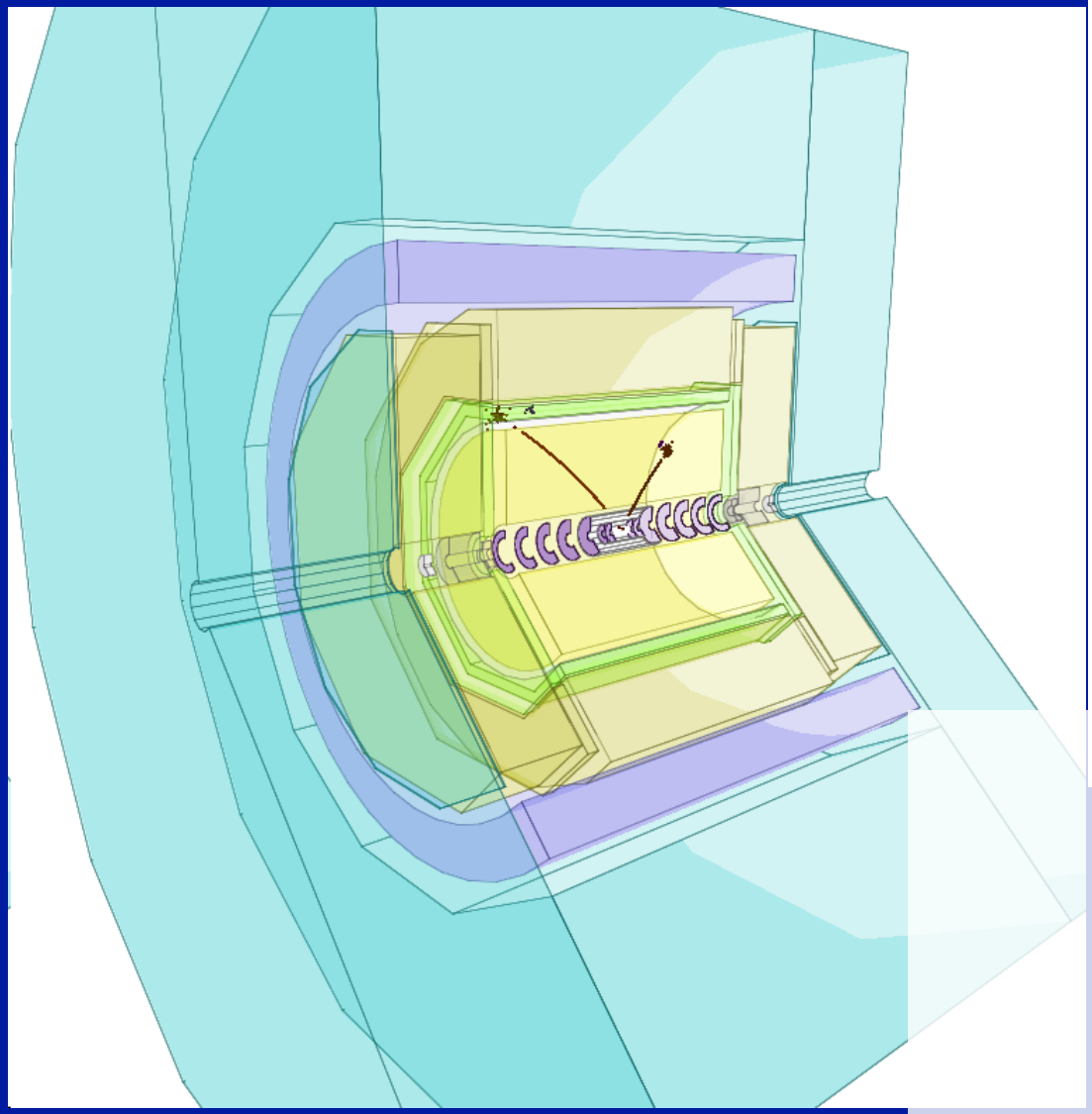
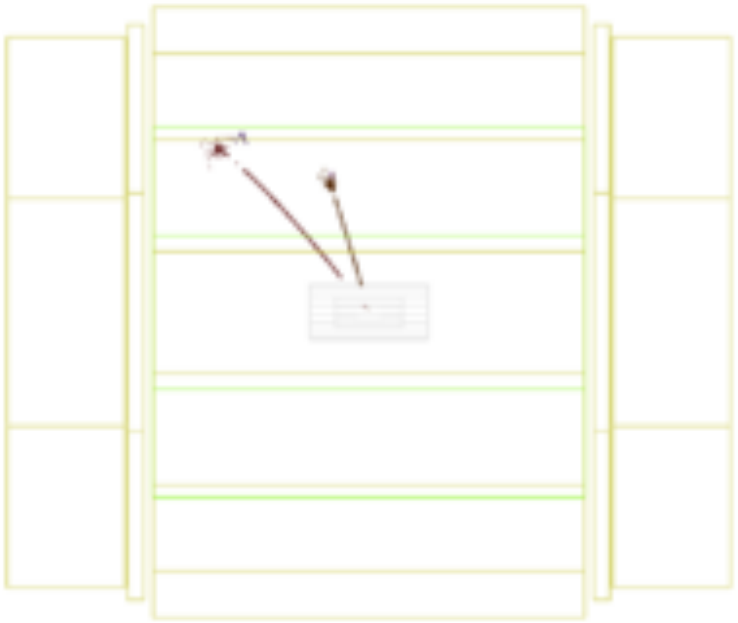
Characterizing Light Higgsinos from Natural SUSY at ILC $\sqrt{s}$ = 500 GeV





Jacqueline Yan (KEK)

Friday Physics Meeting

June 24, 2016

Outline

- Change in lepton finding method
- 4f bkg samples
- Extraction of Higgsino mass and cross section
- Material for Suvi's conference
- Plans

Need sufficient bkg samples to produce reliable results for expected precisions of masses and cross sections

what we did until ECFA

- Used MVA based lepton finder (same as for Higgs recoil)
- Muons : full sim (lack of 4f statistics) electrons: SGV

Current method

- Request sent to Miyamoto-san for full sim generation

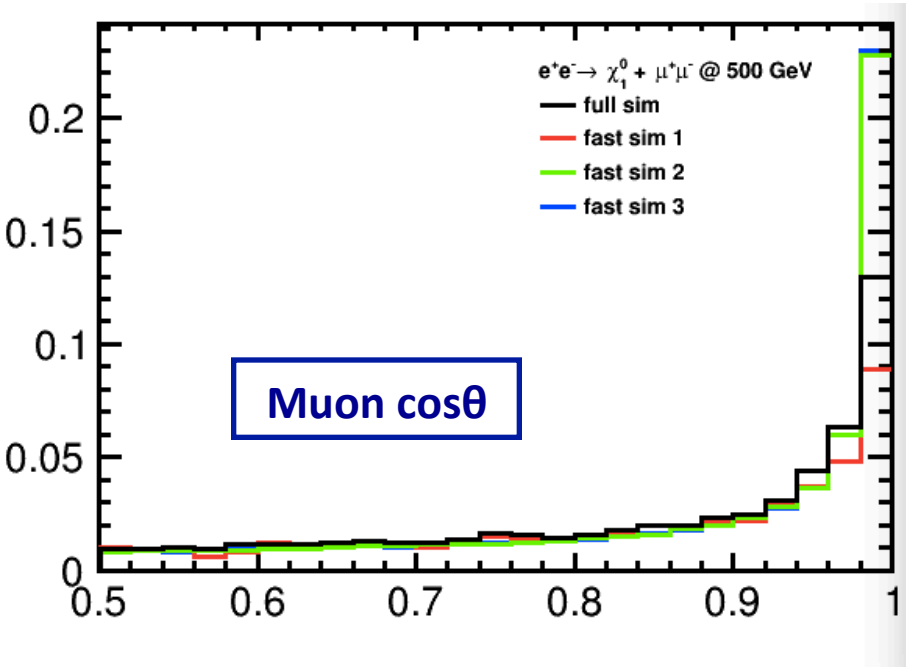
Meanwhile ….

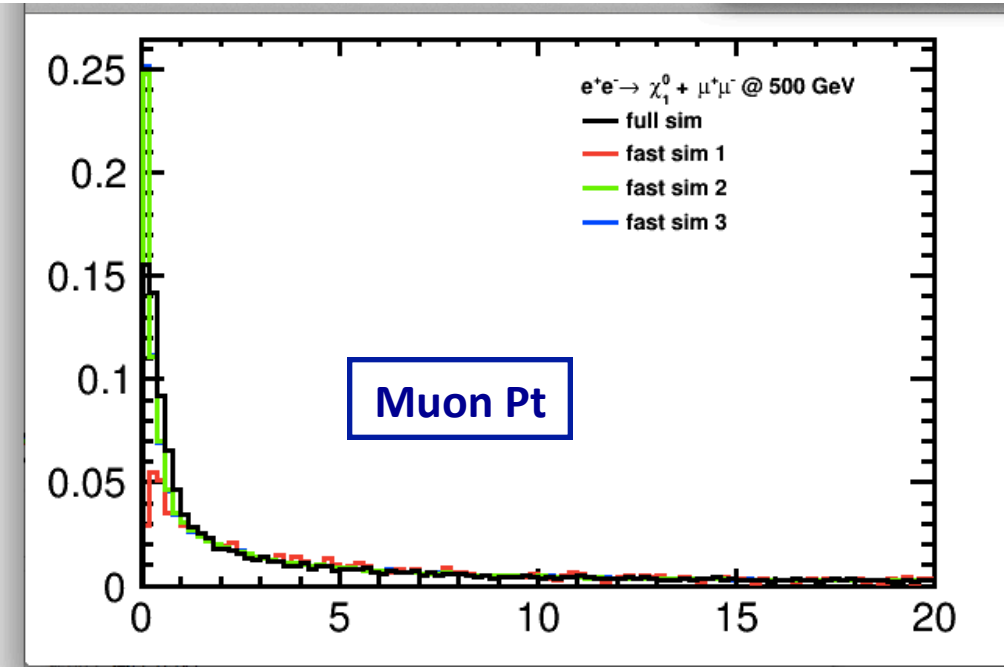
- **Changed to simpler lepton finding** (cone energy + impact parameter)

- checked difference in efficiency between full and (several) SGV samples

- **Use SGV for dominant 4f bkg processes**

- **Comparison of reconstructed info between full sim and fast sim (Before isolated lepton finder)**





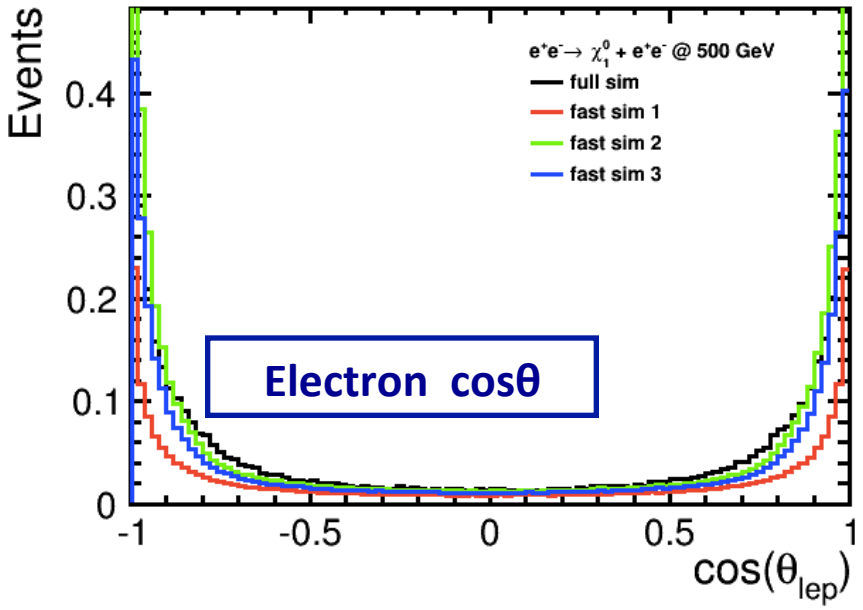
N1N2 pure left pol
SGV1, SGV2, SGV3 (in order of date) vs full sim

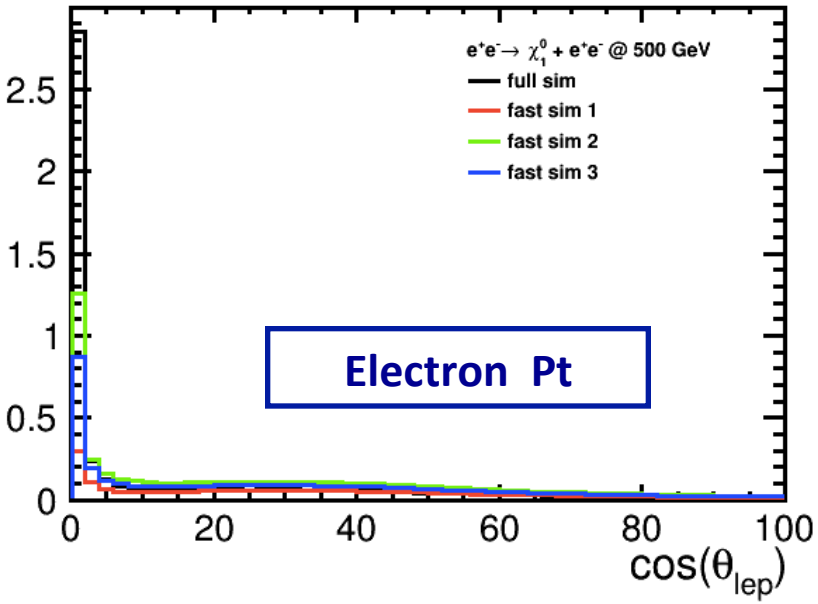
Pt and cosθ consistent between full sim and fast sim samples
Except for low Pt/ forward θ region which will be cut away anyhow

We are using SGV3 now

Normalized to # of generated events

- **Comparison of reconstructed info between full sim and fast sim (Before isolated lepton finder)**

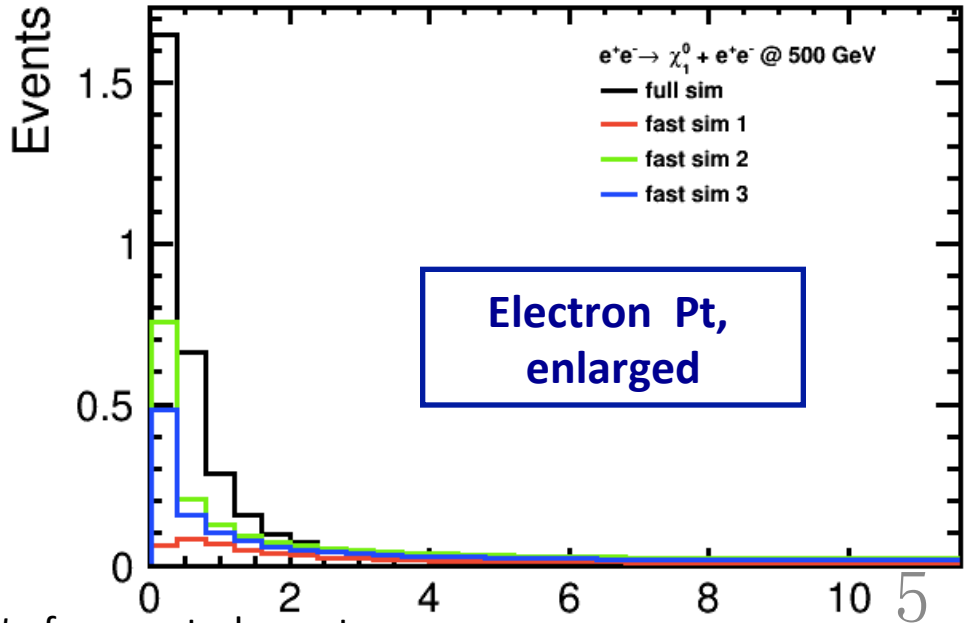




N1N2 pure left pol
SGV1, SGV2, SGV3
(in order of date) vs full sim

some inconsistency in Pt and cosθ between full sim and fast sim samples
Only in low Pt/ forward θ regions

We are using SGV3 now



Normalized to # of generated events

Extraction of Higgsino Mass

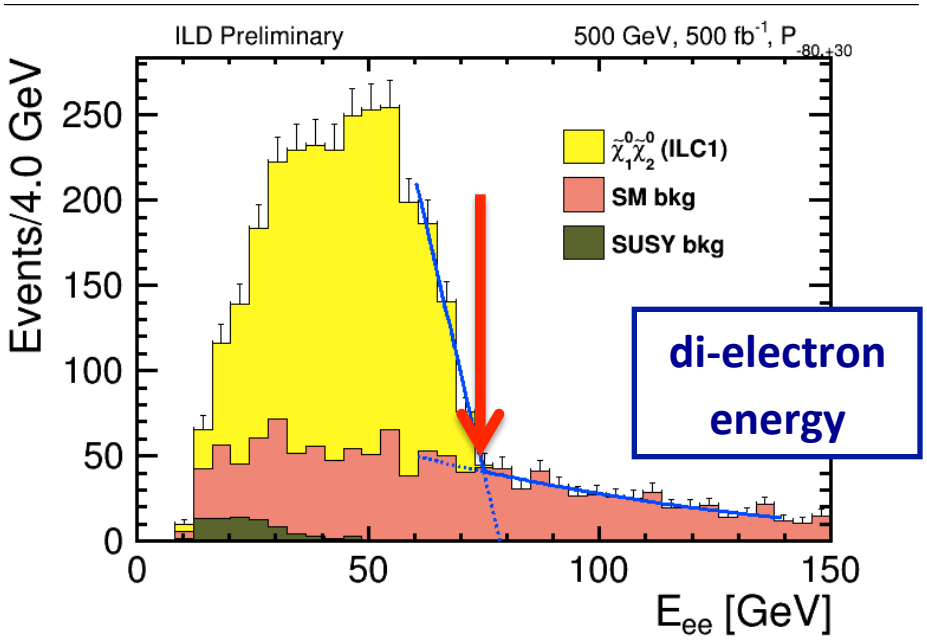
[work in progress]

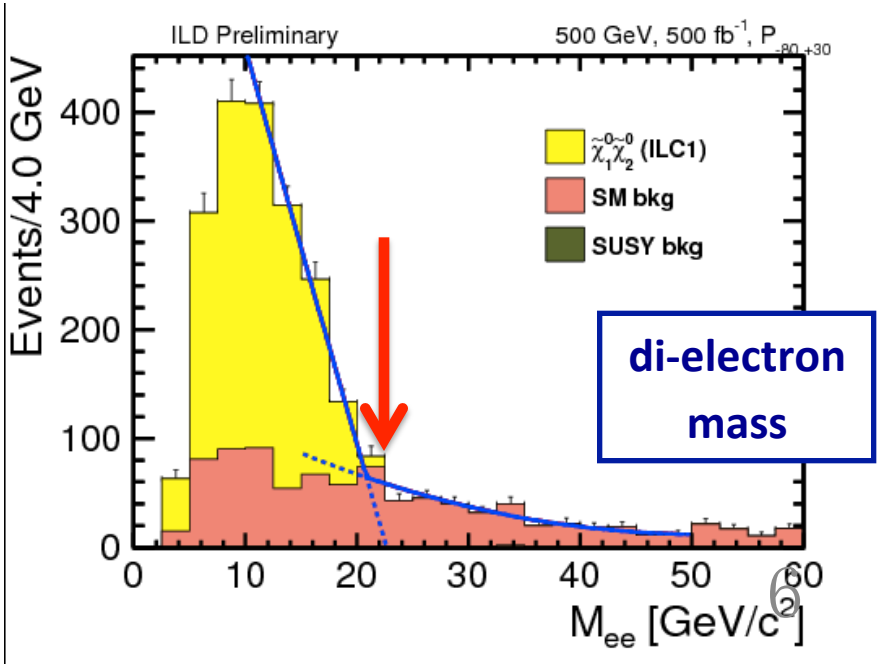
Neutralino mixed production with leptonic decay

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

- 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)





Cuts have been designed so as not to destroy upper edge

- Use toy MC (generated from MC data fit) to evaluate statistical uncertainty
- began process of kinematic edge extraction

Edge extraction precision ~1 %

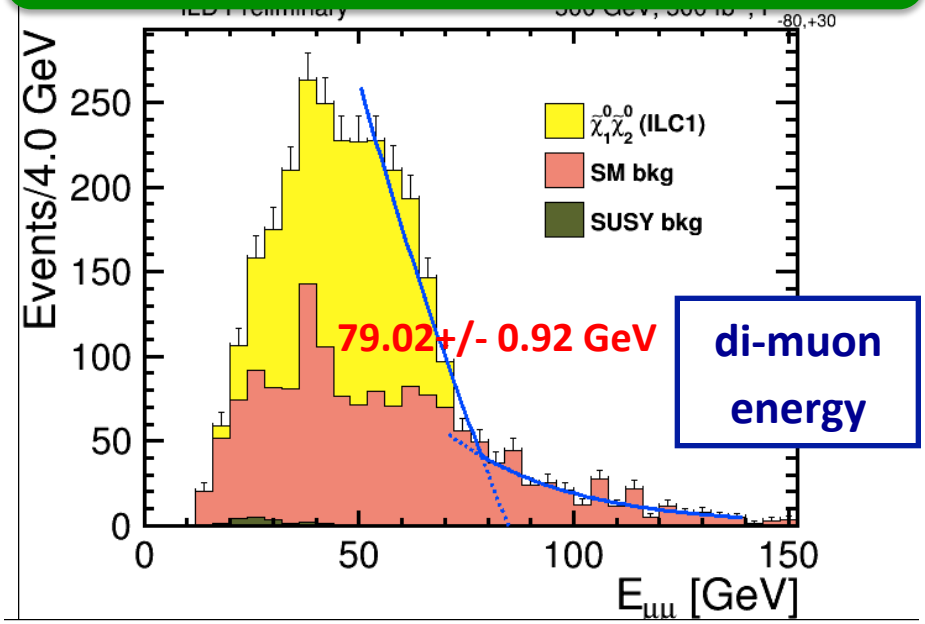
Neutralino mixed production with leptonic decay

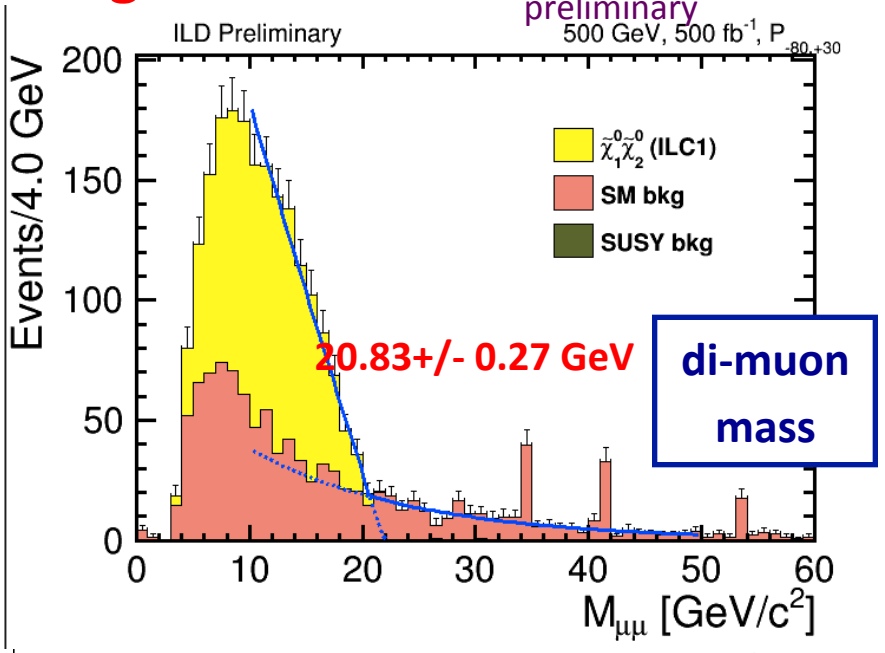
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

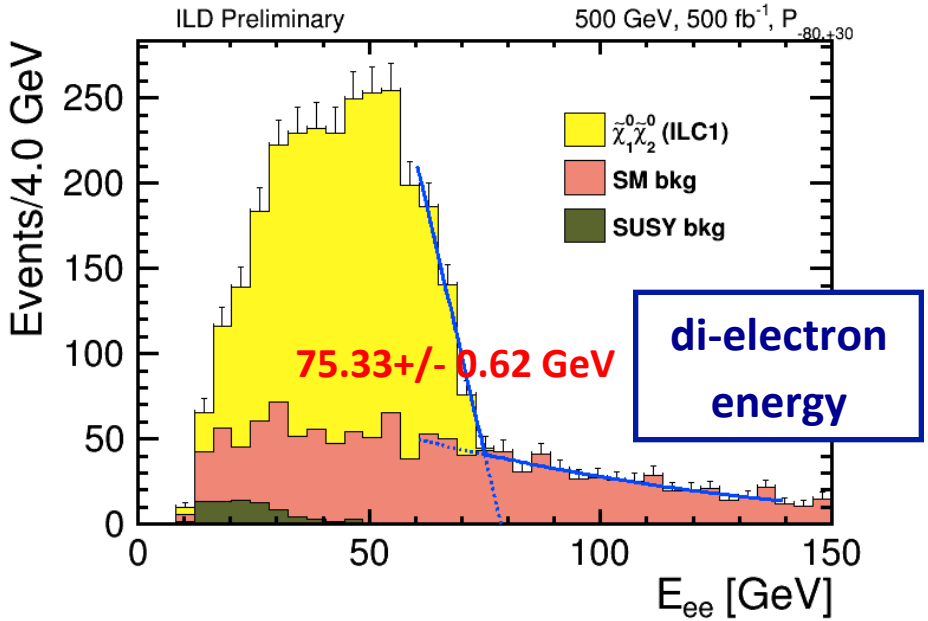
Polarization (Pe-,Pe+) = (-0.8, +0.3)

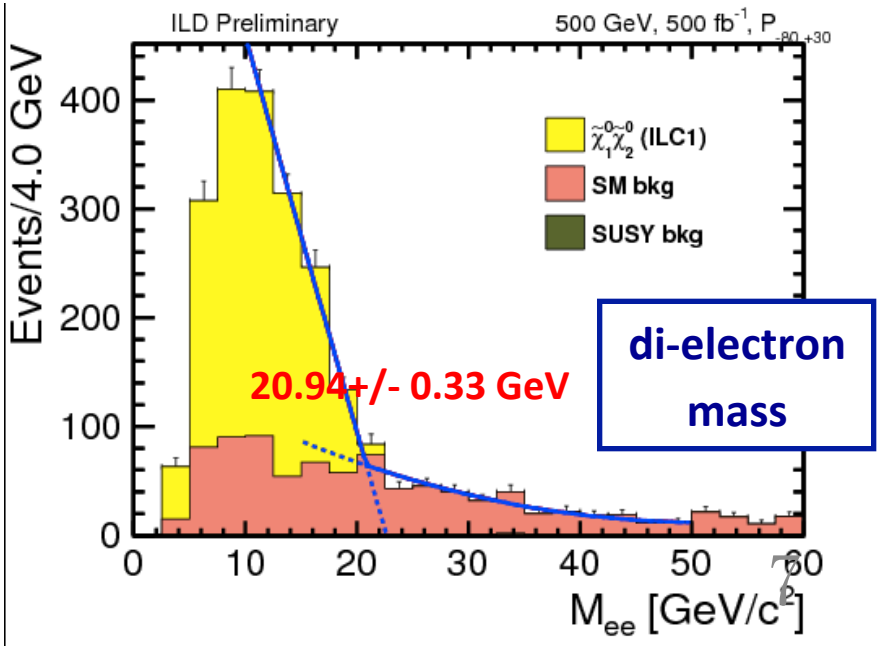
Edge Extraction

Numbers from Toy MC preliminary









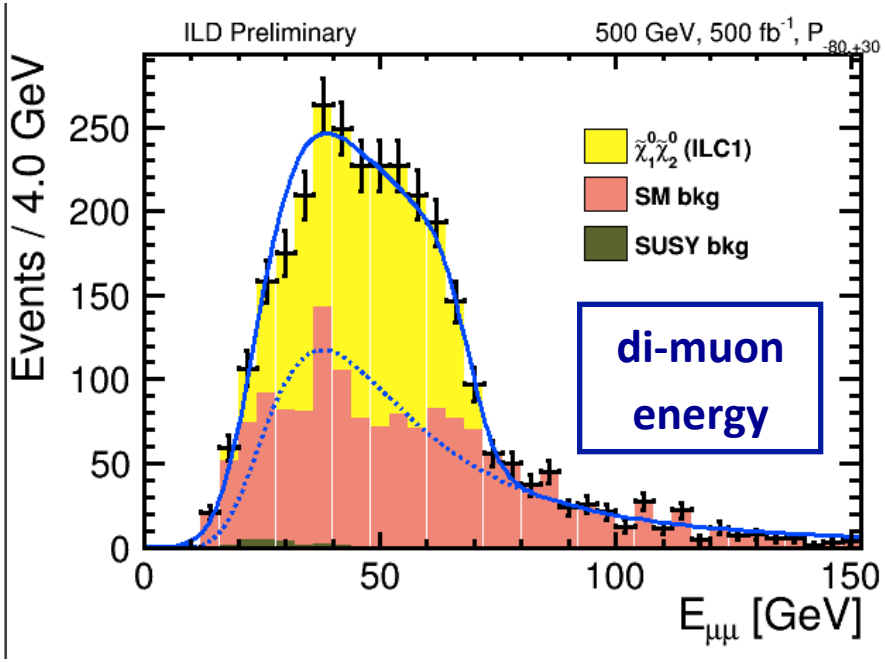
Extraction of Cross Section [work in progress]

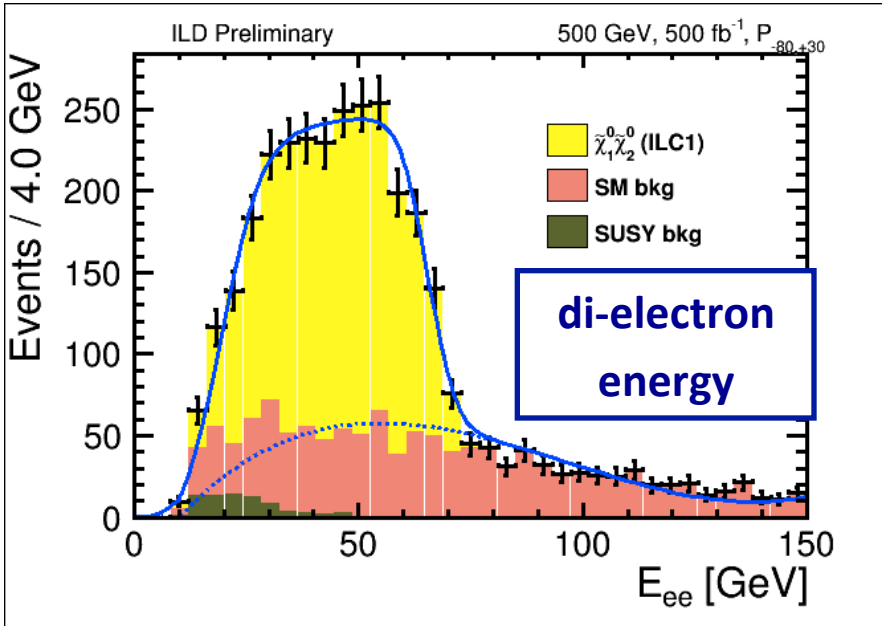
Strategy: Fit overall shape to estimate total number of signal events

Neutralino mixed production with leptonic decay

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

preliminary





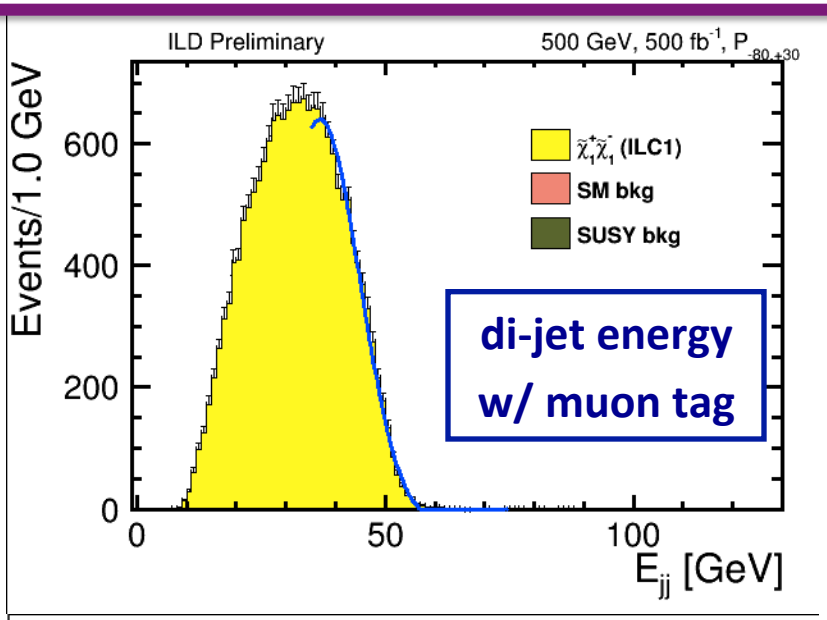
The results of Higgsino mass and cross section become input to the parameter fit to extract SUSY parameters (e.g. Wino and Bino masses, tanβ, etc.)

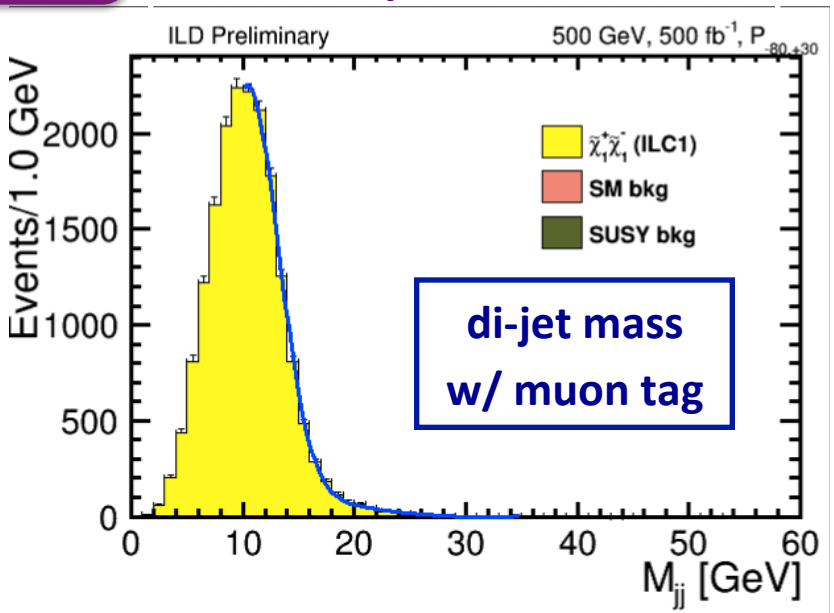
Chargino pair production with semileptonic decay

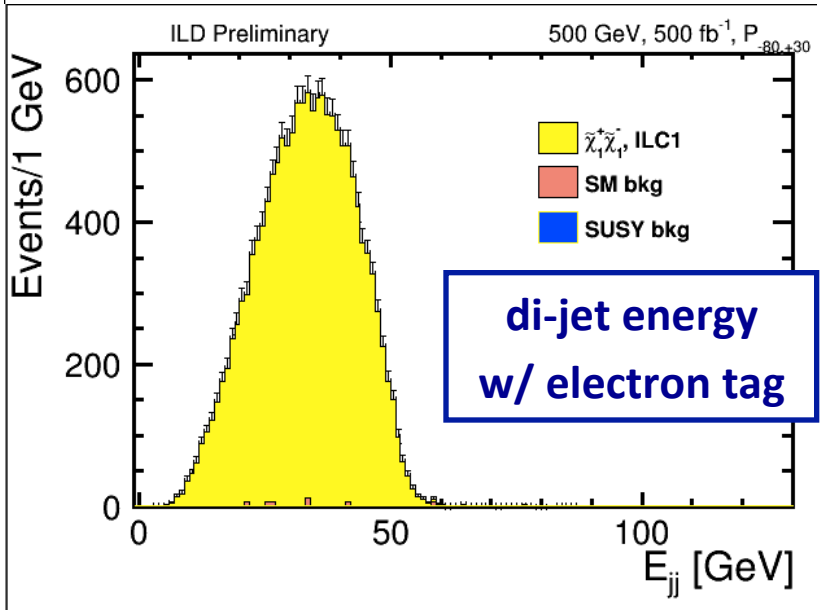
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq' \ell\nu$$

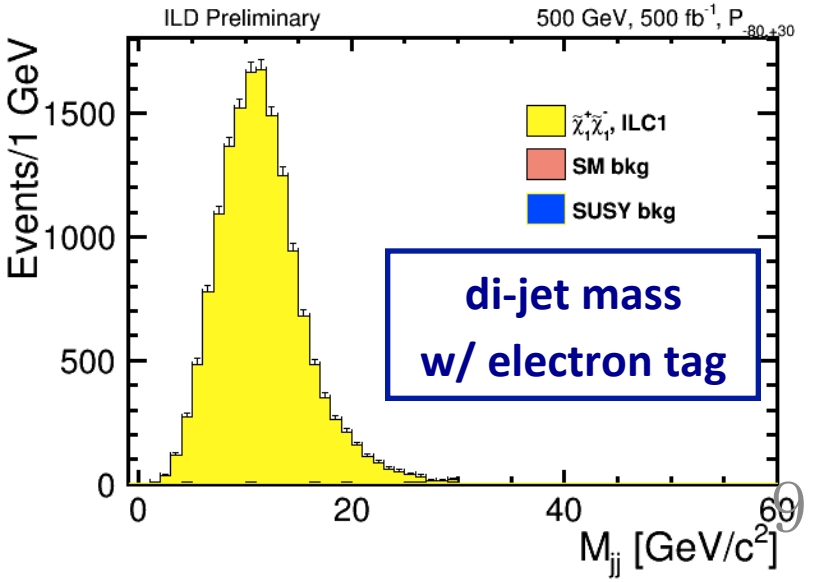
Polarization (Pe-,Pe+) = (-0.8, +0.3)

SM and SUSY backgrounds almost fully eliminated









Plans

- Continue extraction of edge and cross sections for neutralino mixed production ($\chi_1^0 \chi_2^0$) and chargino pair production ($\chi_1^+ \chi_1^-$)
- Tentative plan is to use newest SGV samples for dominant 4f bkg and simplified lepton selection
- If no major problem, we should produce some concrete results soon, and at same time start analysis which includes gamma-gamma overlay bkg

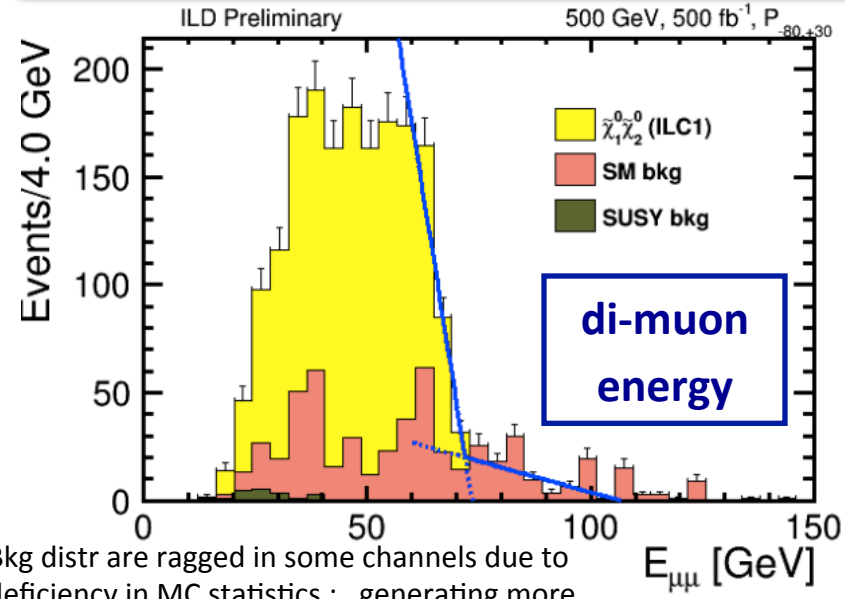
Additional Material

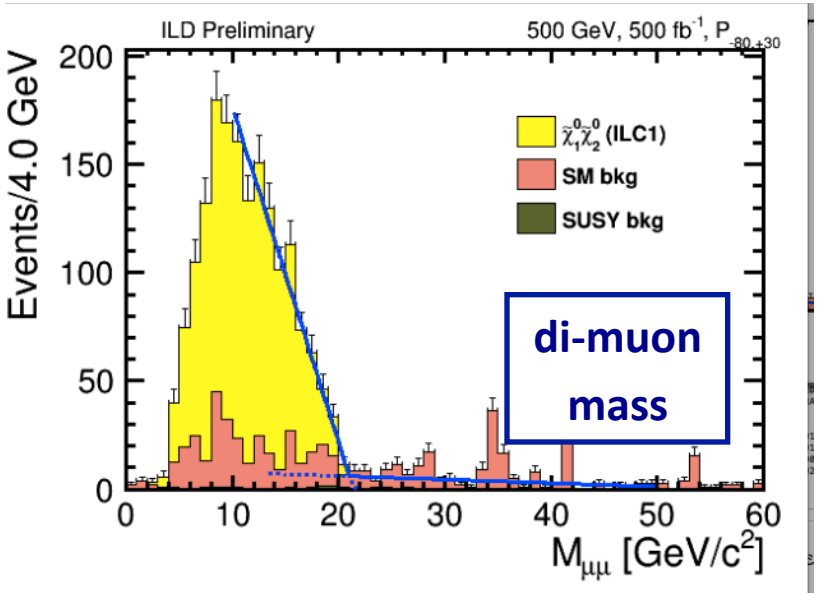
Neutralino mixed production with leptonic decay

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

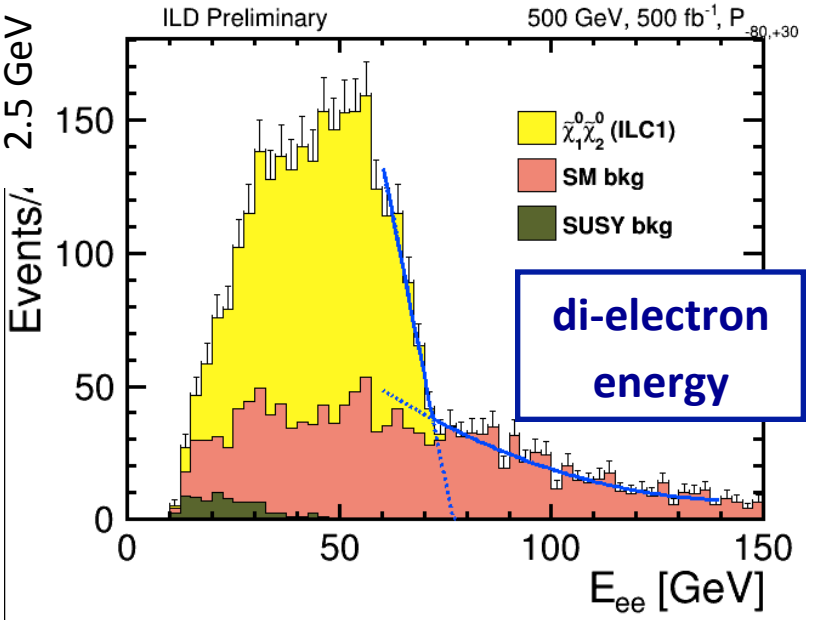
Polarization (Pe-,Pe+) = (-0.8, +0.3)

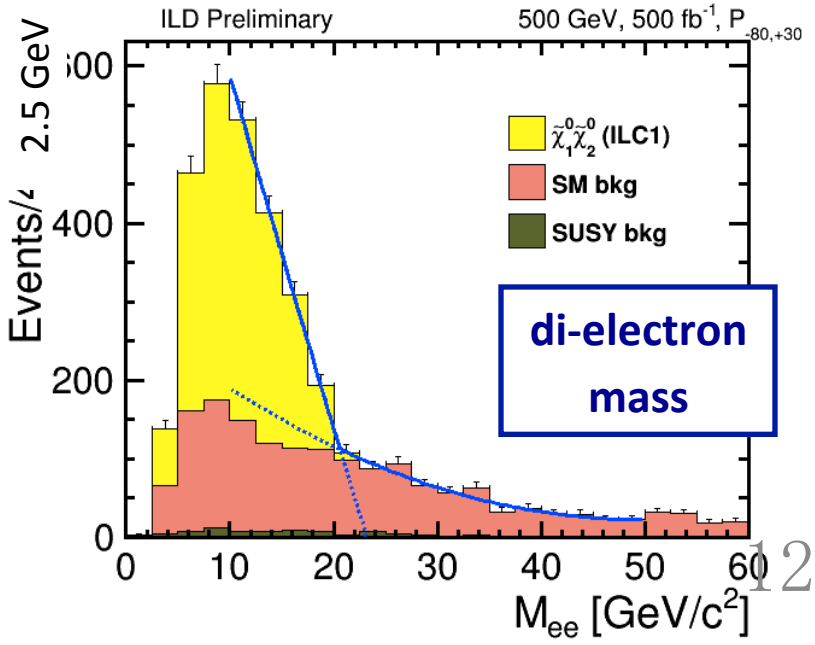
OLD VERSION



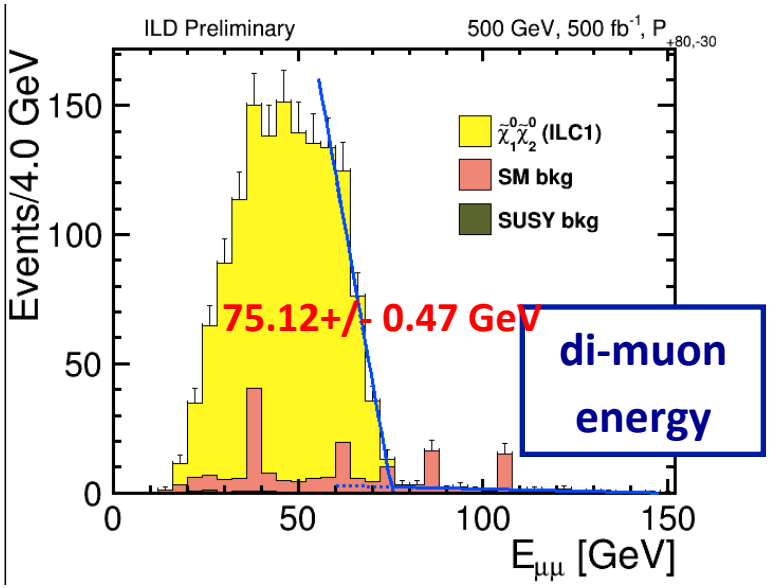


Bkg distr are ragged in some channels due to deficiency in MC statistics,; generating more





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

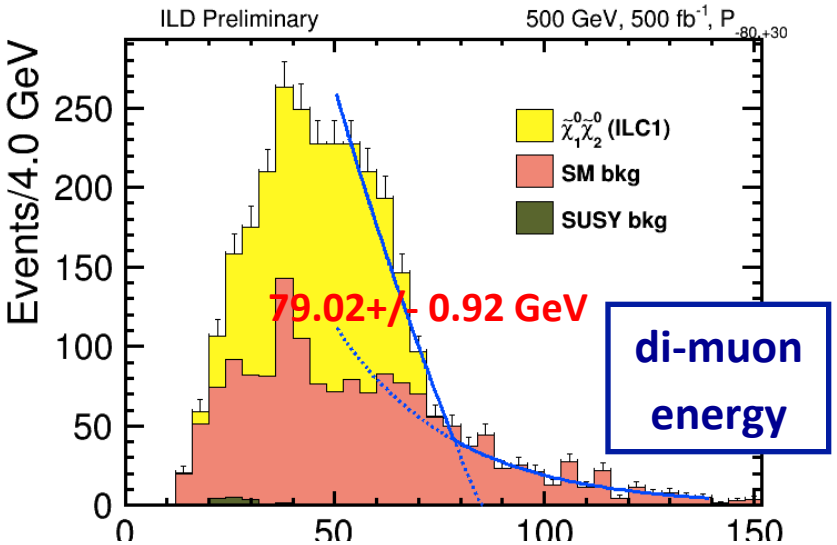


Neutralino mixed production with leptonic decay

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

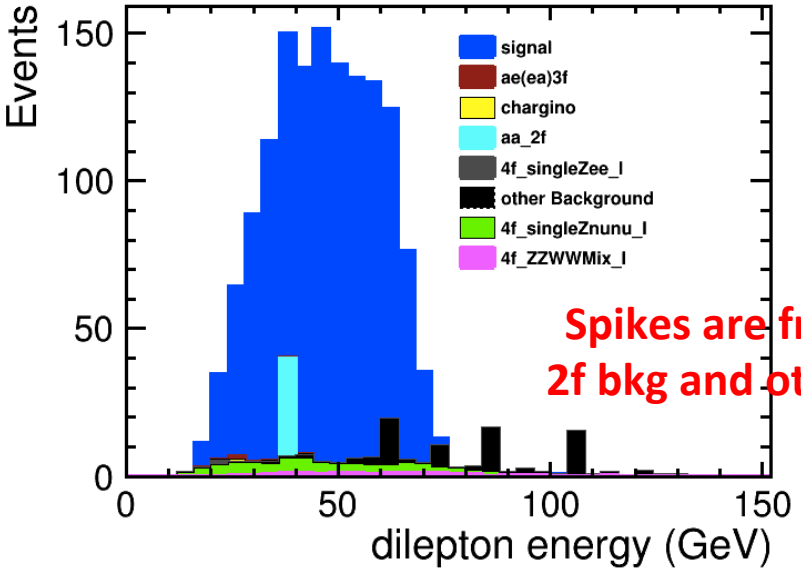
Comparing left and right pol

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

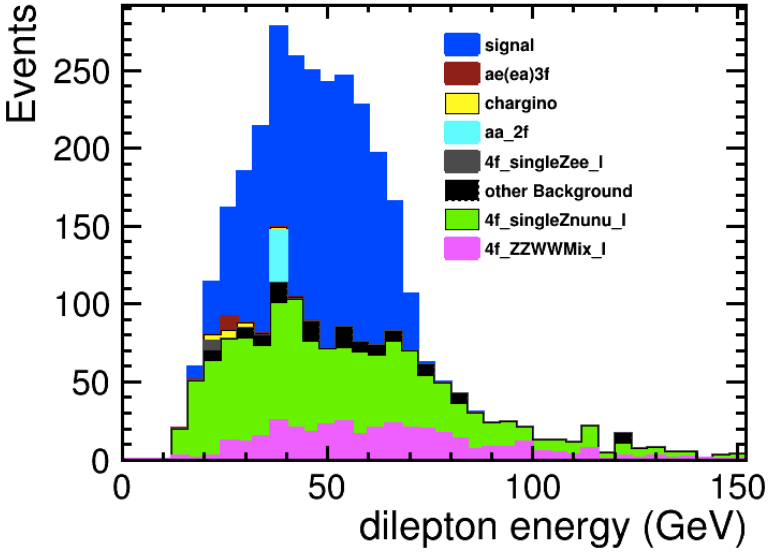


Do we need more statistics for right pol ?

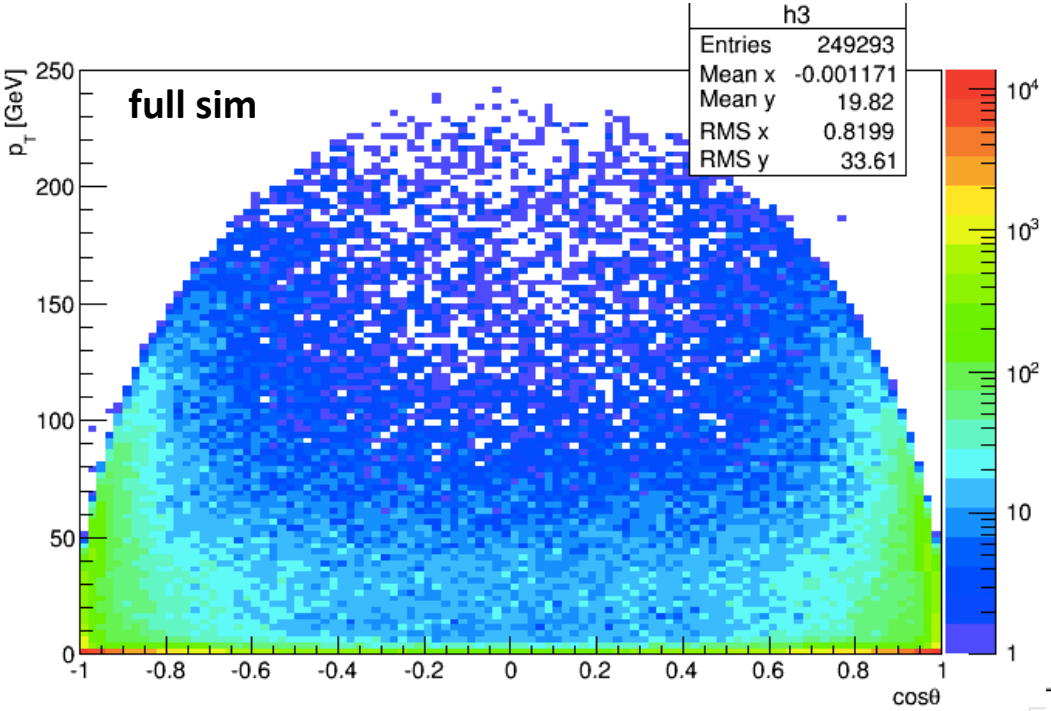
Such as for measuring cross section



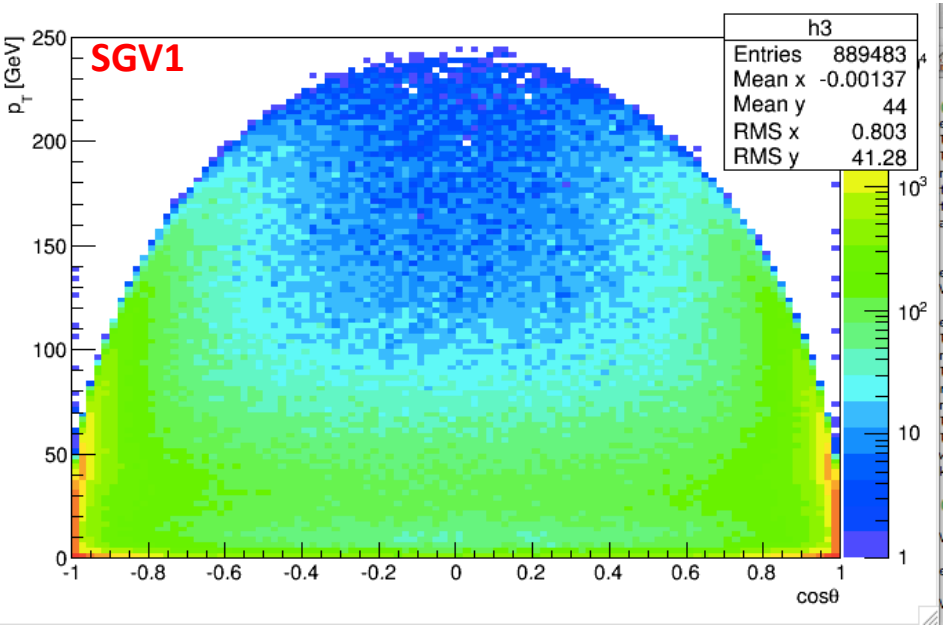
Spikes are from 2f bkg and others

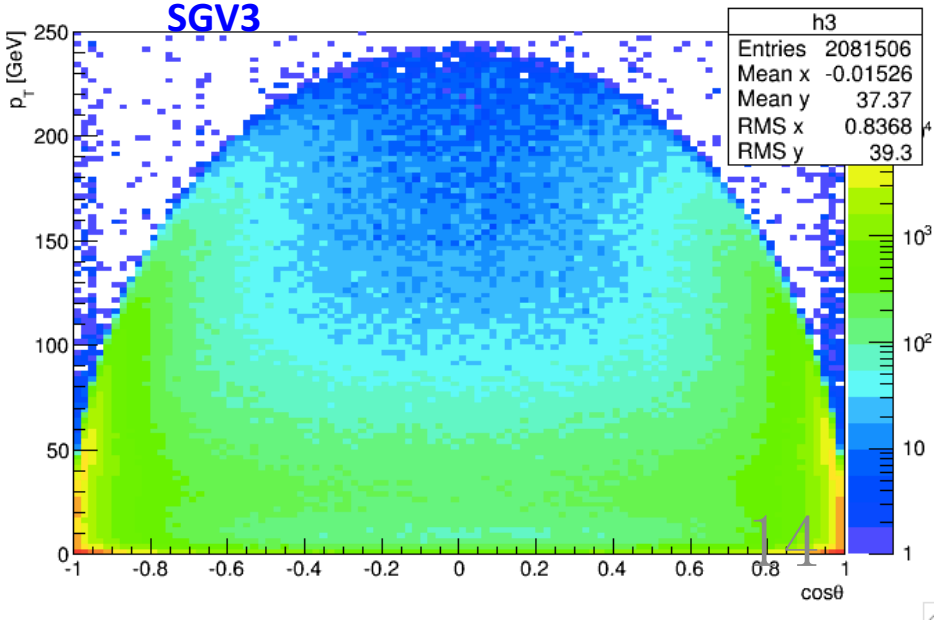


- **Comparison of reconstructed info between full sim and fast sim (Before isolated lepton finder)**



Electron Pt vs Cos

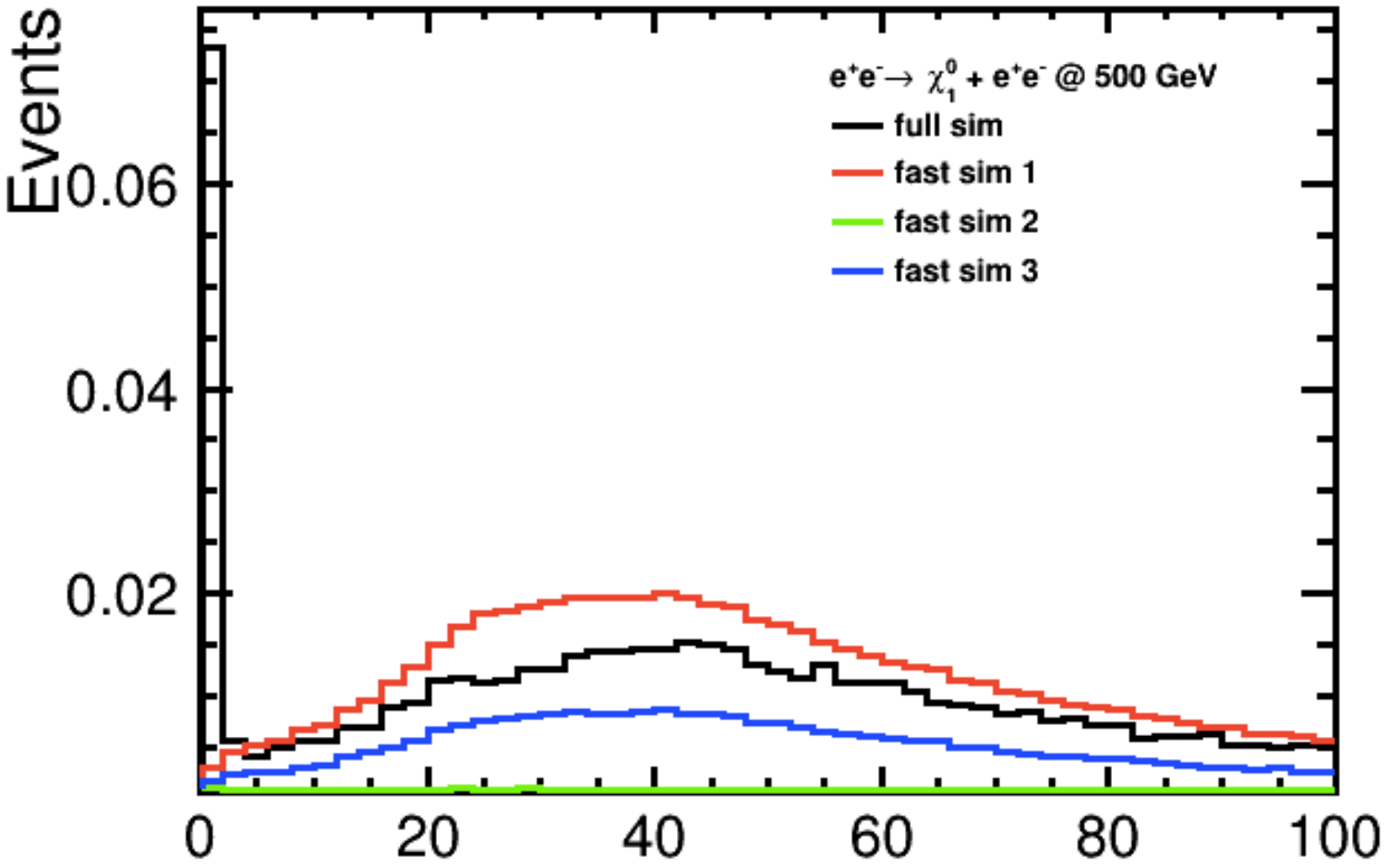




- **Comparison of reconstructed info between full sim and fast sim (AFTER isolated lepton finder)**

SGV1, SGV2, SGV3 (in order of date)
vs full sim
Electrons in SGV do not use cheating

Electron Pt

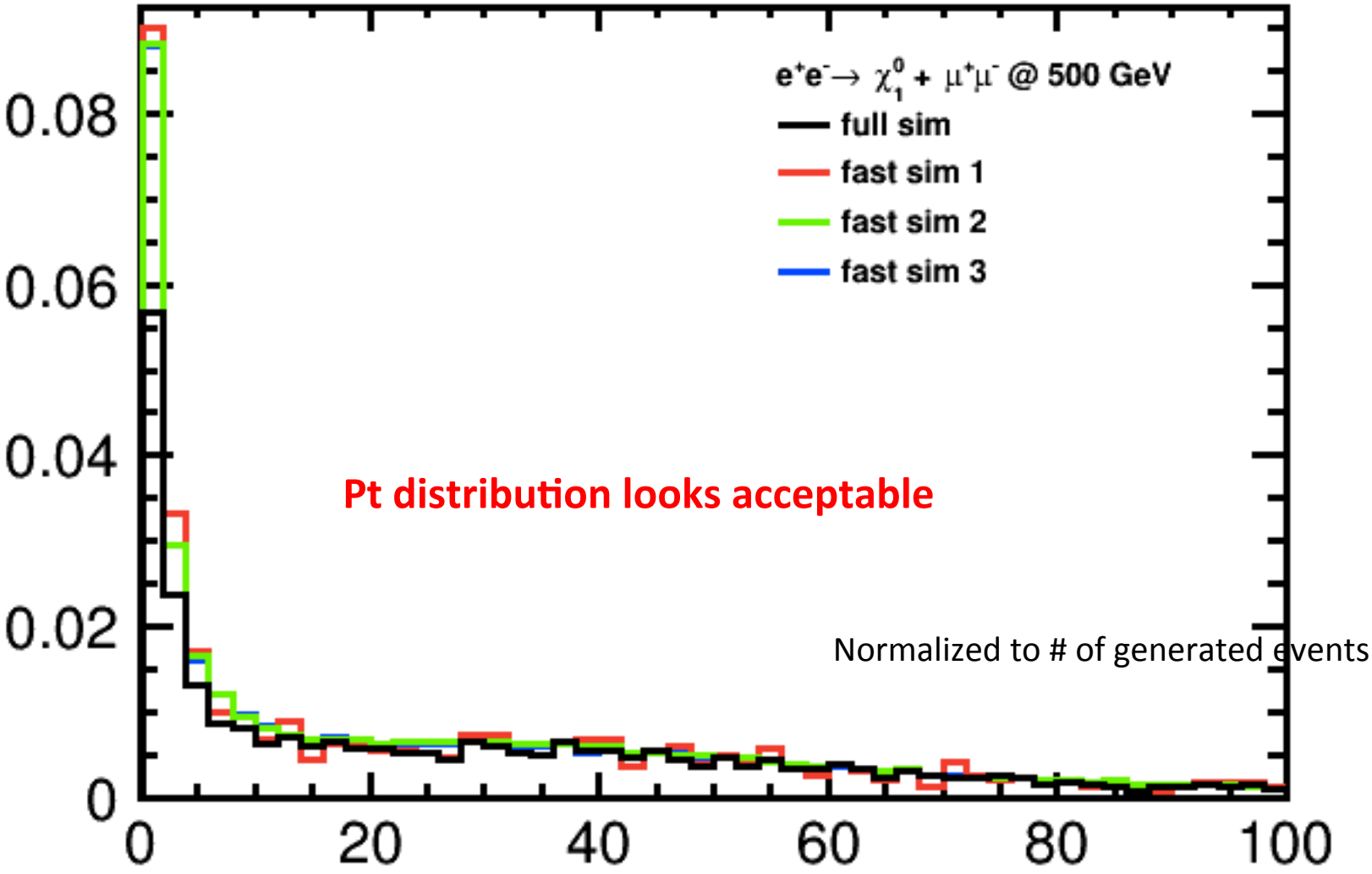


Normalized to # of generated events

- **Comparison of reconstructed info between full sim and fast sim (AFTER isolated lepton finder)**

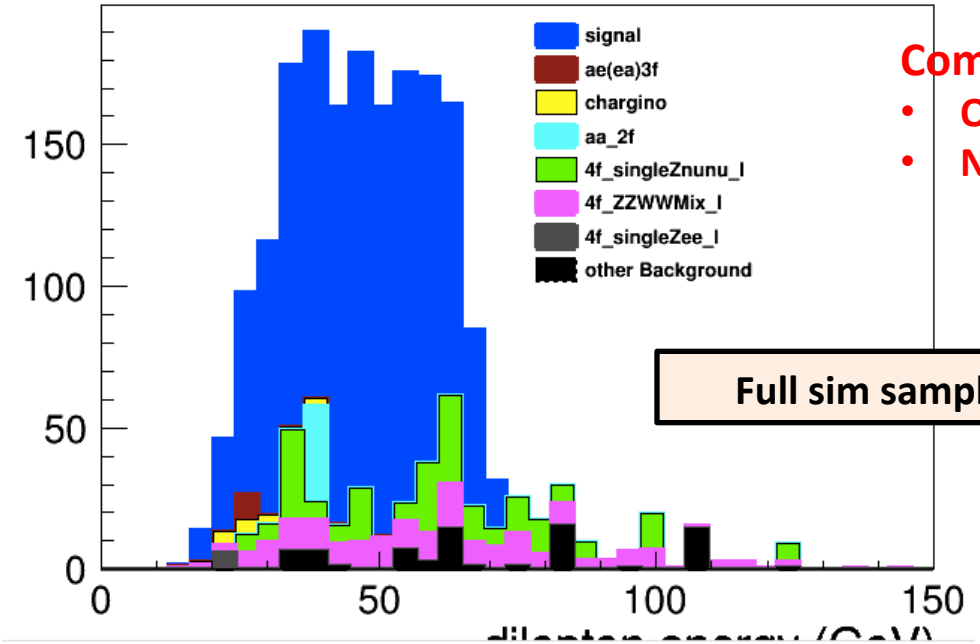
SGV1, SGV2, SGV3 (in order of date)
vs full sim
Muons in SGV use cheating

Muon Pt



Pt distribution looks acceptable

Normalized to # of generated events



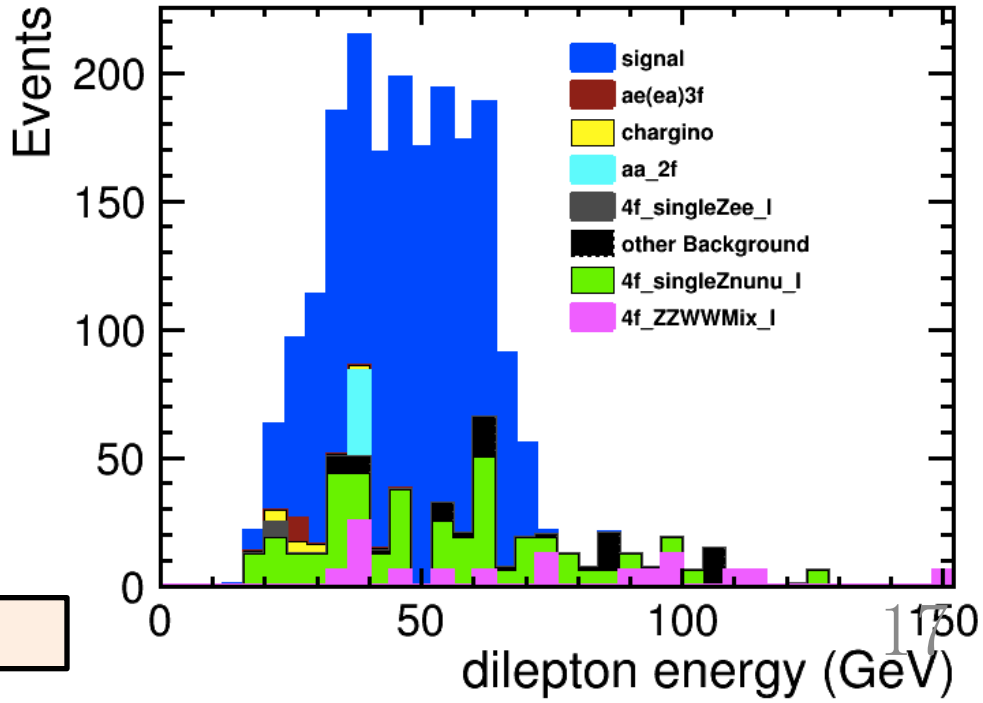
Compare effect of lepton finding methods

- **Old : MVA based**
- **New: simple cone energy and impact parameter**

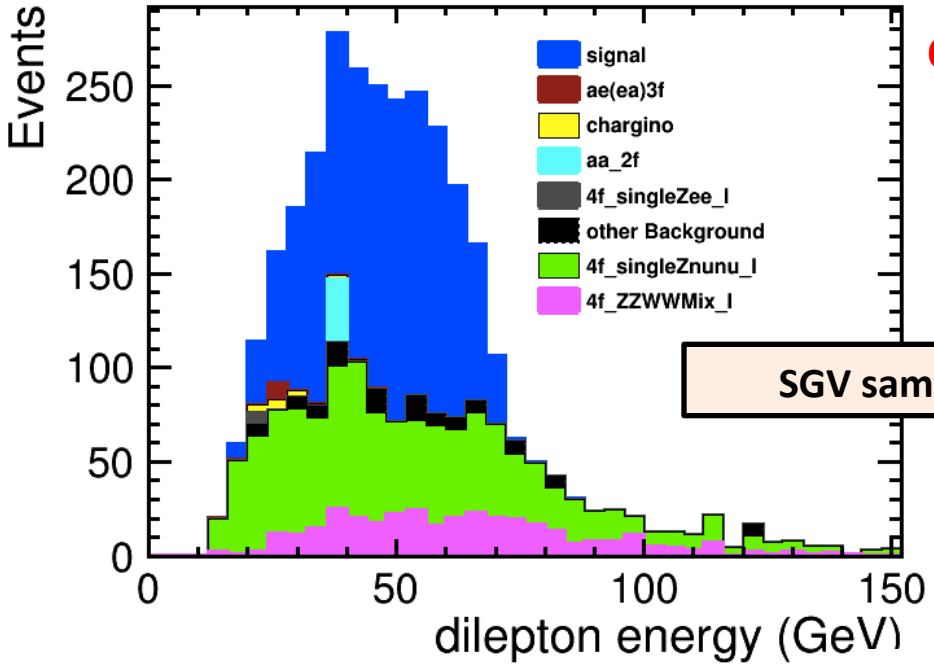
E_μμ, left pol

Full sim samples, old lepton finding

Not huge difference (?)



Full sim samples, new lepton finding

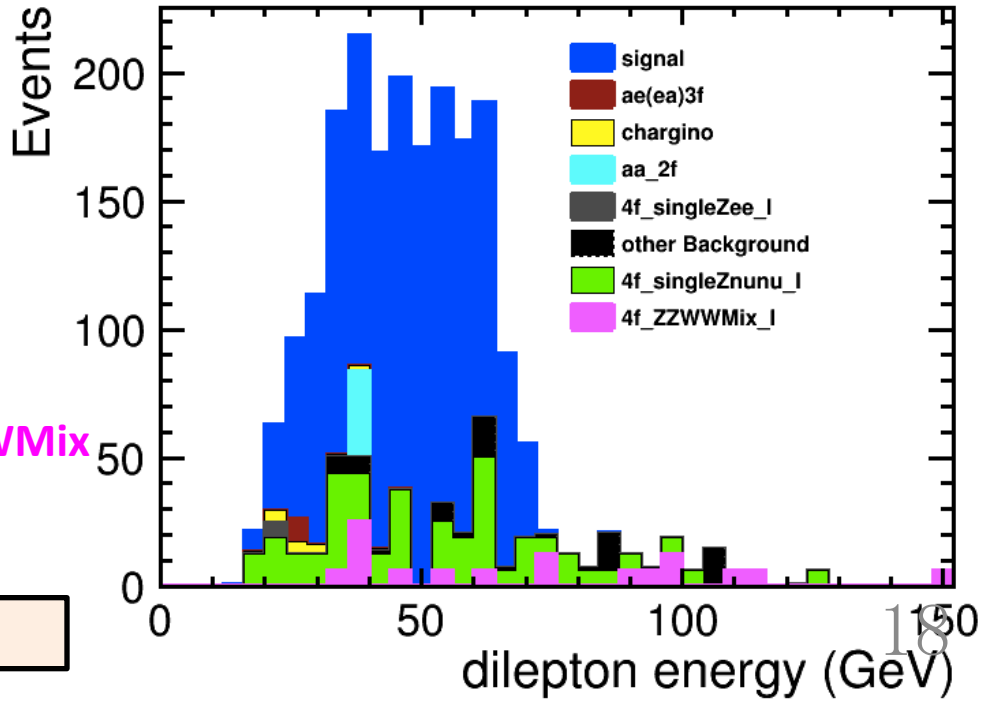


Compare full sim and SGV
lepton finding method:
simple cone energy and impact parameter

E_μμ, left pol

SGV samples, new lepton finding

Significant difference between full and SGV



SGV for 4f_singleZnunu and 4f_ZZorWWMix

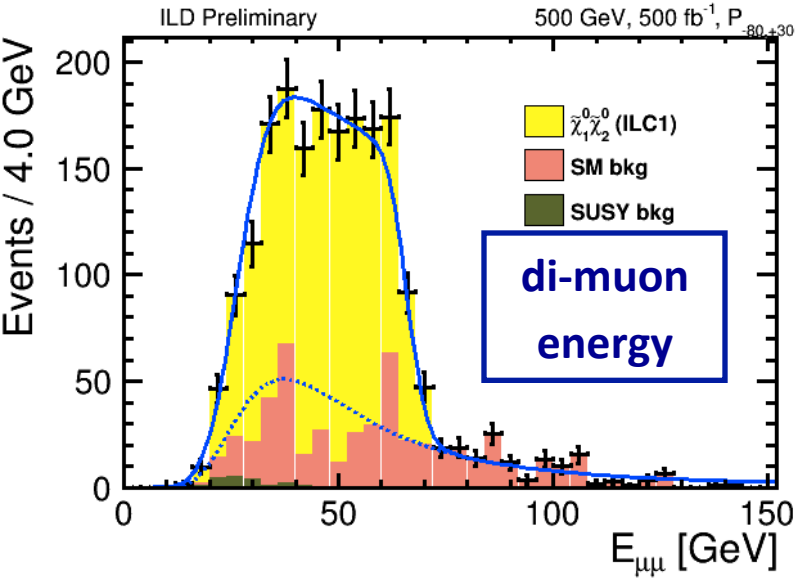
Full sim samples, new lepton finding

Extraction of Cross Section

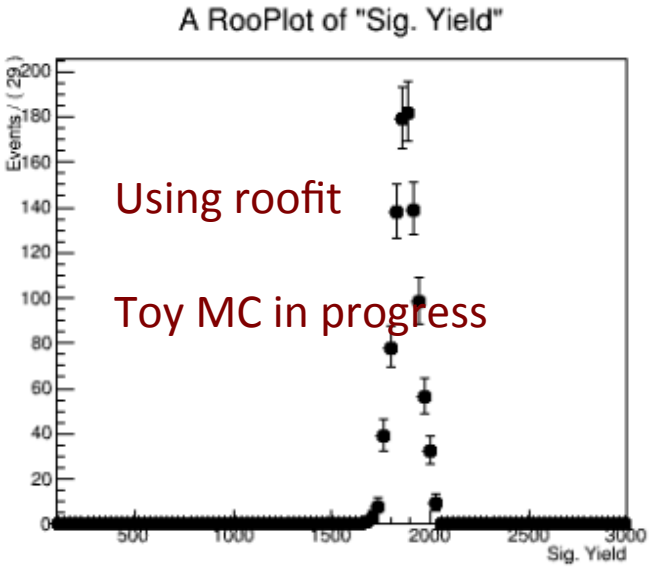
Neutralino mixed production with leptonic decay

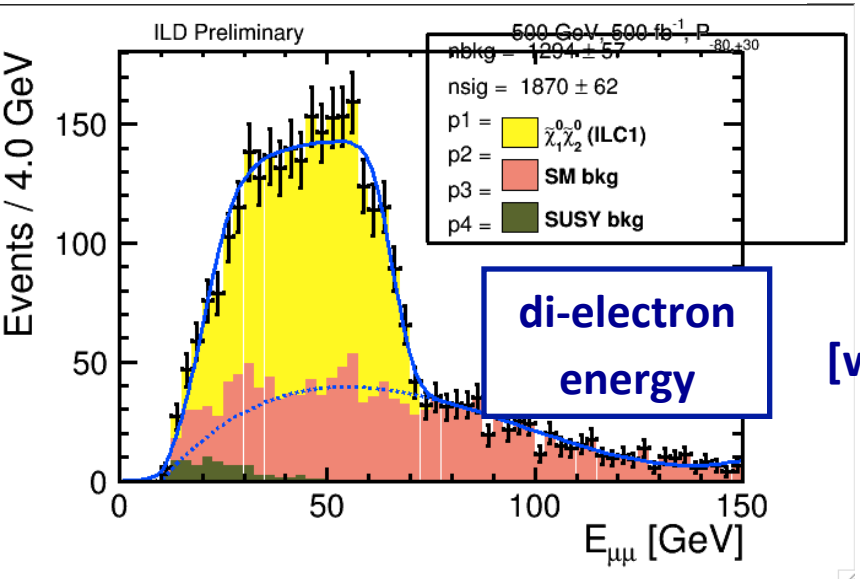
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+\ell^-$$

Strategy: Fit overall shape to estimate total number of signal events

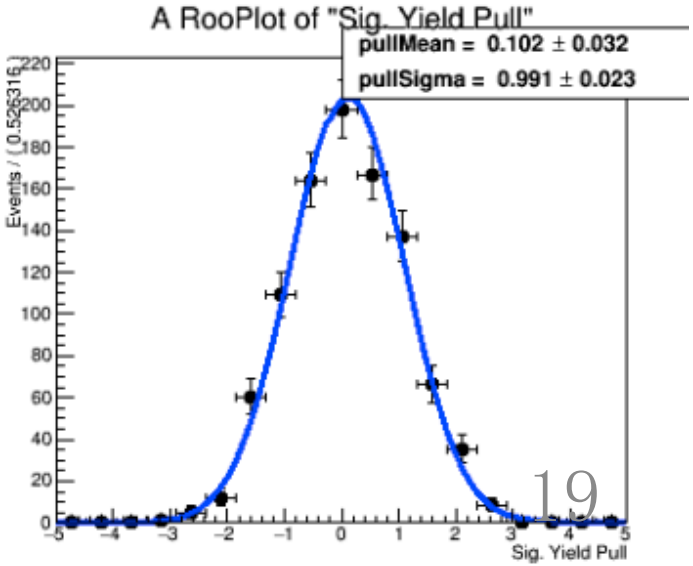


Precision about 3%(?)





[work in progress]



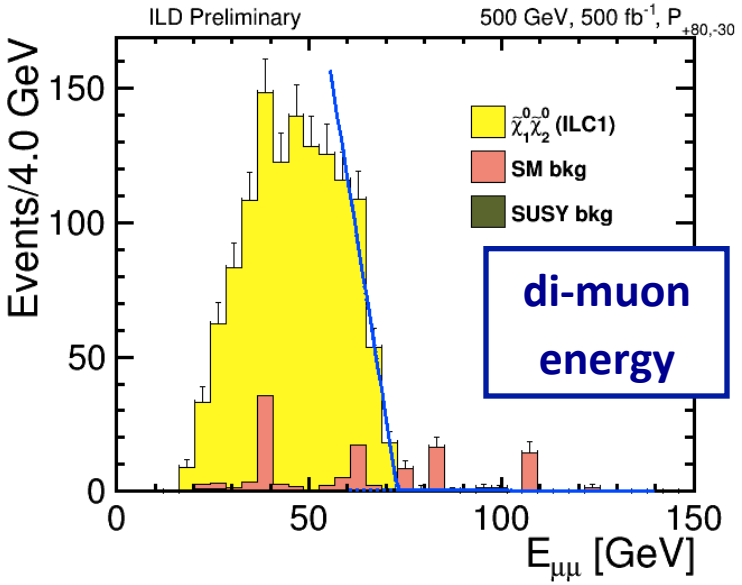
Neutralino mixed production with leptonic decay

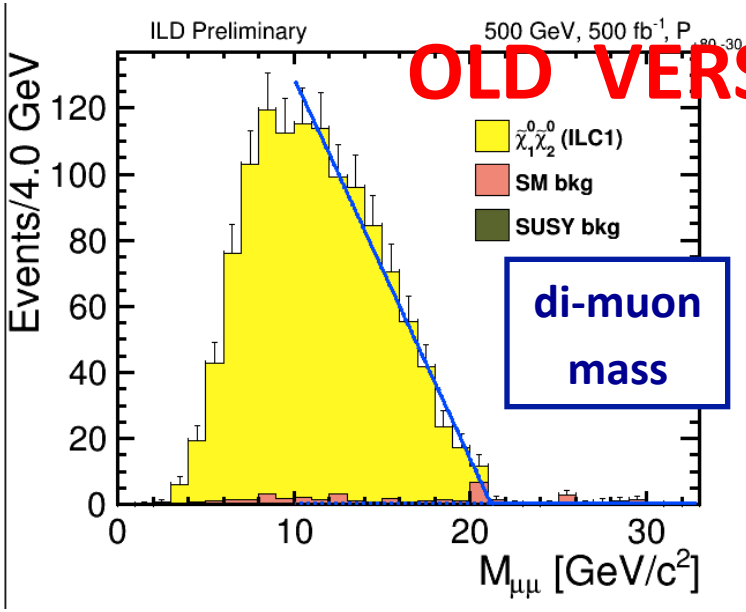
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

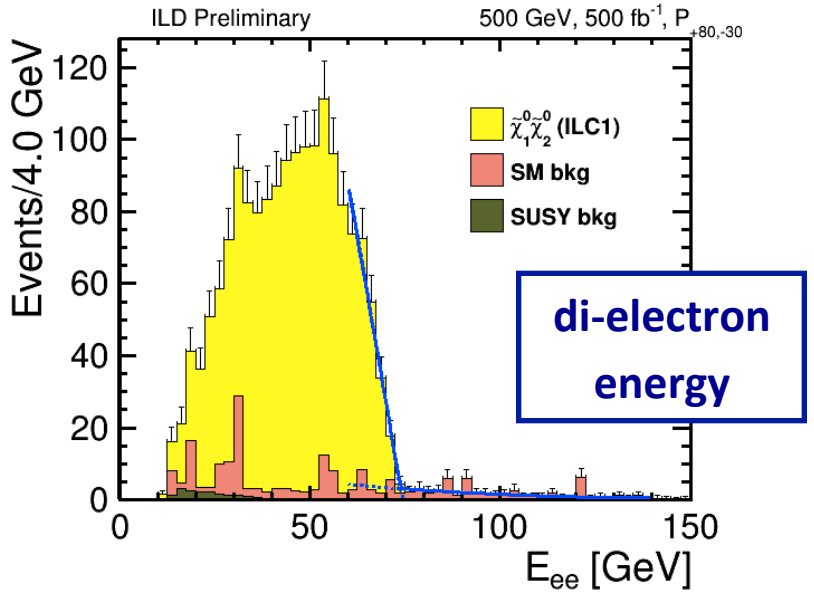
Polarization (Pe-, Pe+) = (+0.8, -0.3)

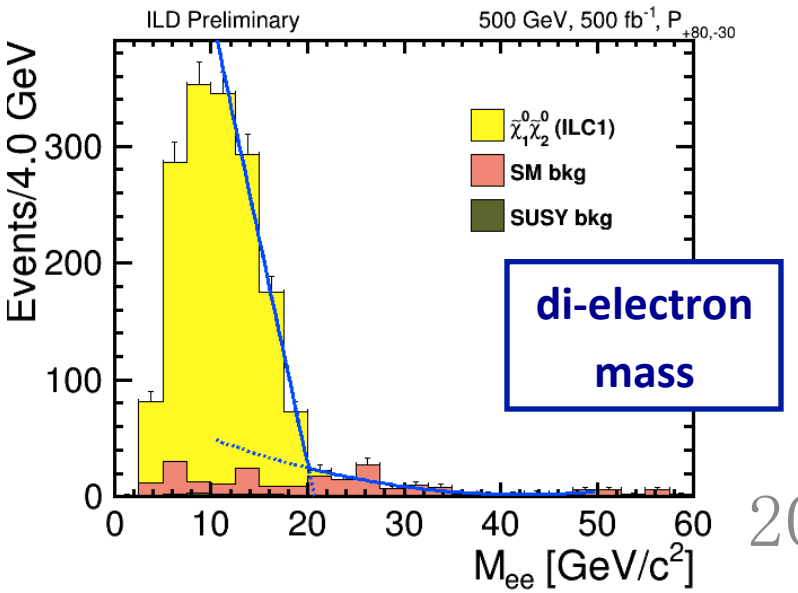
→ better S/B ratio w.r.t. left-handed polarization

OLD VERSION







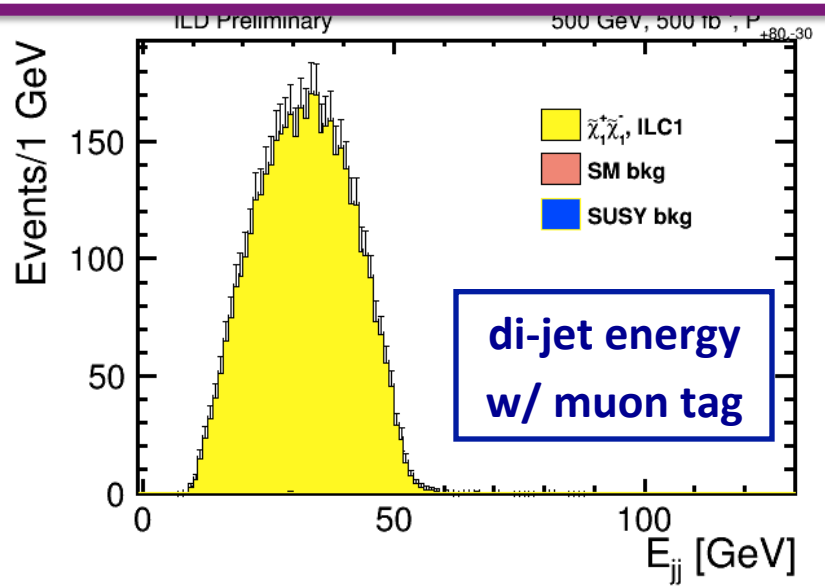


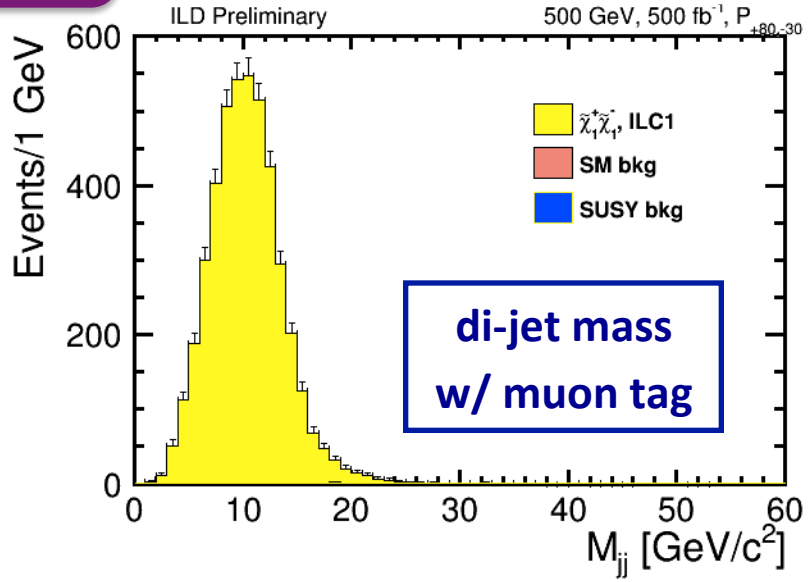
Chargino pair production with semileptonic decay

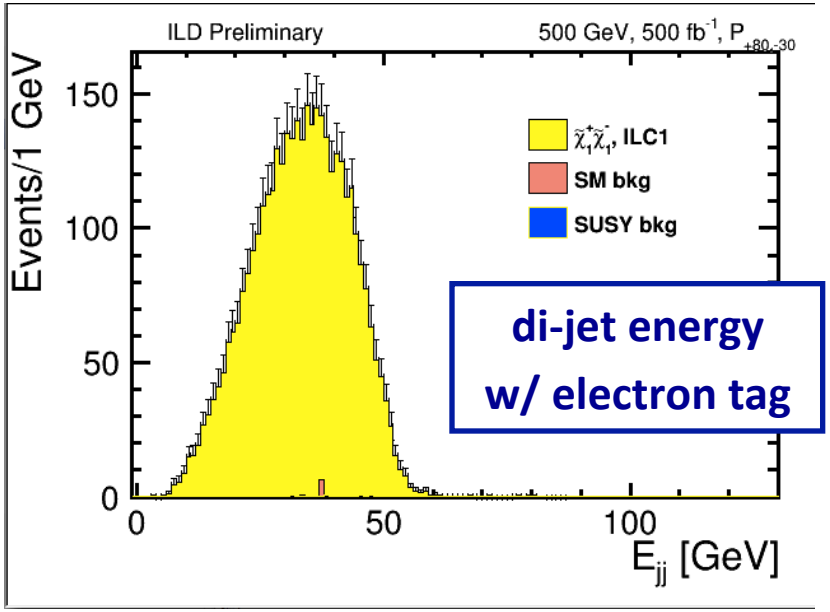
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq' \ell\nu$$

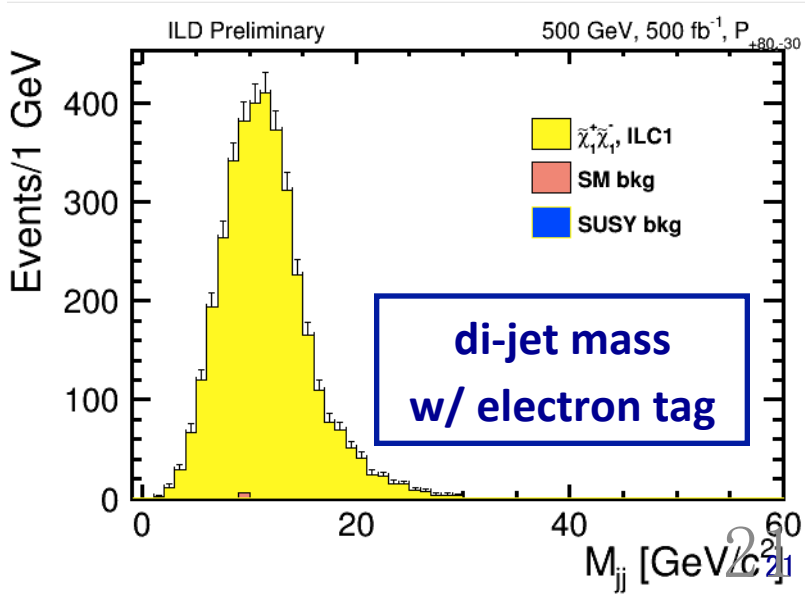
Polarization (Pe-, Pe+) = (+0.8, -0.3)

distribution similar to left-handed pol., but smaller signal

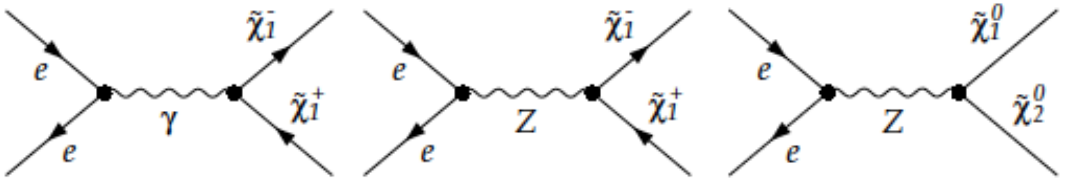








Benchmarks in this Study



RNS model (Radiatively-driven natural SUSY)

- **4 light Higgsinos:** $\tilde{\chi}_1^0$ (LSP) $\quad \tilde{\chi}_2^0 \quad \tilde{\chi}_1^+ \quad \tilde{\chi}_1^-$

- **ΔM about 10-20 GeV complies with naturalness** (ISR tag not needed)

This study: **√s = 500 GeV**
Full detector simulation

Currently studying ILC1 benchmark

(Pe-, Pe+)	(-1.0,+1.0)	(+1.0,-1.0)
$\sigma(\chi_1^+\chi_1^-)$ [fb]	1800	335
$\sigma(\chi_1^0\chi_2^0)$ [fb]	491	379

BR($\chi_1^+ \rightarrow \chi_1^0$ qq')	67%
BR($\chi_1^+ \rightarrow \chi_1^0$ lν) (l=e,μ)	22%
BR($\chi_2^0 \rightarrow \chi_1^0$ qq')	58%
BR($\chi_2^0 \rightarrow \chi_1^0$ ll) (l=e,μ)	7.4%

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
$M(\chi_2^0)$ [GeV]	124.0	157.8
$M(\chi_3^0)$ [GeV]	267.0	538.8

Higgs precision measurements useful for parameter determination

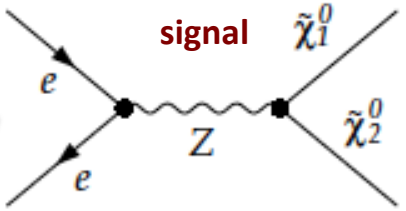
Defined at GUT scale
Defined at weak scale
Observables

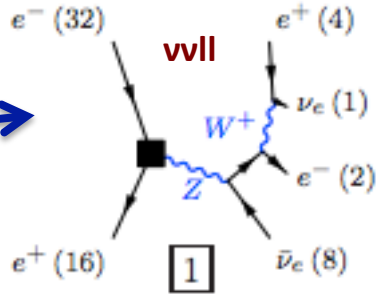
Event Selection

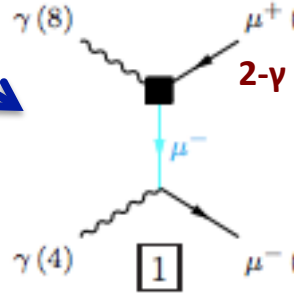
Neutralino mixed production with leptonic decay

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

- 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





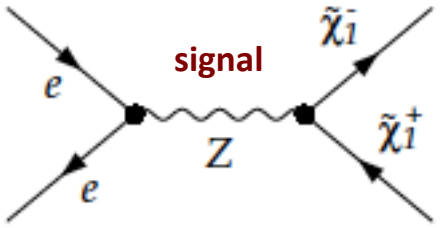


Chargino pair production with semileptonic decay

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

- 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)



SUSY Parameter Determination

[S.-L. Lehtinen]

Why?

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

How?

- **Global χ^2 fit of SUSY parameters to observables using Fittino** [hep-ph/0412012]
- **Fit GUT scale (NUHM2) parameters**

Reminder:

Benchmark	ILC2
M_0 [GeV]	5000
$M_{1/2}$ [GeV]	1200
A_0 [GeV]	-8000
tanβ	15
μ [GeV]	150
M_A [GeV]	1000

Defined at GUT scale
Defined at weak scale

Observables and assumed precision for ILC2 benchmark

observable	value	uncertainty
mass $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$	$\sim$ 160 GeV	0.2 GeV
$BR(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-)$	0.106	0.1
$BR(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 q\bar{q})$	0.590	0.1
$BR(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 q\bar{q}')$	0.671	0.1
$BR(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 l\nu_l)$	0.329	0.1
$\sigma(\tilde{\chi}_1^0\tilde{\chi}_2^0)$, 4 polarisations	$140 - 300$ fb^{-1}	1%
$\sigma(\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp)$, 4 polarisations	$200 - 970$ fb^{-1}	1%

- Uncertainty to be updated with results from simulation study
- Study required precision that allows for full parameter determination

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
- Evis – Eγmax < 40 GeV : visible energy (very small for signal)
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- Pt_mis > 10 GeV
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- 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)

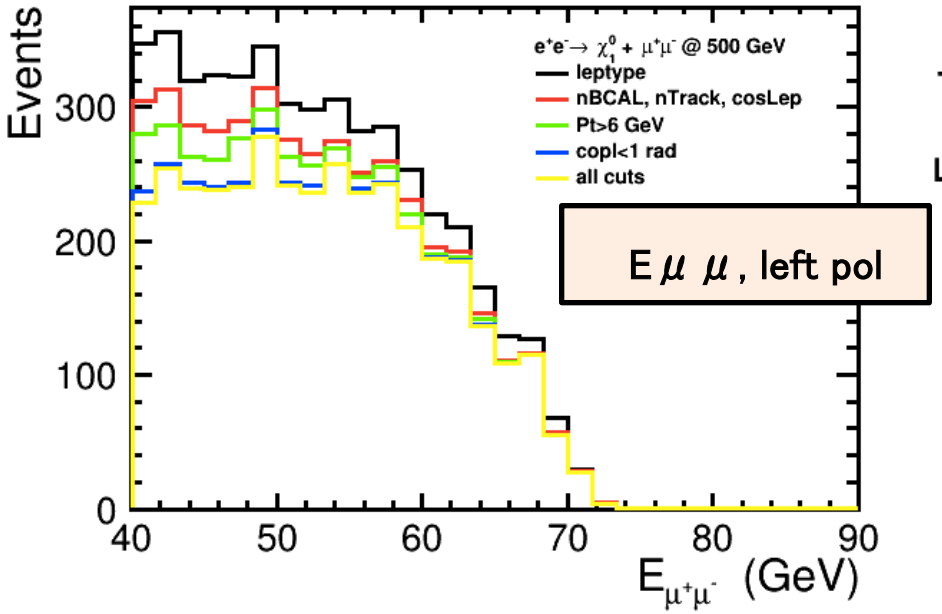
Kinematic edge is a function of Higgsino mass and ΔM

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

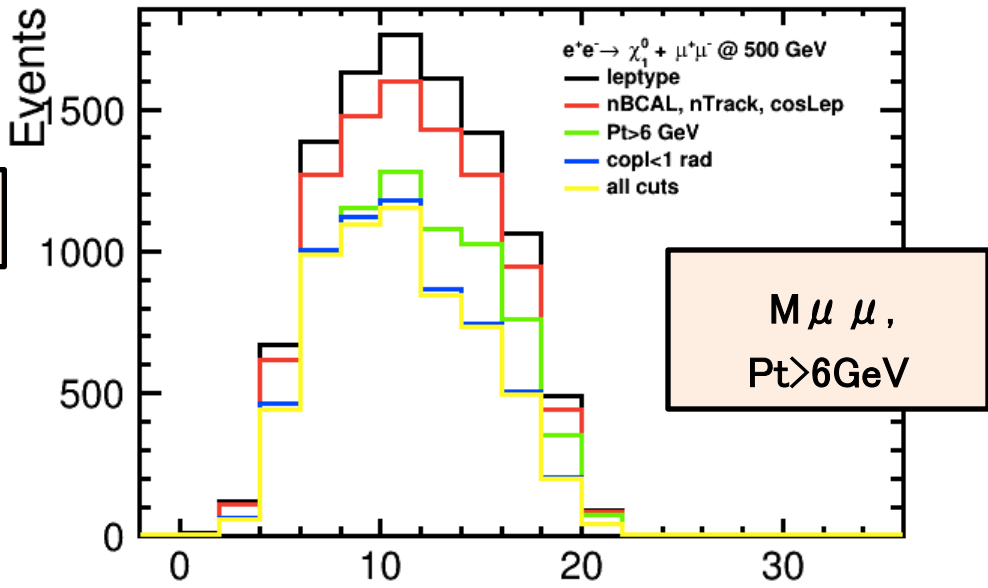
	sig	bkg	4f_l	aa_2f	ae_3f	SUSY bkg
xsec	300.8	3.00E6	10566.2	2.68E6	261580	1065.2
N_gen	150395	1.50E9	5.28E6	1.34E9	1.31E8	532585
Lep_type nTrack=2	1974	9.1E8	444255	8.9E8	2.2E7	2426
BCAL veto	1950	6.0E6	149871	5.5E6	965354	2411
Pt_lep,1,2	1675	2.0E6	105721	1.4E6	295459	1986
cosθ_lep	1624	1.3E6	56001	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)

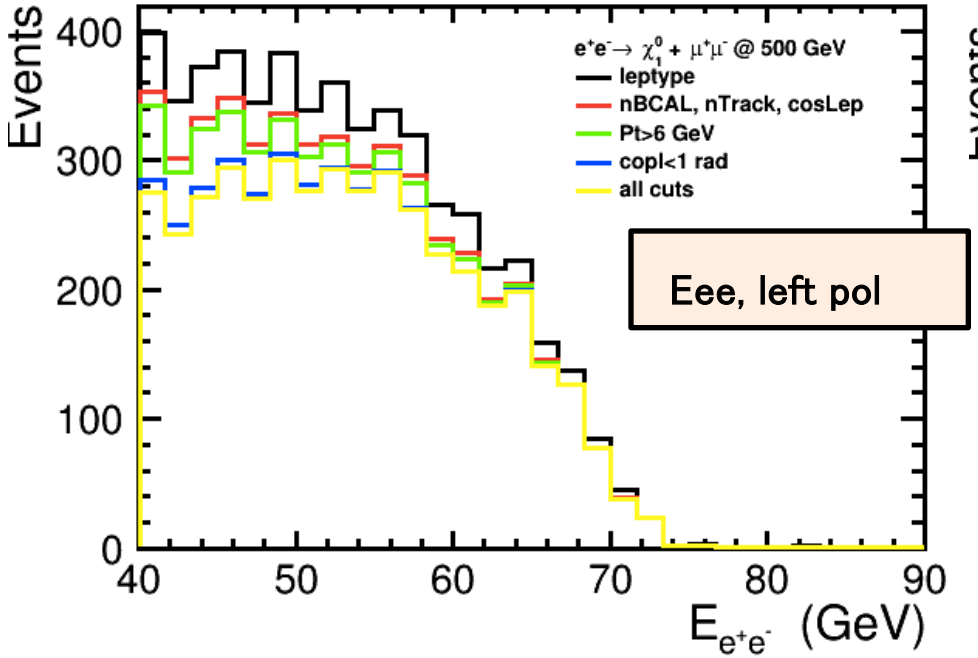
	sig	bkg	4f_l	aa_2f	ae_3f	SUSY bkg
Xsec [fb]	1065.2	3.00E6	10566.2	2.68E6	261580	300.8
N_gen	532585	1.50E9	5.28E6	1.34E9	1.31E8	150395
nLep=1 BCAL veto	57983	1.5E9	443296	1.2E6	860530	1135
Ptmis	38240	2.7E6	377010	465397	519308	964
Jet_coplanarity	26085	1.5E6	86399	83683	109325	531
Jet_cosθ nTrack (per 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



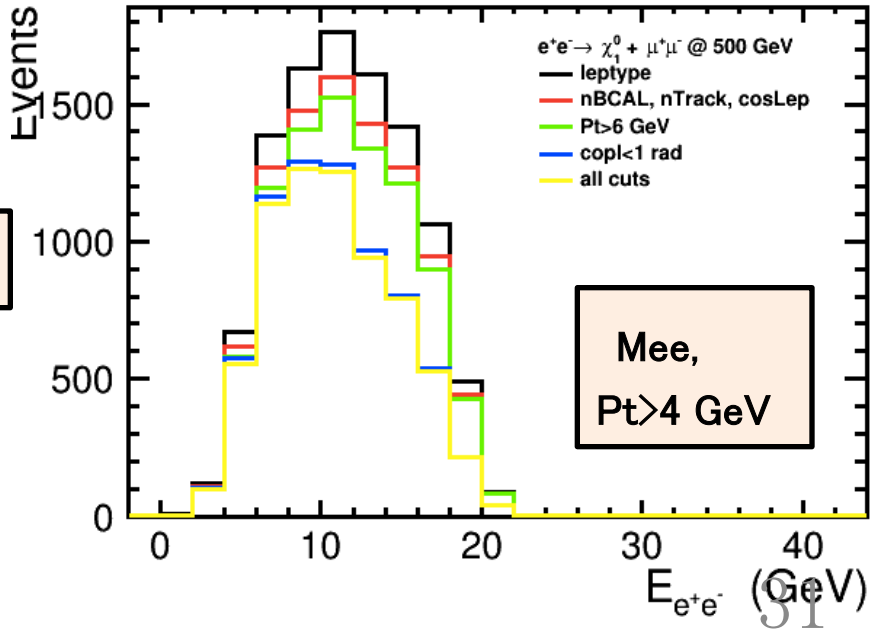
Eμ μ, left pol



Mμ μ,
Pt>6GeV



Eee, left pol



Mee,
Pt>4 GeV