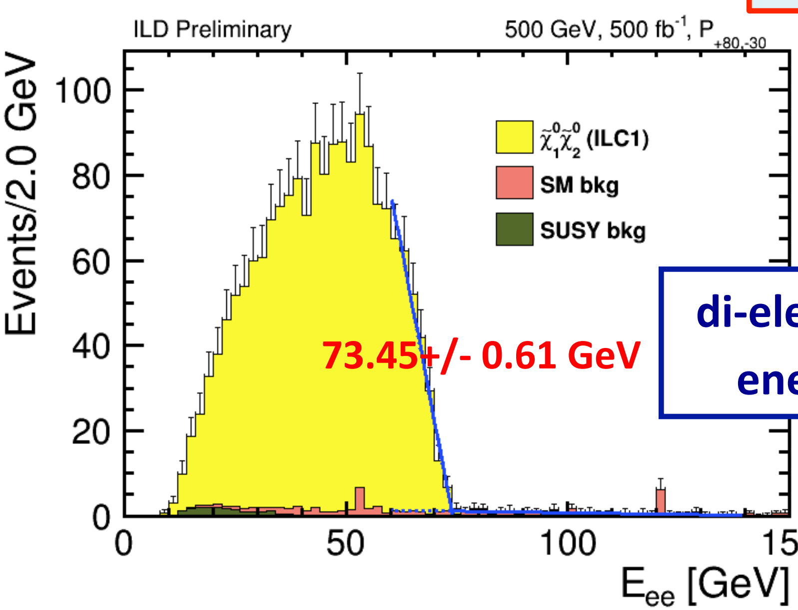
Precision slightly better (?)

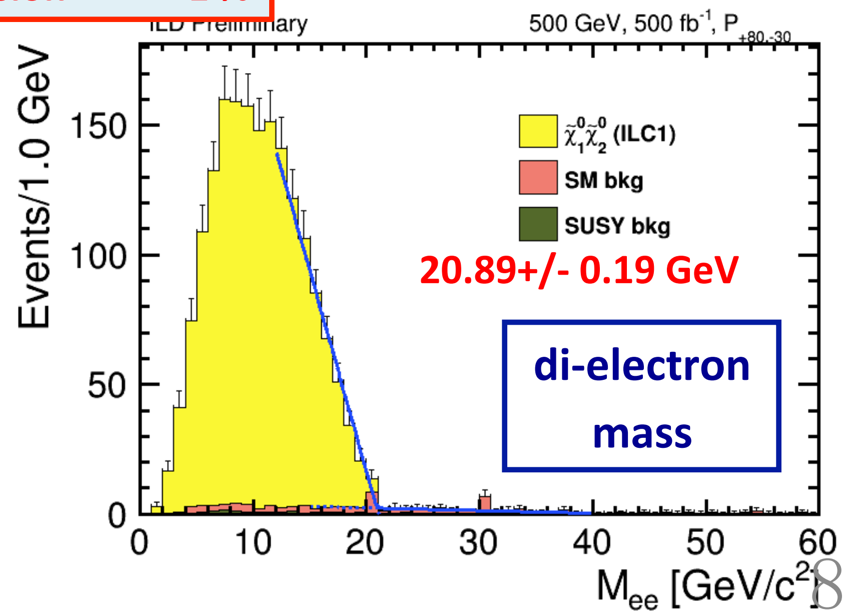
preliminary





Edge precision < ~ 1 %





Neutralino mixed production with leptonic decay

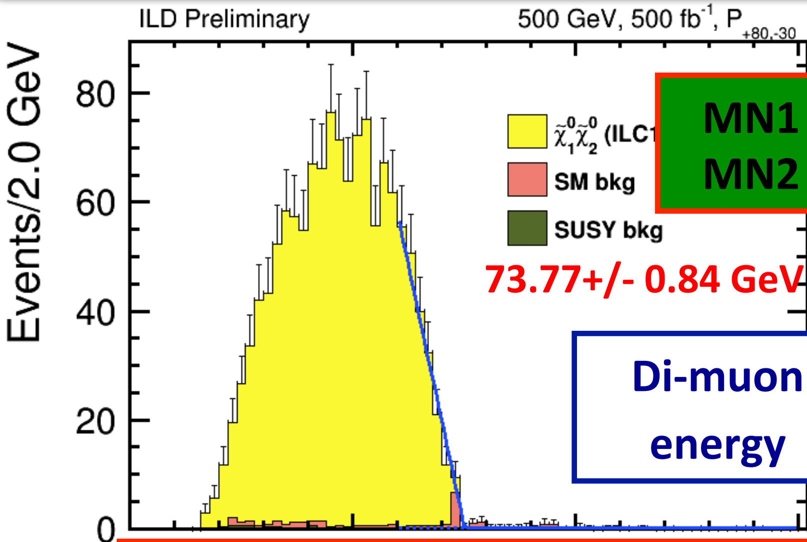
$$e^+e^- \rightarrow \tilde{\chi}_1^0\,\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$$

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

Much less bkg

Precision slightly better (?)

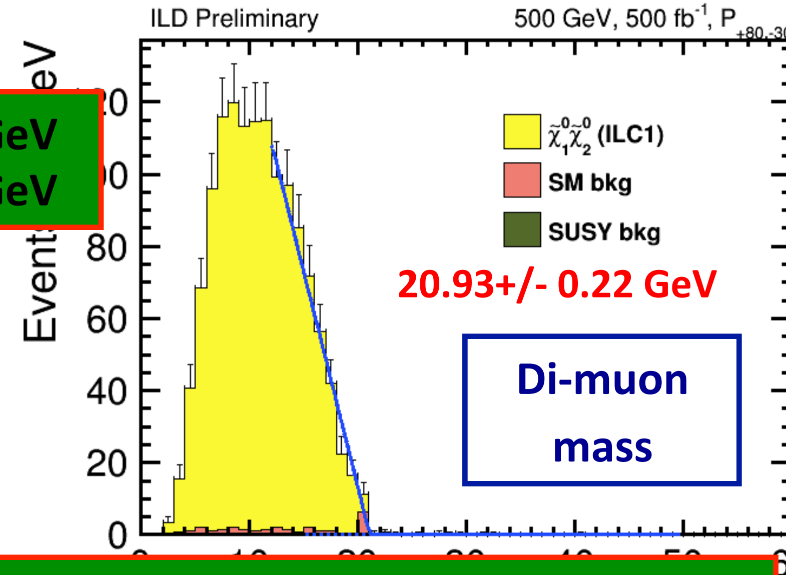
preliminary



MN1 = 103.1 GeV
MN2 = 124.0 GeV

73.77+/- 0.84 GeV

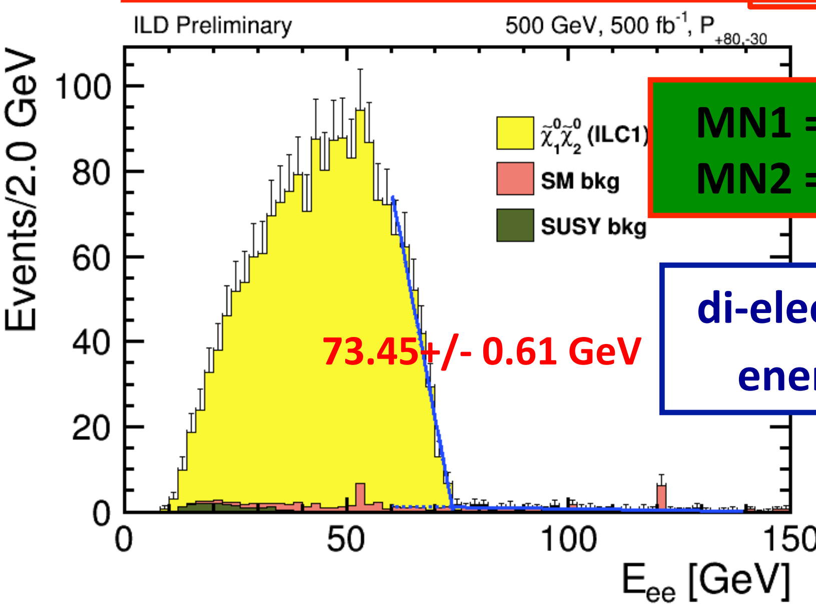
Di-muon energy



20.93+/- 0.22 GeV

Di-muon mass

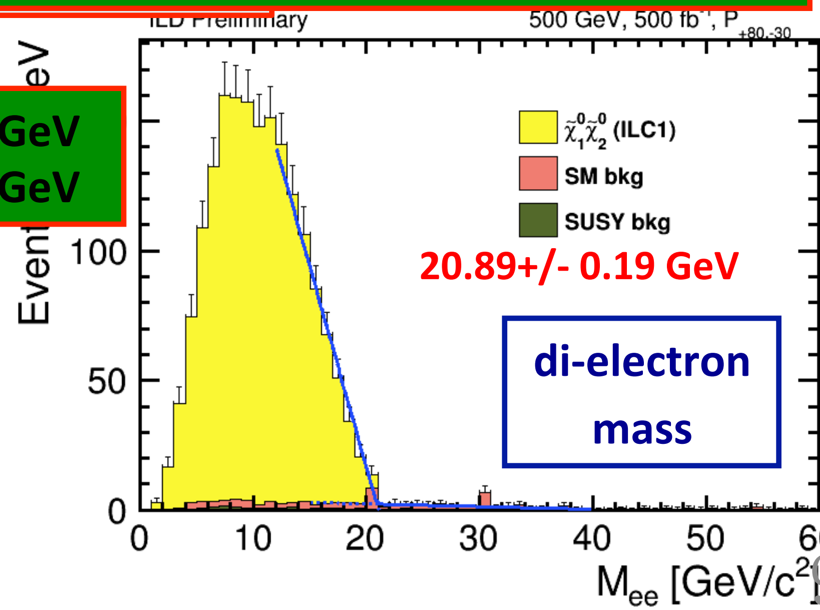
Theoretical values: MN1 = 102.7 GeV MN2 = 124.0 GeV



MN1 = 103.4 GeV
MN2 = 124.3 GeV

73.45+/- 0.61 GeV

di-electron energy



20.89+/- 0.19 GeV

di-electron mass

Chargino pair production with semileptonic decay

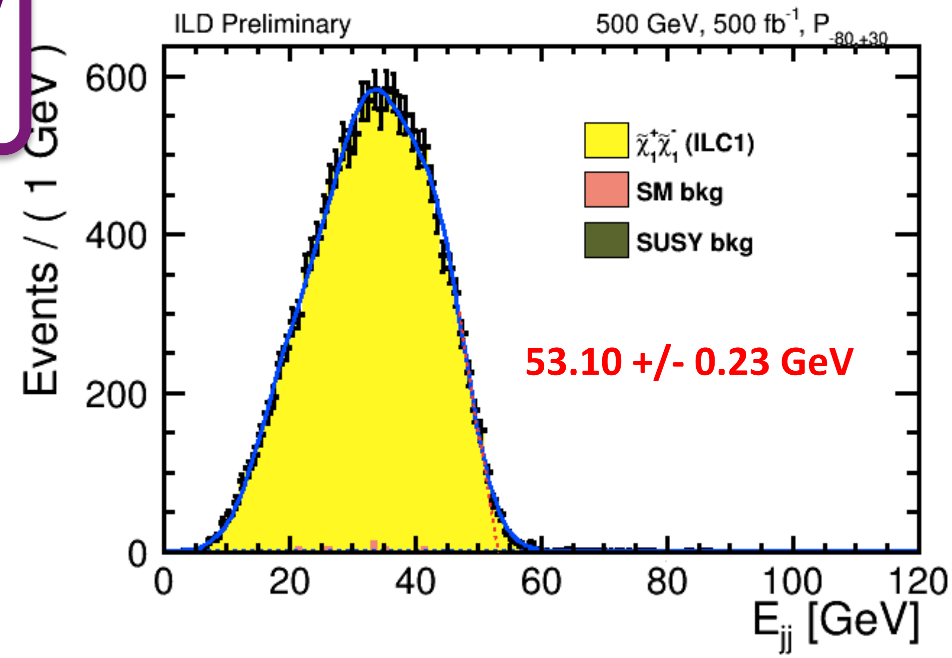
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 q q' \ell \nu$$

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

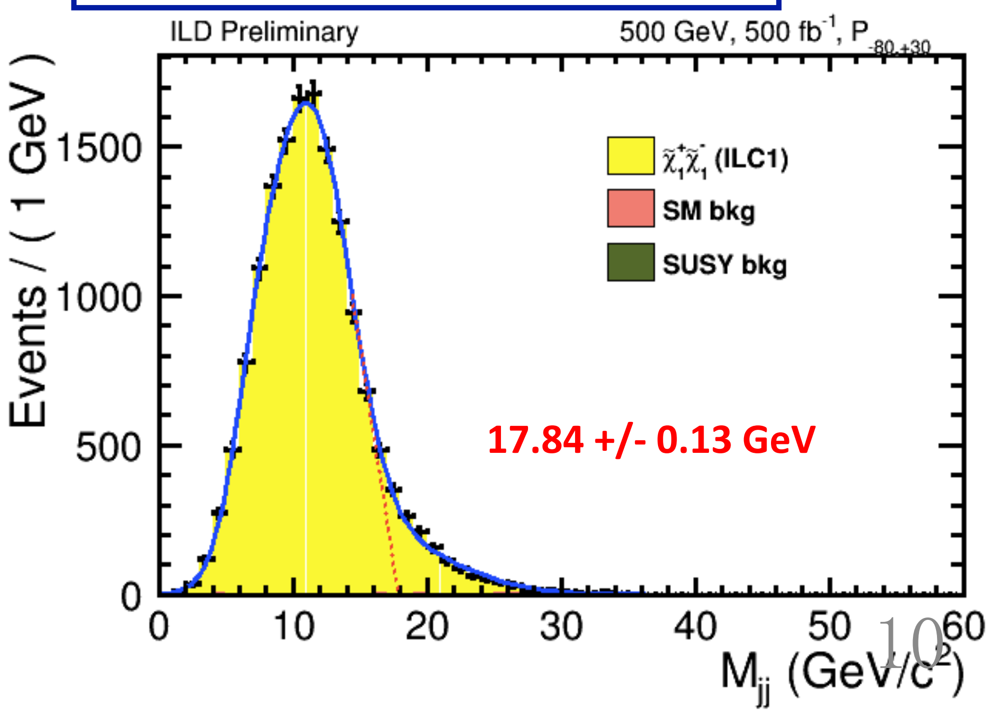
SM and SUSY backgrounds almost fully eliminated

Edge precision < ~ 0.5 %

di-jet energy w/ electron tag



di-jet mass w/ electron tag



Edge extraction: steepest slope method

Theoretical values:
E_max = 56.4 GeV   ΔM = 15.1 GeV

Error Propagation

- Edge precision ～1 %

➔ uncertainty of Higgsino mass 1.5 – 2%

～0.5% for Chargino

Propagation of edge error to Higgsino mass error

In this section, the relevant symbols are defined as follow:

E_{max}: higher kinematic edge of dilepton energy; δE_{max}: its uncertainty (from fit)
ΔM: mass difference between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$; $\delta\Delta M$: its uncertainty (from fit)
$M_{1(2)}$: mass of $\tilde{\chi}_{1(2)}^0$
β: boost of $\tilde{\chi}_2^0$ in the lab frame;$\gamma = 1/\sqrt{1-\beta^2}$
P: momentum of $\tilde{\chi}_2^0$ in the lab frame
The uncertainty of the mass of $\tilde{\chi}_2^0$ (M_2) is expressed using δE_{max} and $\delta\Delta M$ as

$$\delta M_2 = \sqrt{\left(\frac{\partial M_2}{\partial \Delta M}\right)^2 \delta\Delta M^2 + \left(\frac{\partial M_2}{\partial E_{max}}\right)^2 \delta E_{max}^2} \quad (0.1)$$

Both E_{max} and ΔM, along with their uncertainties, are obtained through a fit to the observed distributions of dilepton and invariant mass, respectively.

E_{max} can be expressed as

$$E_{max} = \gamma(1+\beta)\frac{\Delta M}{2}\left(1 + \frac{M_2 - \Delta M}{M_2}\right) \quad (0.2)$$

β and P are functions of M_2, ΔM, and $\sqrt{s}$, given by

$$\beta = P/\sqrt{P^2 + M_2^2} \quad (0.3)$$

$$P = \frac{\sqrt{s}}{2}\sqrt{1 - 2\left[\left(\frac{M_2-\Delta M}{\sqrt{s}}\right)^2 + \left(\frac{M_2}{\sqrt{s}}\right)^2\right] + \left[\left(\frac{M_2-\Delta M}{\sqrt{s}}\right)^2 - \left(\frac{M_2}{\sqrt{s}}\right)^2\right]^2} \quad (0.4)$$

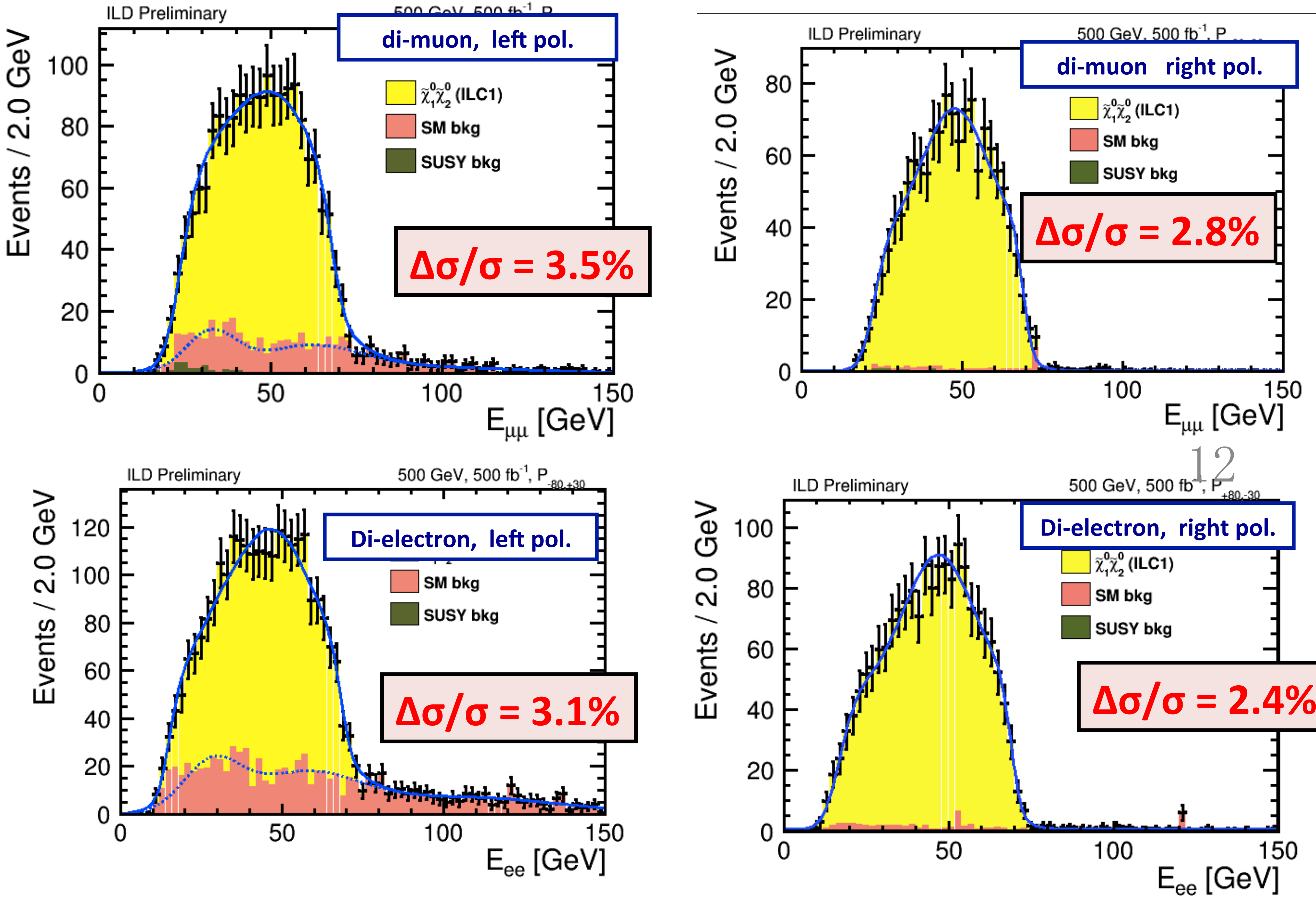
In order to make use of Equation 0.2, the first term in Equation 0.1 can be expressed as

$$\frac{\partial M_2}{\partial \Delta M} = \frac{\partial E_{max}}{\partial \Delta M} \cdot \frac{\partial M_2}{\partial E_{max}} = \frac{\frac{\partial E_{max}}{\partial \Delta M}}{\frac{\partial E_{max}}{\partial M_2}} \quad (0.5)$$

		calculated	calculate	observed	observed	observed	observed	calculated	calculated	calculated	calculated
		M1	M2	delta_M	Δ delta_M	Emax	Δ Emax	Δ M1	Δ M1/M1	Δ M2	Δ M2/M2
N1N2	mm	102.255	123.015	20.76	0.2	73.81	0.86	1.7697	1.73%	1.7583	1.43%
left	ee	100.296	120.811	20.5156	0.324223	74.3688	0.798674	2.1711	2.16%	2.1468	1.78%
N1N2	mm	103.058	123.988	20.93	0.22	73.77	0.84	1.8189	1.76%	1.8056	1.46%
right	ee	103.409	124.299	20.89	0.19	73.45	0.61	1.4406	1.39%	1.4280	1.15%

Extraction of Cross Section

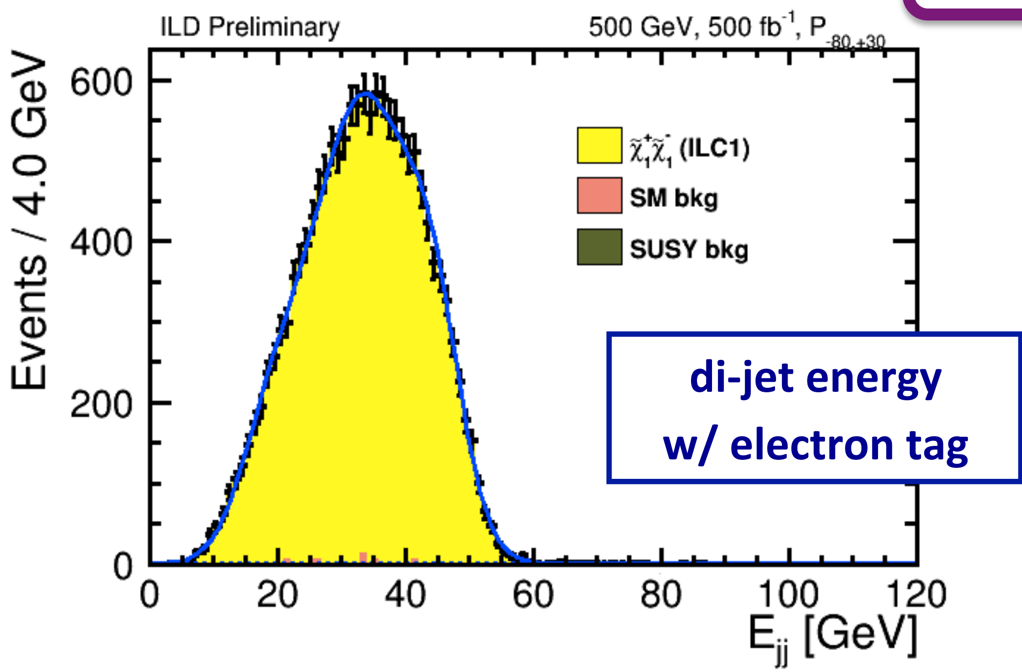
Uncertainty of right pol is about ¾ of left pol (evaluated using Toy MC)



Extraction of Cross Section

Chargino pair production with semileptonic decay

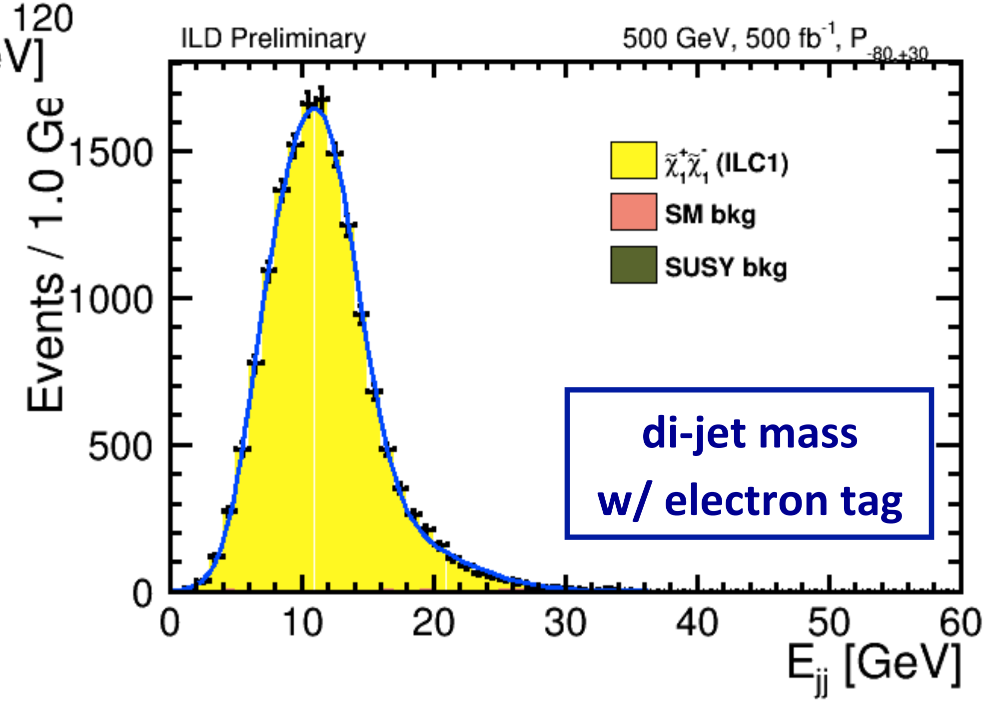
$$e^+e^- \rightarrow \widetilde{\chi}_1^+ \widetilde{\chi}_1^- \rightarrow \widetilde{\chi}_1^0 \widetilde{\chi}_1^0 q q' \ell \nu$$



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

Δσ/σ = 0.8 %

Get same Δσ/σ whether we use E_jj or M_jj



Fit with triple Gaussian

Other channels have similar shapes in the case of chargino

Summary

preliminary results for most channels

- Neutralino: Edge precision ∼1 % → uncertainty of Higgsino mass 1.5 – 2%
- Edge values not far from theoretical values, need some correction for detector effects
- Cross section precision 3-4 % for left pol, 2.8% for right pol

- Chargino : edge precision∼0.5% → uncertainty of Higgsino mass 0.5%
- Cross section precision : 0.8%,

To Do / Plans

- Justify method for edge extraction (chargino) : use MC truth (?)
- explain deviation between extracted and theoretic values

- Converge current analysis to a full set of results

  → input to document which demonstrates ILC new physics discovery potential
- Need to implement gamma gamma overlay bkg

- Plans for publication
- Conduct analysis at other CM energies and polarizations

  → as input for studies on SUSY parameter determination (DESY)

Additional Material

Chargino pair production with semileptonic decay

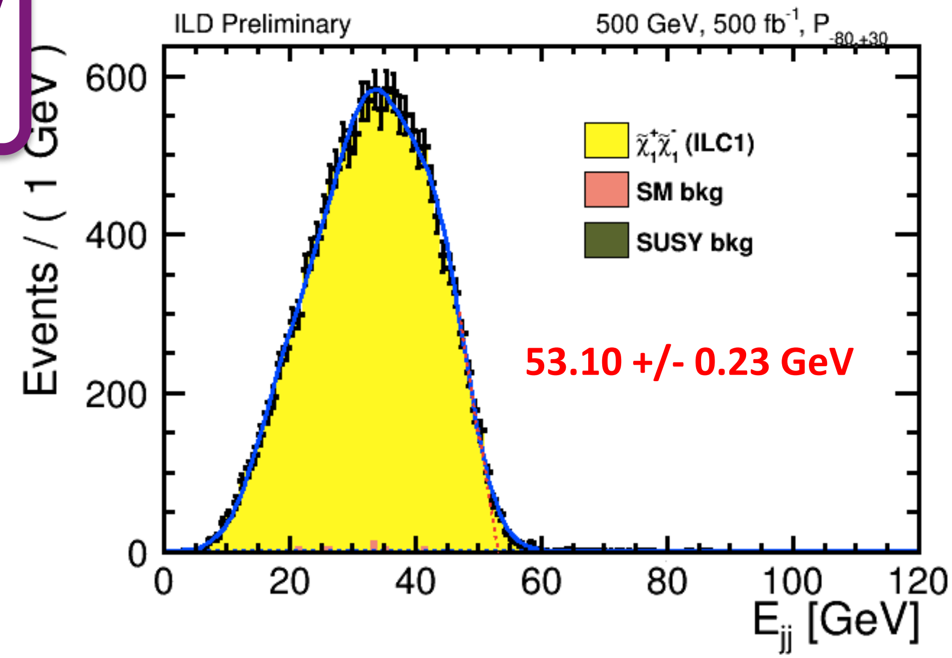
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 q q' \ell \nu$$

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

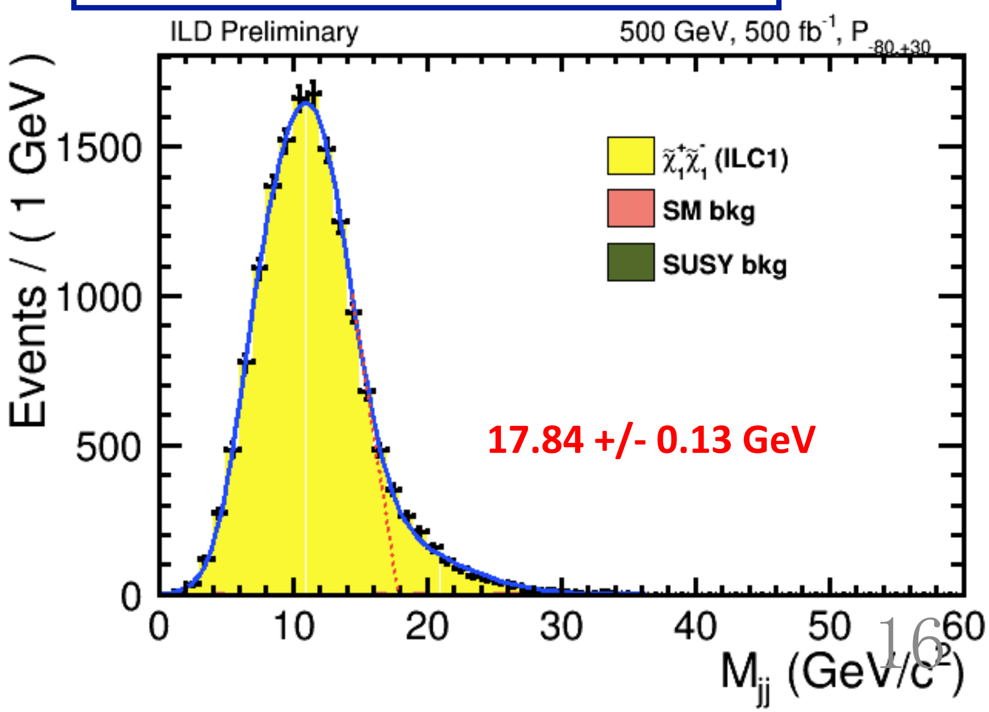
SM and SUSY backgrounds almost fully eliminated

Edge precision < ~ 0.5 %

di-jet energy w/ electron tag



di-jet mass w/ electron tag



MN1 = 125.5 GeV MC1 = 143.4 GeV

Edge extraction: steepest slope method

Theoretical values:
E_max = 56.4 GeV ΔM = 15.1 GeV
MN1 = 102.7 GeV MC1 = 117.8 GeV

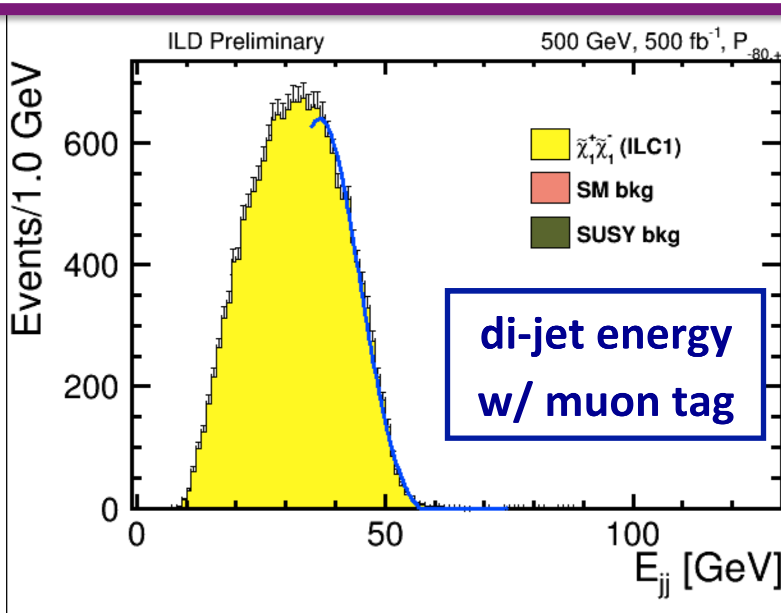
Chargino pair production with semileptonic decay

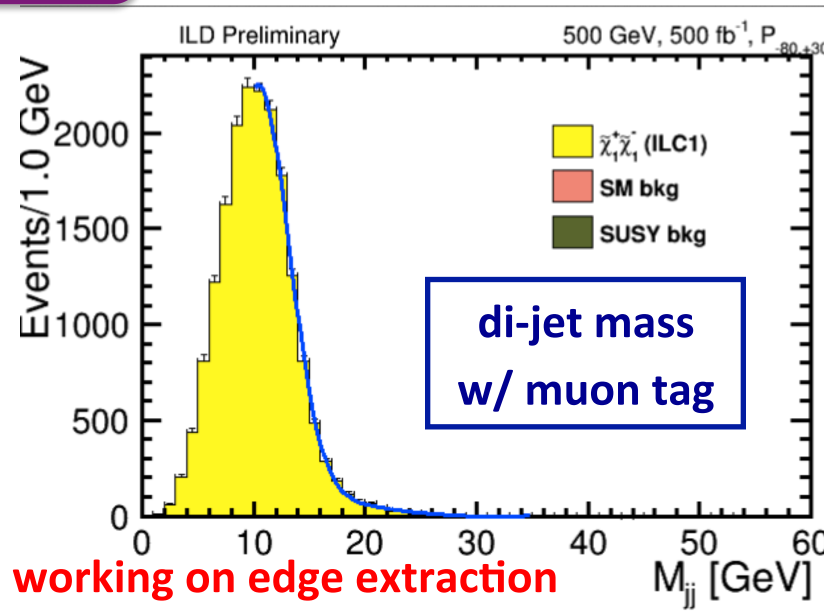
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq'\ell\nu$$

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

SM and SUSY backgrounds almost fully eliminated

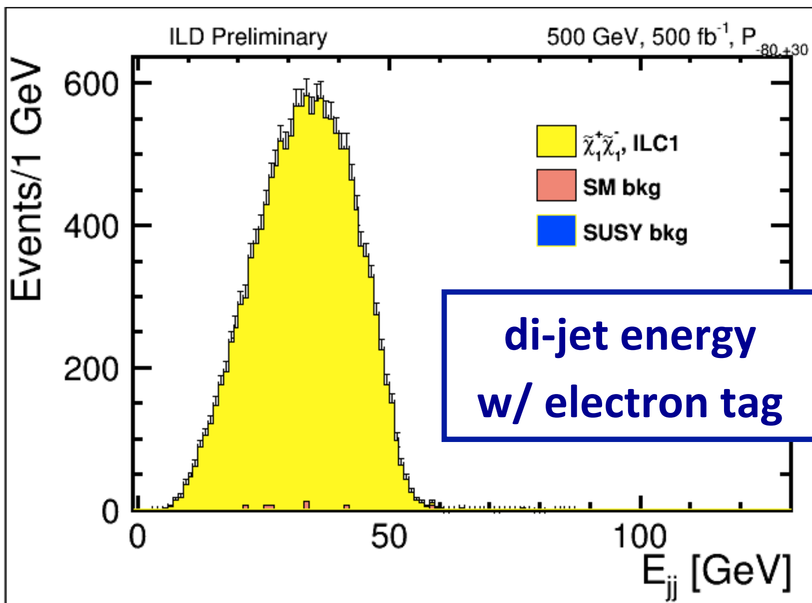
preliminary

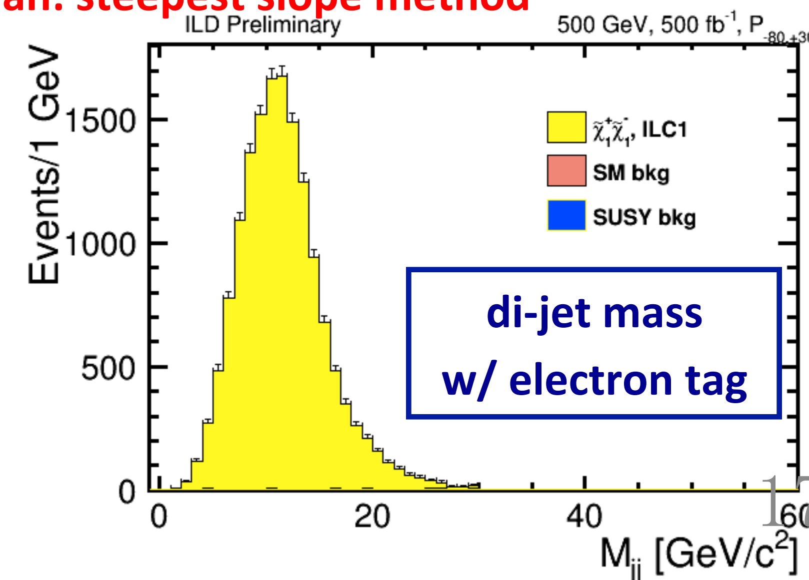


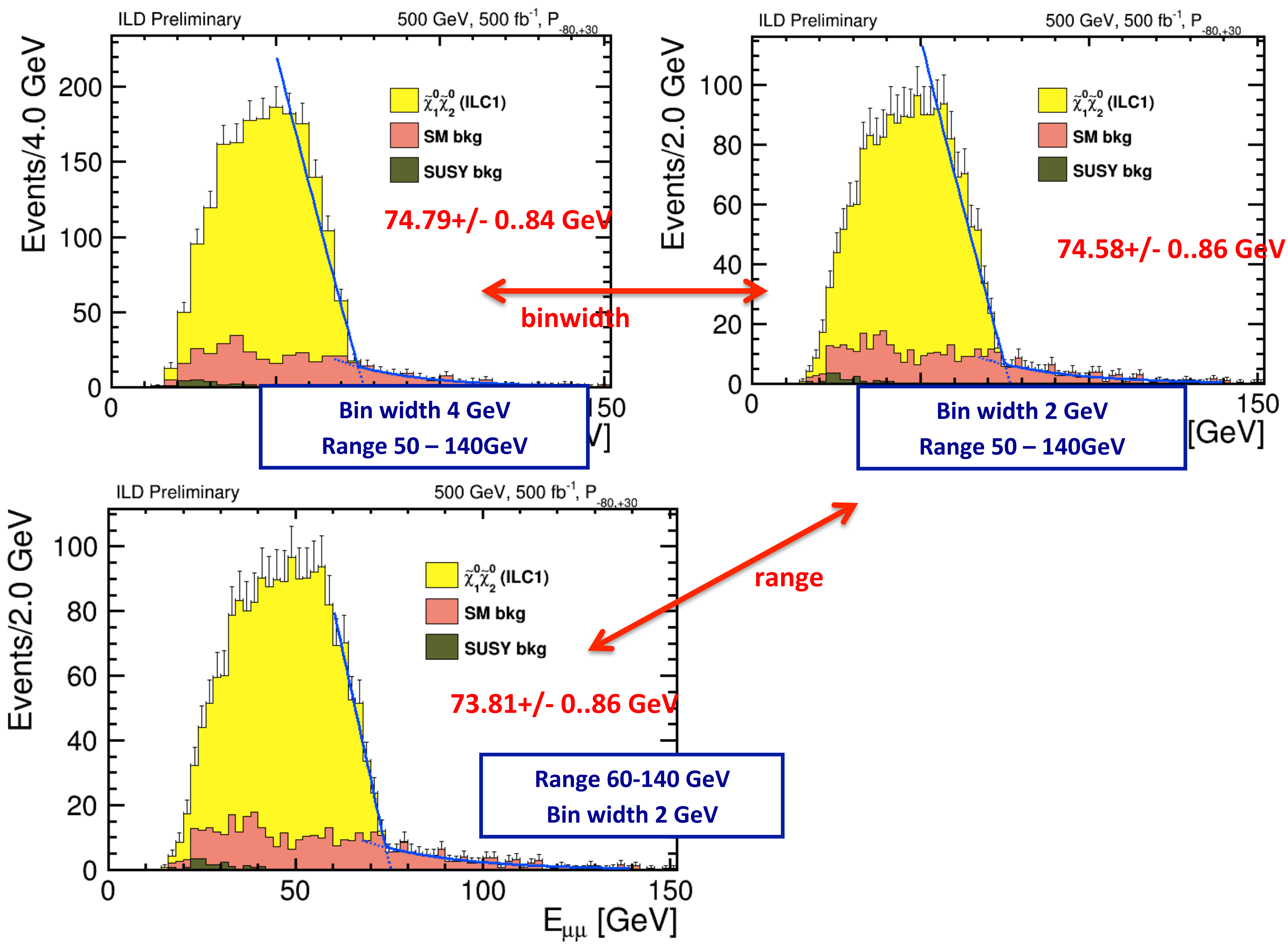


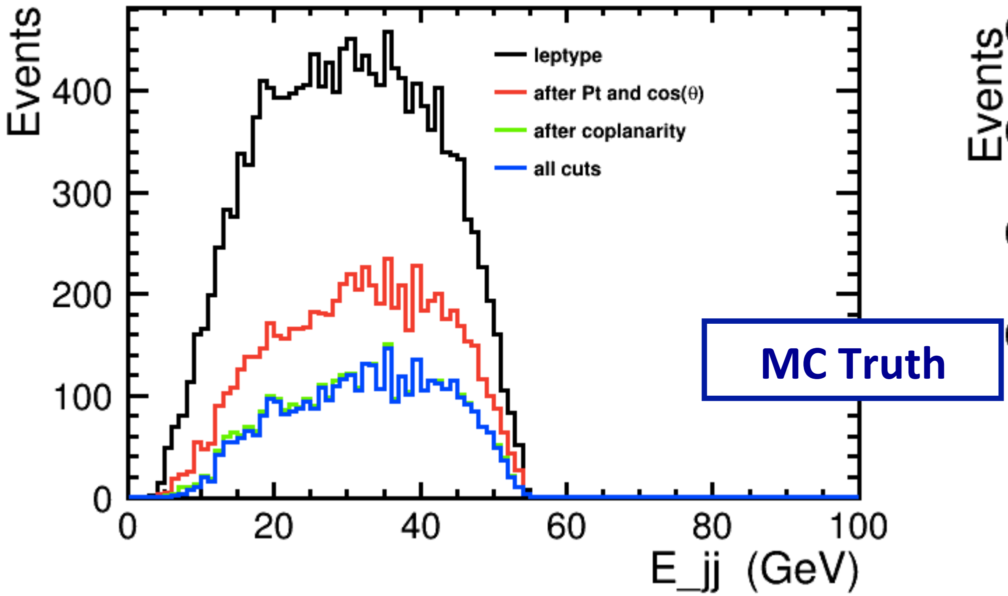
Still working on edge extraction

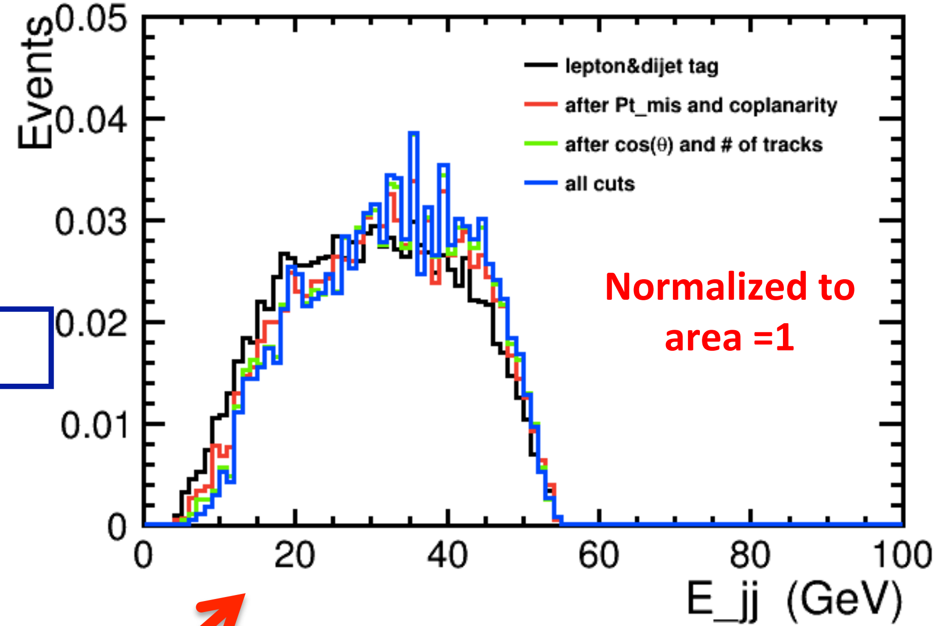
Plan: steepest slope method



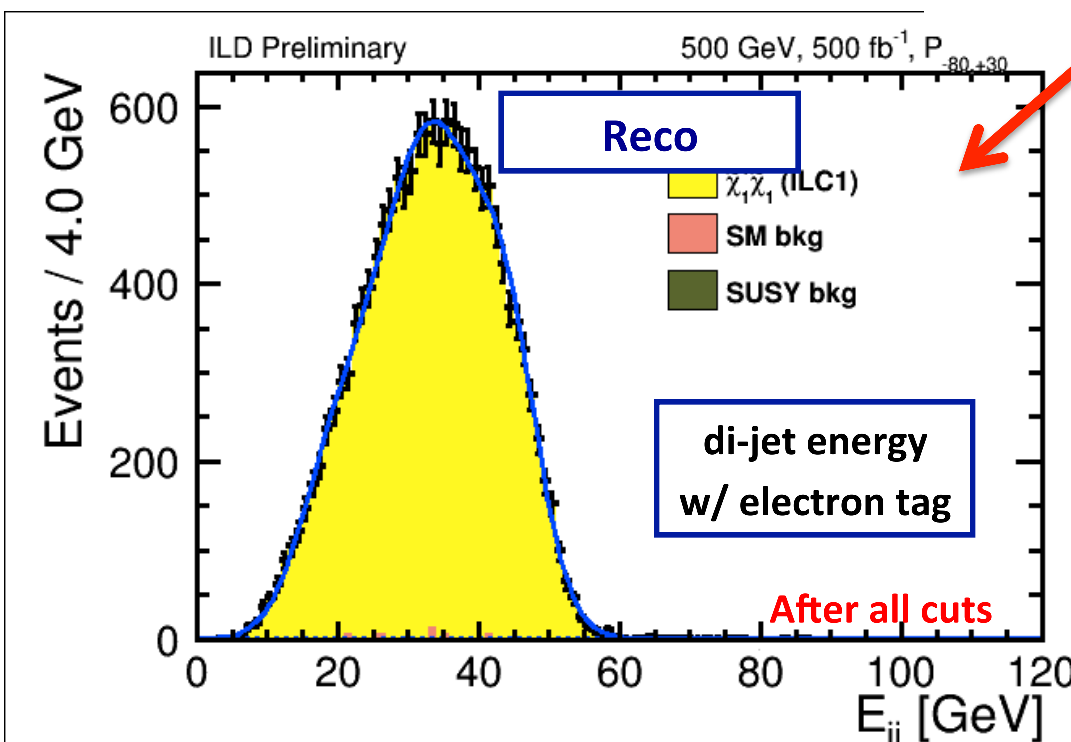



ILD Preliminary
500 GeV, 500 fb-1, P-80,+30
Events/4.0 GeV
χ̃10χ̃20 (ILC1)
SM bkg
SUSY bkg
74.79+/- 0..84 GeV
Bin width 4 GeV
Range 50 – 140GeV
binwidth
ILD Preliminary
500 GeV, 500 fb-1, P-80,+30
Events/2.0 GeV
χ̃10χ̃20 (ILC1)
SM bkg
SUSY bkg
74.58+/- 0..86 GeV
Bin width 2 GeV
Range 50 – 140GeV
[GeV]
range
ILD Preliminary
500 GeV, 500 fb-1, P-80,+30
Events/2.0 GeV
χ̃10χ̃20 (ILC1)
SM bkg
SUSY bkg
73.81+/- 0..86 GeV
Range 60-140 GeV
Bin width 2 GeV
Eμμ [GeV]





Looks SAME



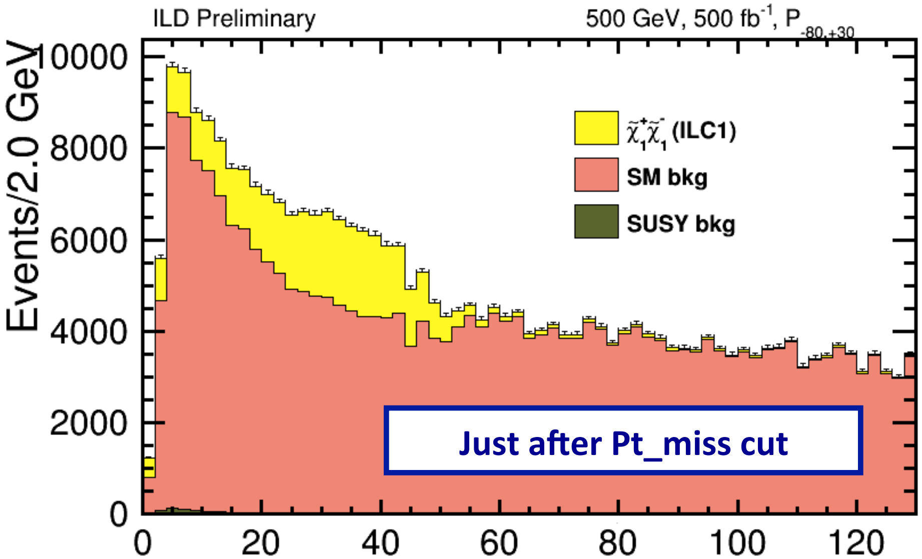
Change in distribution of Di-jet energy with respect to cuts (SIGNAL)

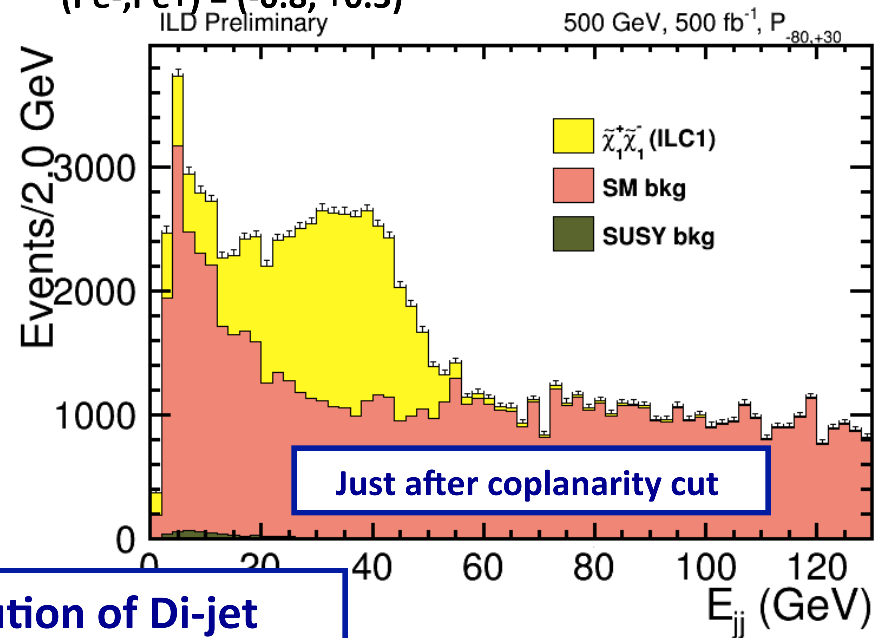
Cuts applied on Reconstructed variables

Chargino pair production with semileptonic decay

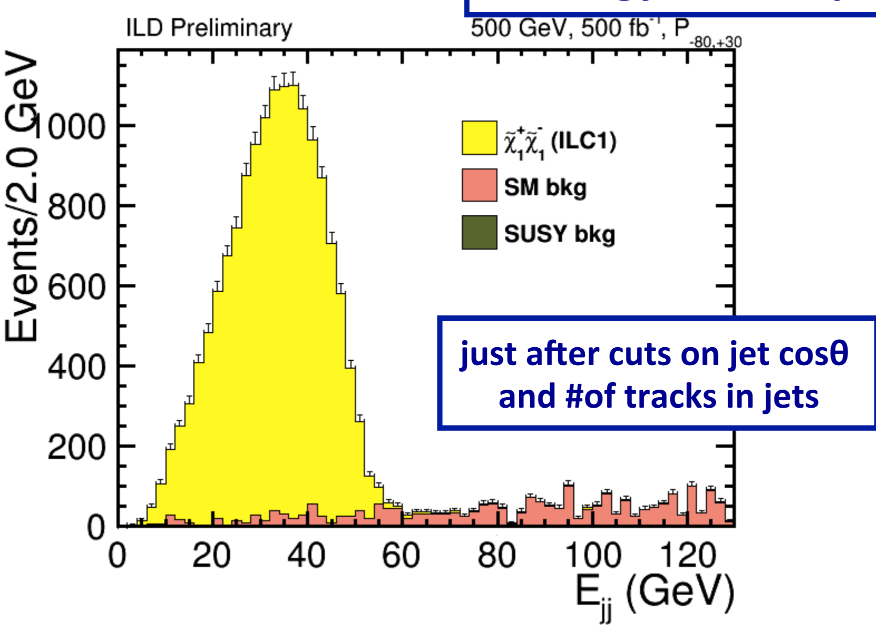
$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq'\ell\nu$$

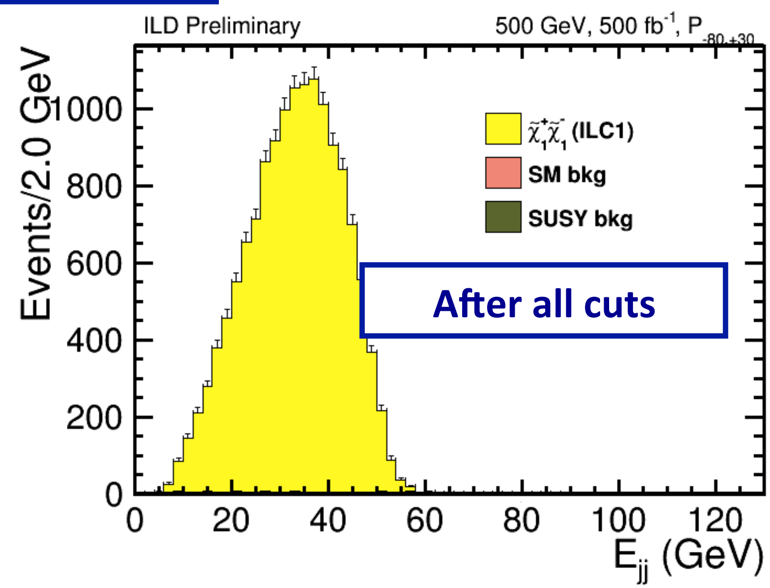
(Pe-,Pe+) = (-0.8, +0.3)





Change in distribution of Di-jet energy with respect to cuts (BKG)



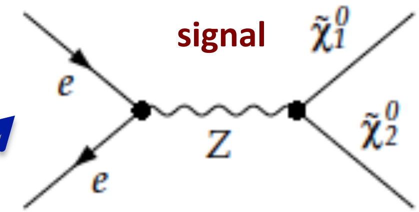


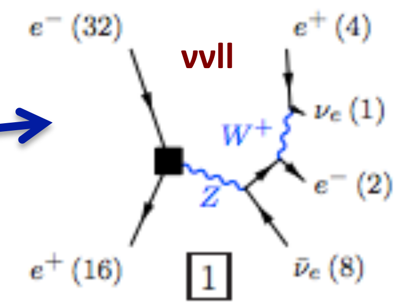
Event Selection

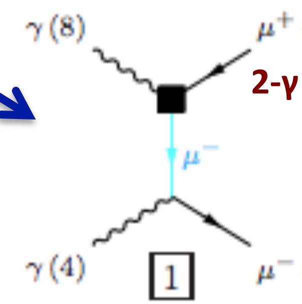
Neutralino mixed production with leptonic decay

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

- 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 (ννll)
- 2-γ processes are removed by BeamCal veto, cuts on lepton track p_T, and coplanarity





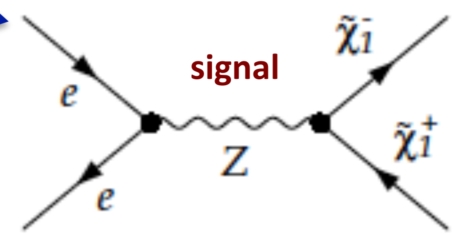


Chargino pair production with semileptonic decay

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

- 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)



Cuts for N1N2

- **lepton type (μμ or ee)** : the two leptonic channels of N1N2 analysis
- **nTrack = 2 :** number of charged tracks
- **no hit in BeamCal :** veto γγ2f BG
- **Pt_lep1,2 > 6 GeV and |cosθlep1,2| < 0.95:**
- **Coplanarity < 1.0 rad :** angle between leptons in x-y plane
- **Evis – Eγmax < 40 GeV :** visible energy (very small for signal)
- **Emis > 300 GeV :** missing energy (very large for signal)
- **|cosθmissing| < 0.98 :** θ of missing energy events
- **|cosθZ| < 0.98 :** Z* production angle
- **Pt_dl < 80 GeV :** transverse momentum of dilepton
- **Minv<50 GeV :** dilepton invariant mass: determines ΔM

last of all observe distributions of Minv and dilepton energy (E_dl)

Kinematic edge is a function of Higgsino mass and ΔM

Cuts for C1C1

- lepton type (μ or e tag) and # of lepton =1
- Pt_{mis} > 10 GeV
- Jet Coplanarity < 1.0 rad
- |cosθjet1,2| < 0.95:
- nTrack(in jet) >1 :
- no hit in BeamCal :
- cosθjet1-lep < 0.2, cosθjet2-lep < 0 angle between jets and leptons
- Evis – Eγmax < 60 GeV :
- Emis > 400 GeV :
- |cosθmissing| < 0.98 :
- |cosθZ| < 0.98 :
- Pt_{jj} < 50 GeV :
- Minv<30 GeV :

last of all observe distributions of Minv and dijet energy (Ejj)

Kinematic edge is a function of Higgsino mass and ΔM

Cuts for N1N2

- **lepton type (μμ or ee)** : the two leptonic channels of N1N2 analysis
- **nTrack = 2 :** number of charged tracks
- **no hit in BeamCal :** veto γγ2f BG
- **Pt_lep1,2 > 6 GeV and |cosθlep1,2| < 0.95:**
- **Coplanarity < 1.0 rad :** angle between leptons in x-y plane
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- **Pt_dl < 80 GeV :** transverse momentum of dilepton
- **Minv<50 GeV :** dilepton invariant mass: determines ΔM

last of all observe distributions of Minv and dilepton energy (E_dl)

Kinematic edge is a function of Higgsino mass and ΔM

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last of all observe distributions of Minv and dijet energy (Ejj)

Kinematic edge is a function of Higgsino mass and ΔM

Cut table N1N2 , μμ (Pe-, Pe+) = (-80,+30)

	sig	bkg	4f_l	aa_2f	ae_3f	SUSY bkg
xsec	300.8	3.00E6	10566.2	2.68E6	261580	1065.2
N_gen	150395	1.50E9	5.28E6	1.34E9	1.31E8	532585
Lep_type nTrack=2	1974	9.1E8	444255	8.9E8	2.2E7	2426
BCAL veto	1950	6.0E6	149871	5.5E6	965354	2411
Pt_lep,1,2	1675	2.0E6	105721	1.4E6	295459	1986
cosθ_lep	1624	1.3E6	56001	910330	167734	1950
coplanarity	1407	48366	5272	3509	33067	22
Evis	1404	14325	2465	2248	4743	22
Emis, cosθmis	1393	1063	929	34	9	19
cosZ, Pt_ll, Minv	1393	545	429	34	9	19

Cut table C1C1 , μtag (Pe-, Pe+) = (-80,+30)

	sig	bkg	4f_l	aa_2f	ae_3f	SUSY bkg
Xsec [fb]	1065.2	3.00E6	10566.2	2.68E6	261580	300.8
N_gen	532585	1.50E9	5.28E6	1.34E9	1.31E8	150395
nLep=1 BCAL veto	57983	1.5E9	443296	1.2E6	860530	1135
Ptmis	38240	2.7E6	377010	465397	519308	964
Jet_coplanarity	26085	1.5E6	86399	83683	109325	531
Jet_cosθ nTrack (per jet) > 1	14612	305870	3066	555	2234	22
cosθjet-lep Evis	14308	3753	791	100	41	0
Emis, cosθmis	14231	83	57	3	0	0
Pt_jj, M_jj	14173	51	31	3	0	0