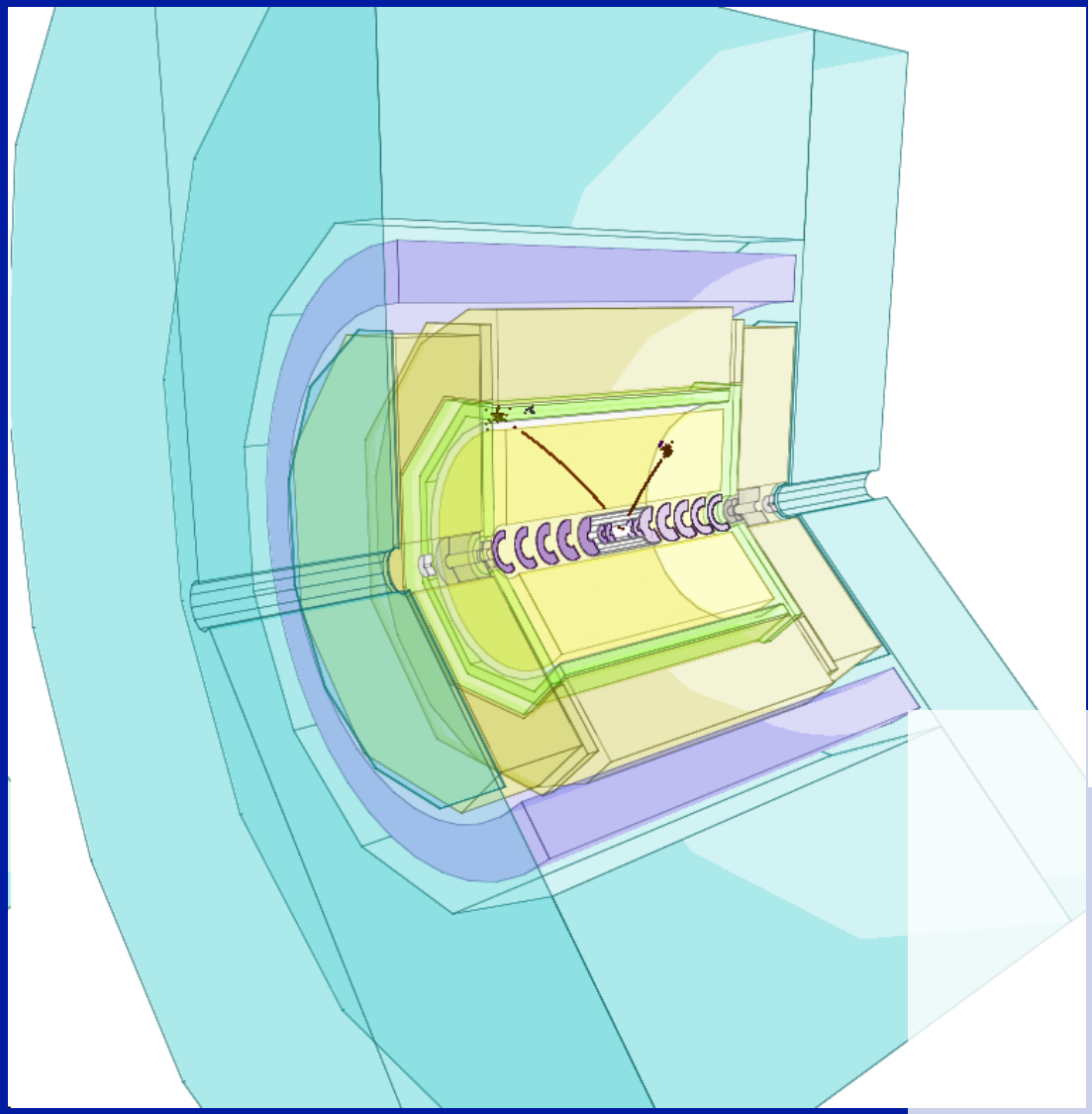
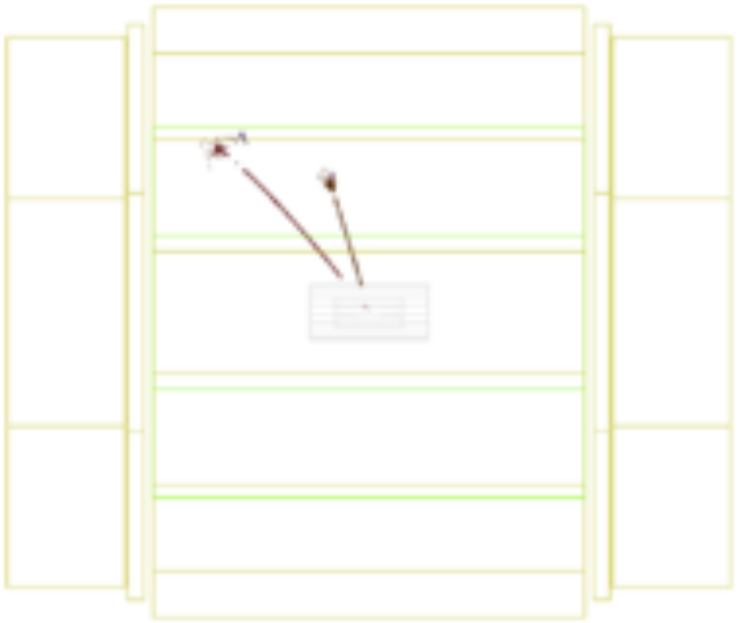
Characterizing Light Higgsinos from Natural SUSY at ILC $\sqrt{s}$ = 500 GeV





Jacqueline Yan (KEK)

Friday Meeting

7/29/2016

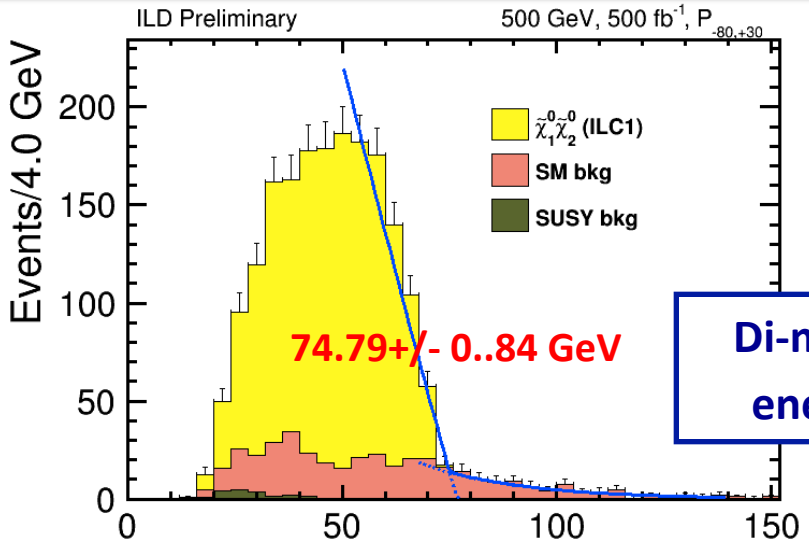
Neutralino mixed production with leptonic decay

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

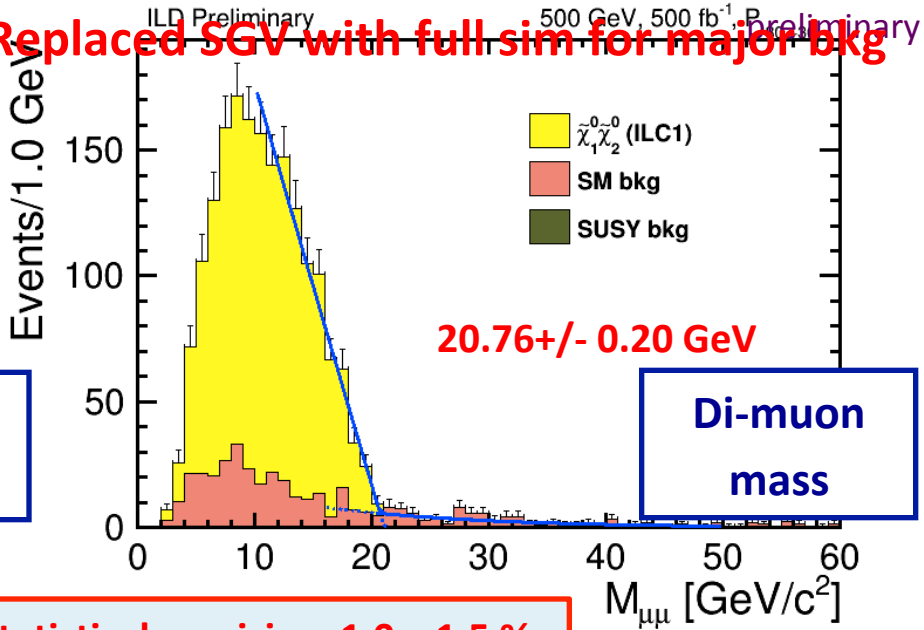
Polarization (Pe-,Pe+) = (-0.8, +0.3)

NEW

Replaced SGV with full sim for major bkg

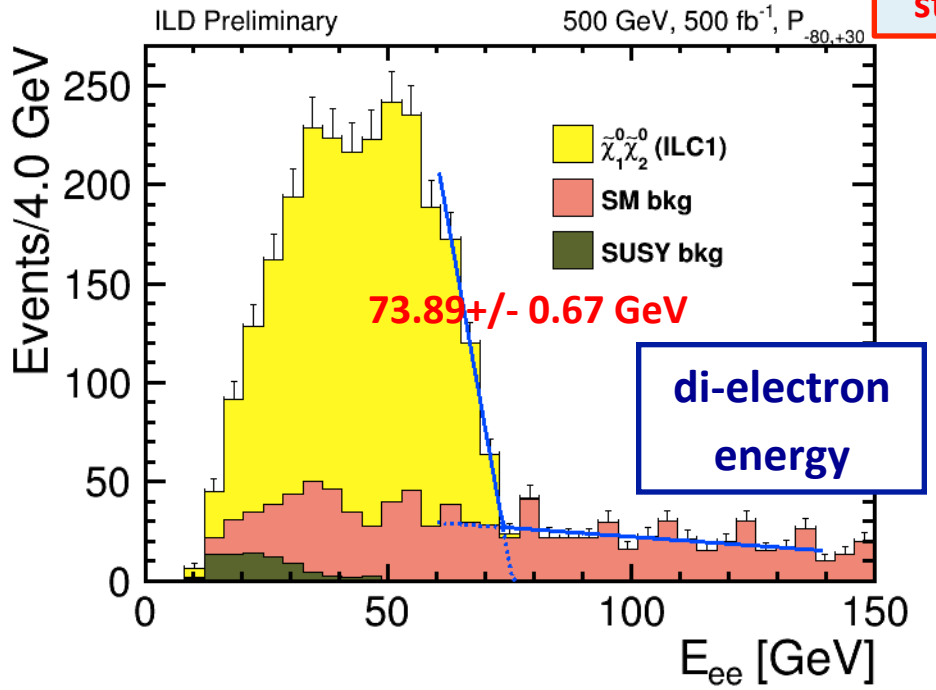


Di-muon energy

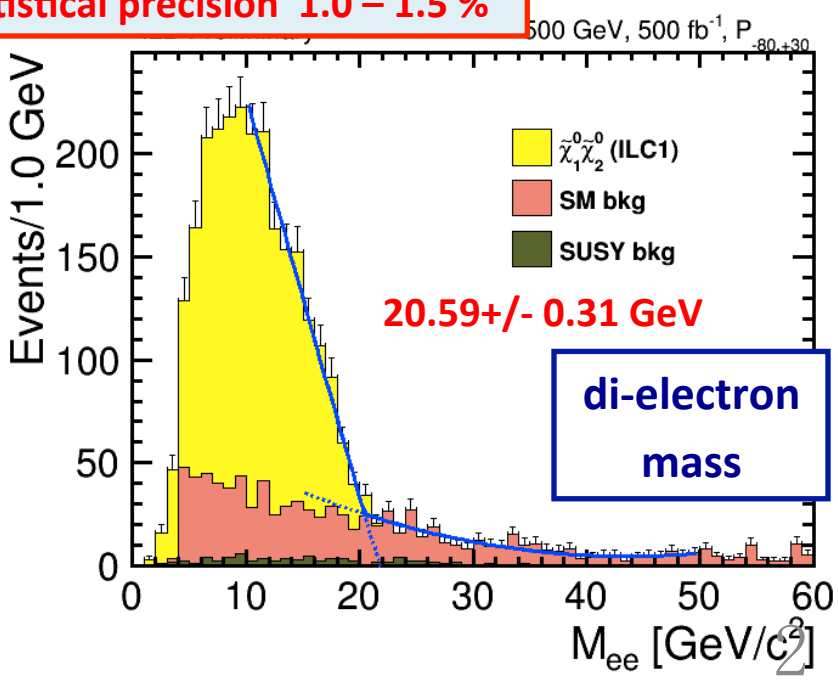


Di-muon mass

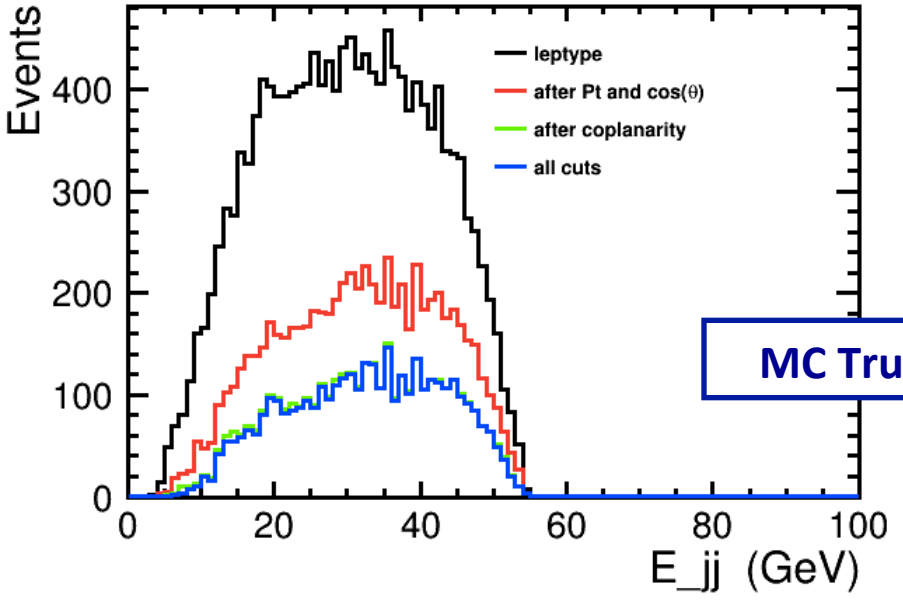
statistical precision 1.0 – 1.5 %



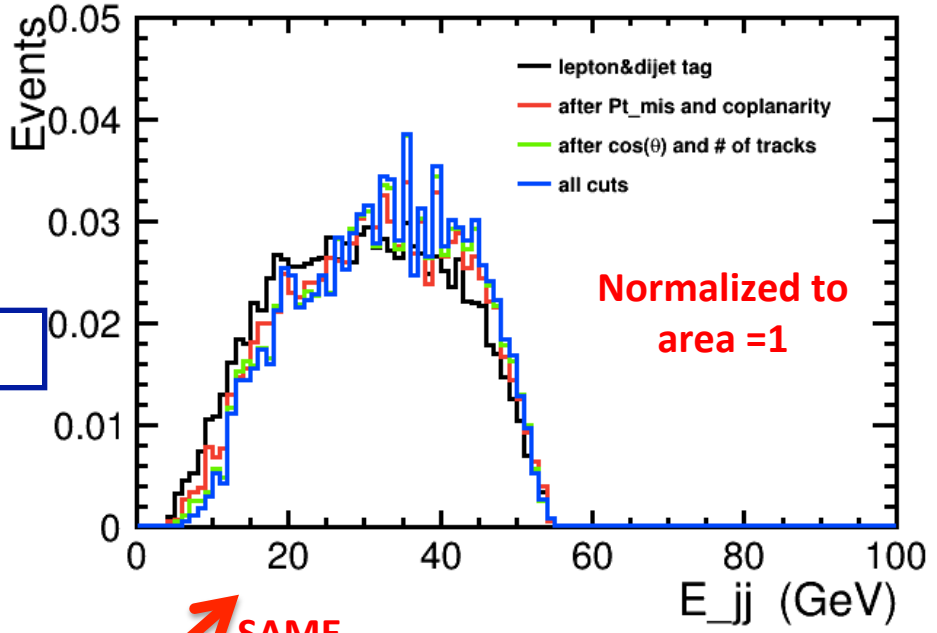
di-electron energy



di-electron mass



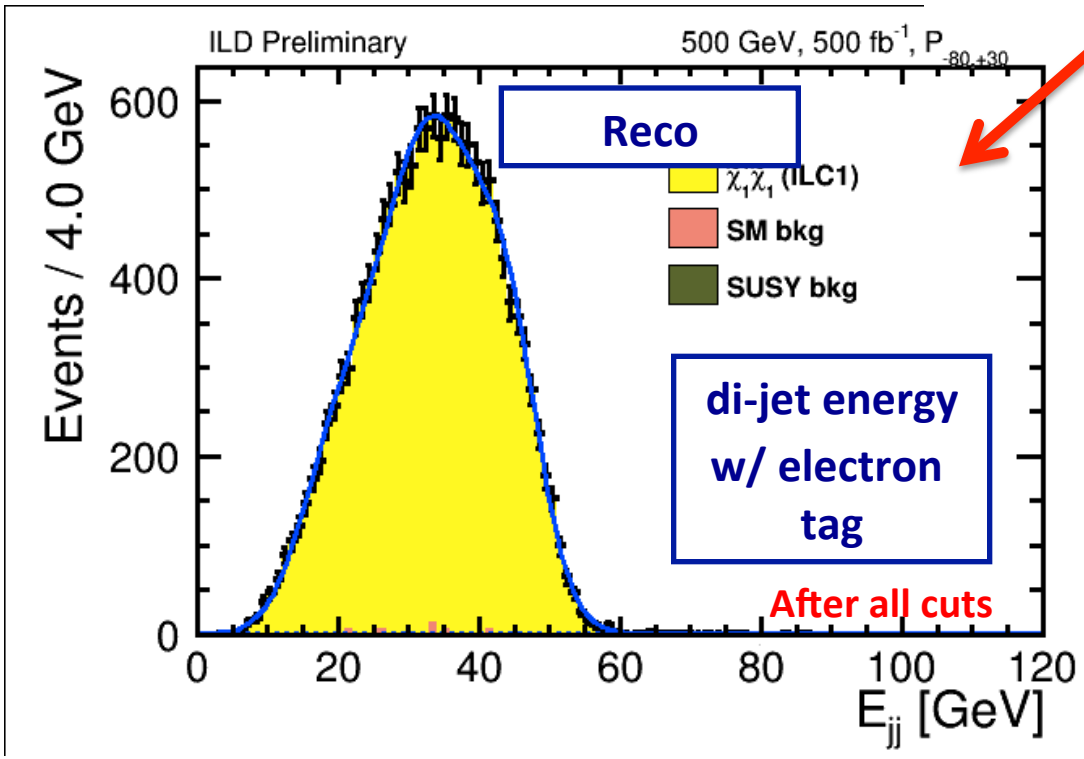
MC Truth



Normalized to area =1

SAME

No square shape



Reco

di-jet energy w/ electron tag

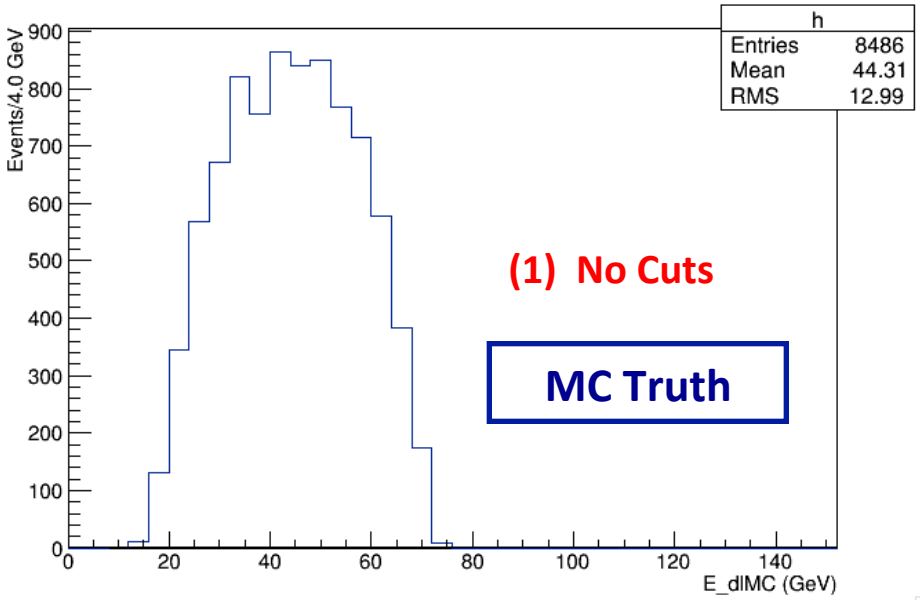
After all cuts

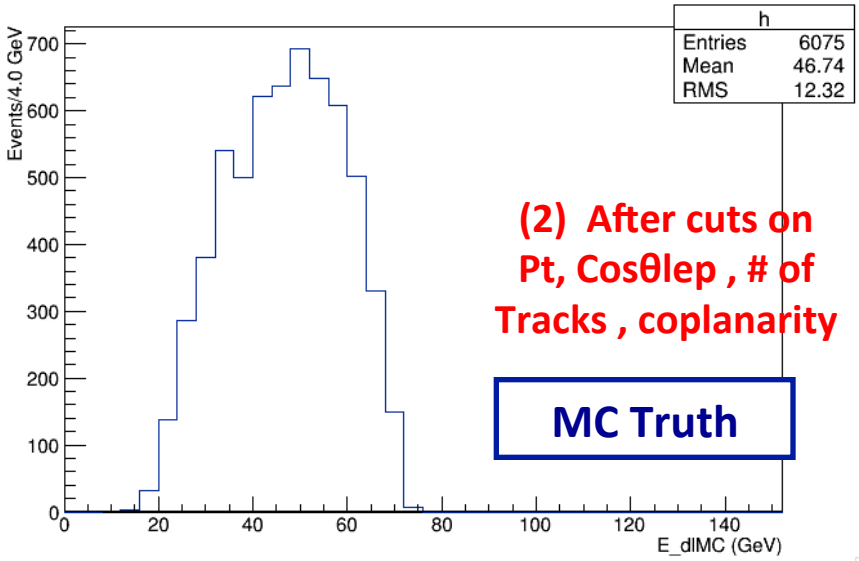
Di-jet energy

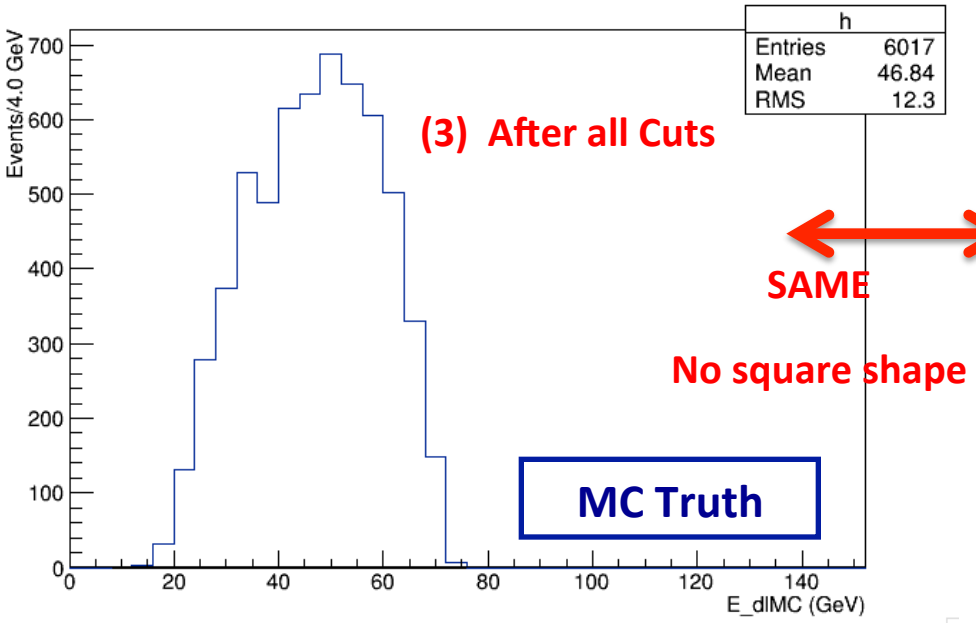
Cuts applied on Reconstructed variables

di-muon energy

Cuts applied on Reconstructed variables

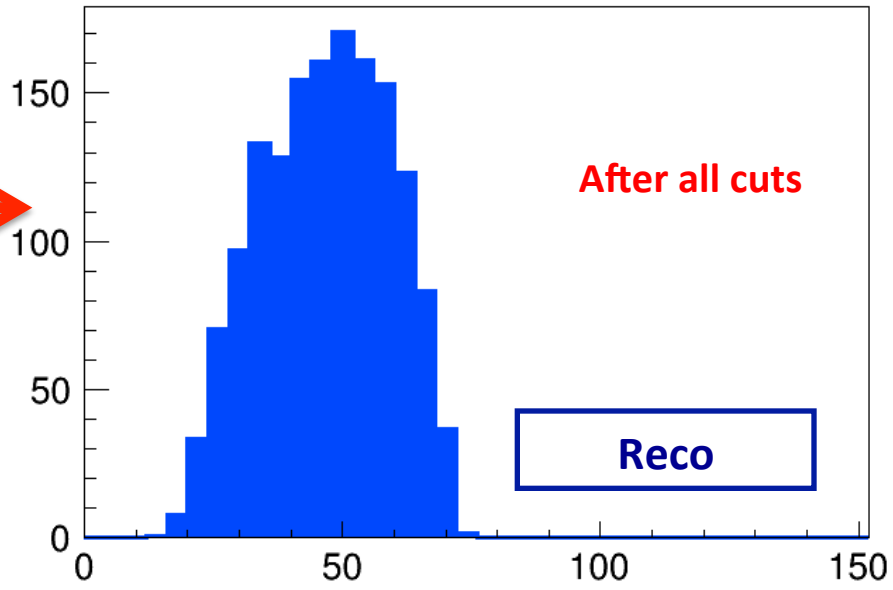


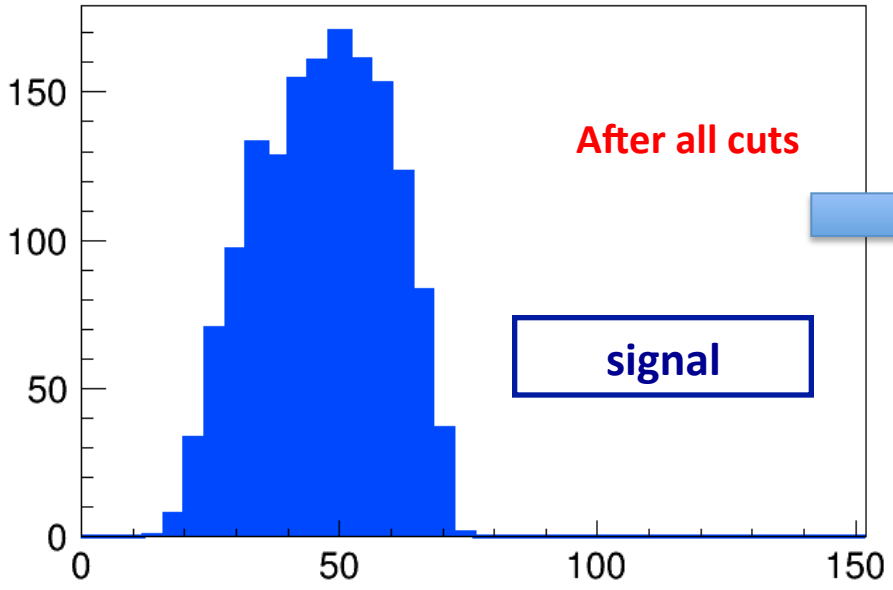


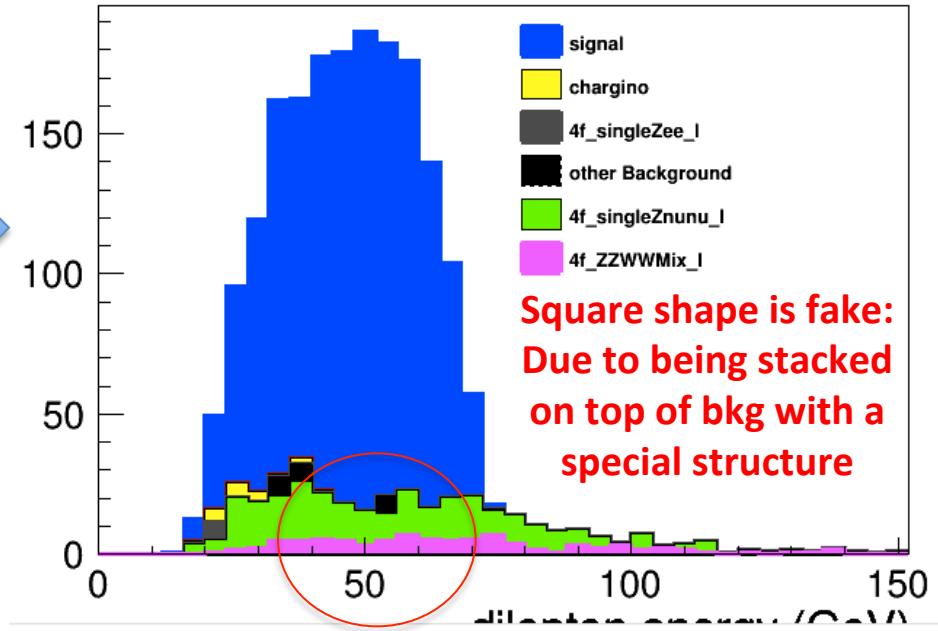


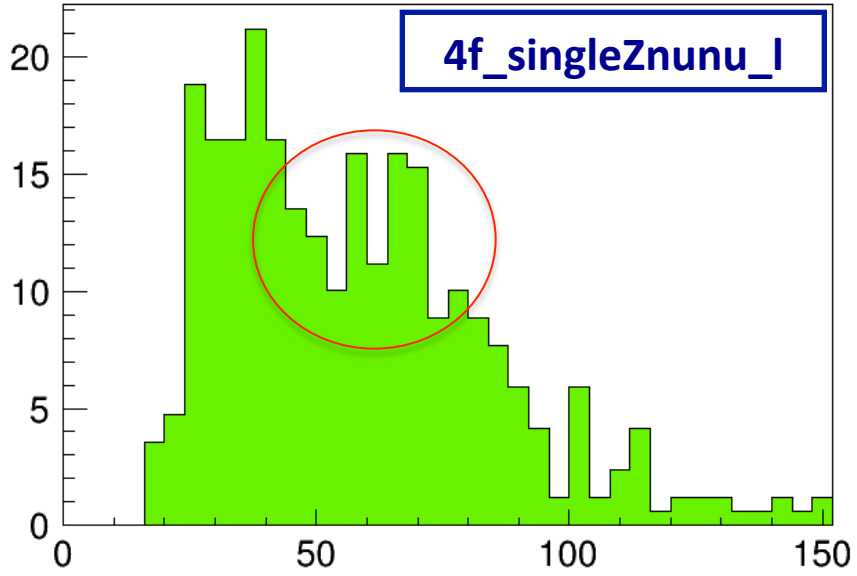
SAME

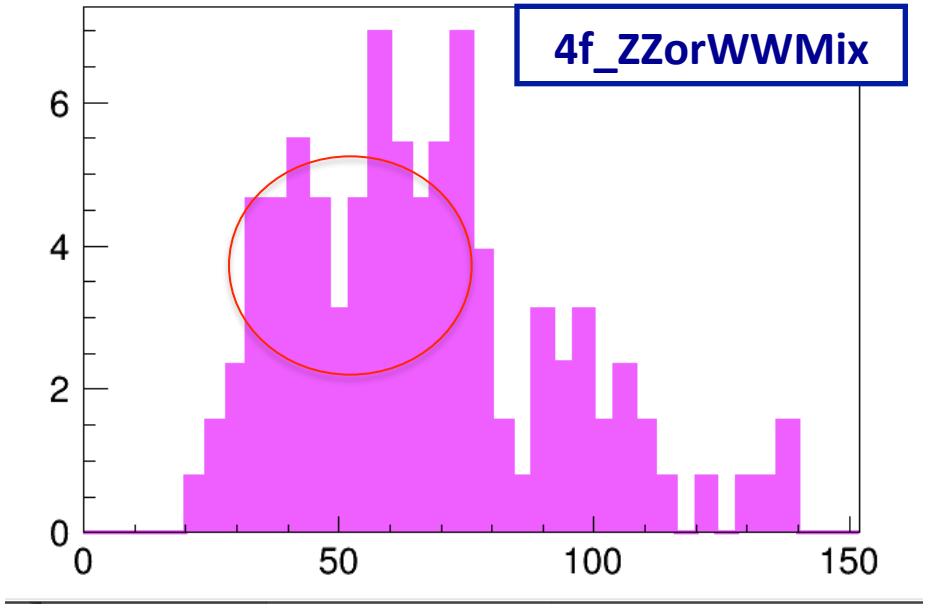
No square shape

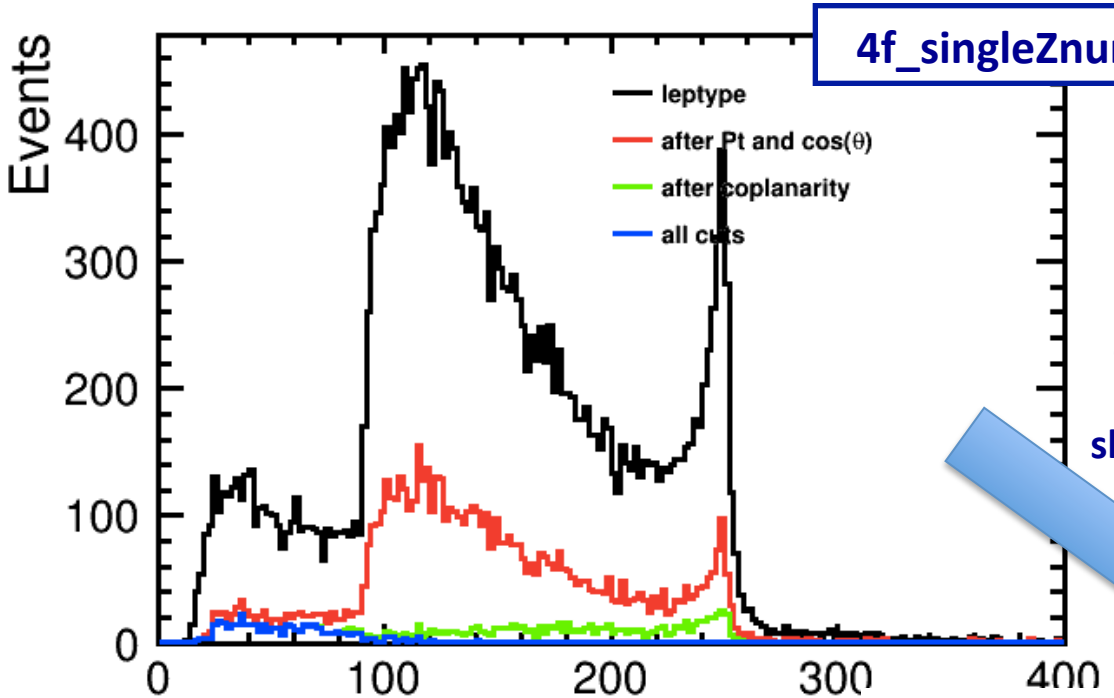



After all cuts
signal

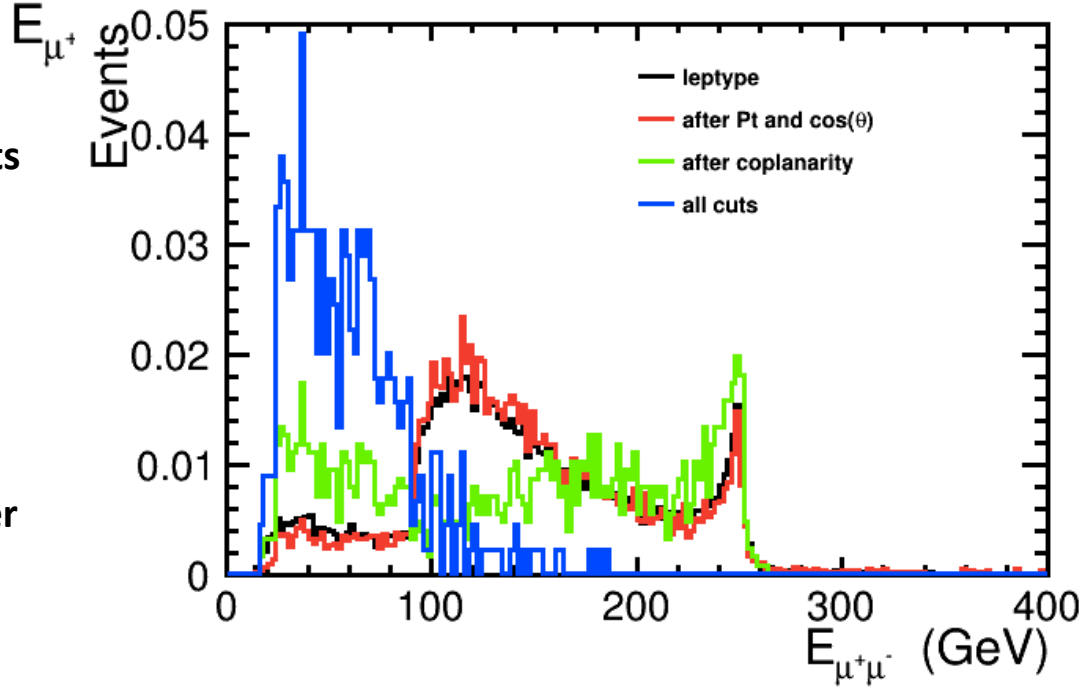

signal
chargino
4f_singleZee_l
other Background
4f_singleZnunu_l
4f_ZZWWMix_l
Square shape is fake:
Due to being stacked
on top of bkg with a
special structure


4f_singleZnunu_l


4f_ZZorWWMix



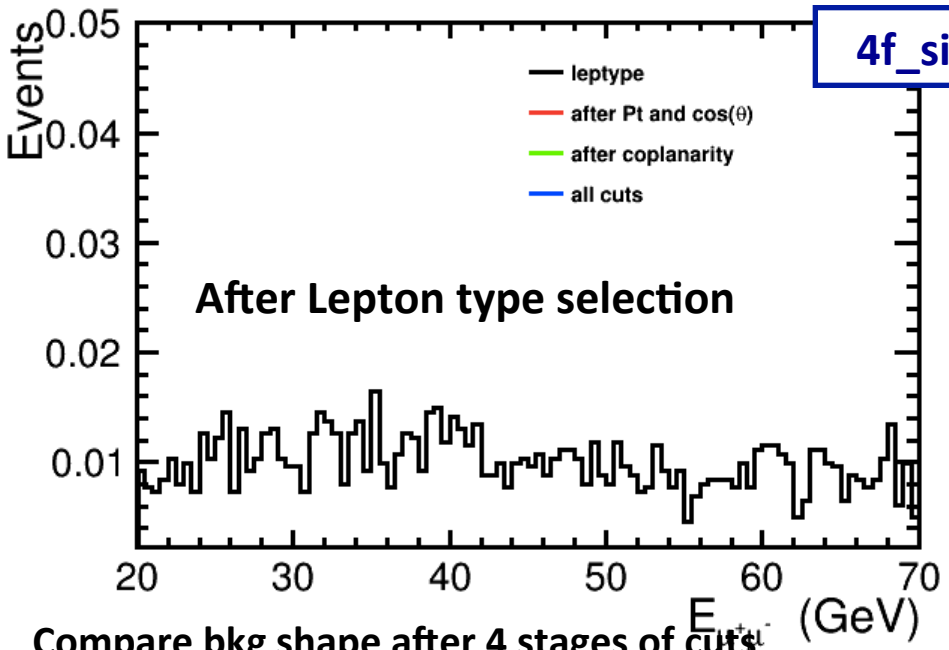
Scaled to area=1 in order to compare shape of distrubution

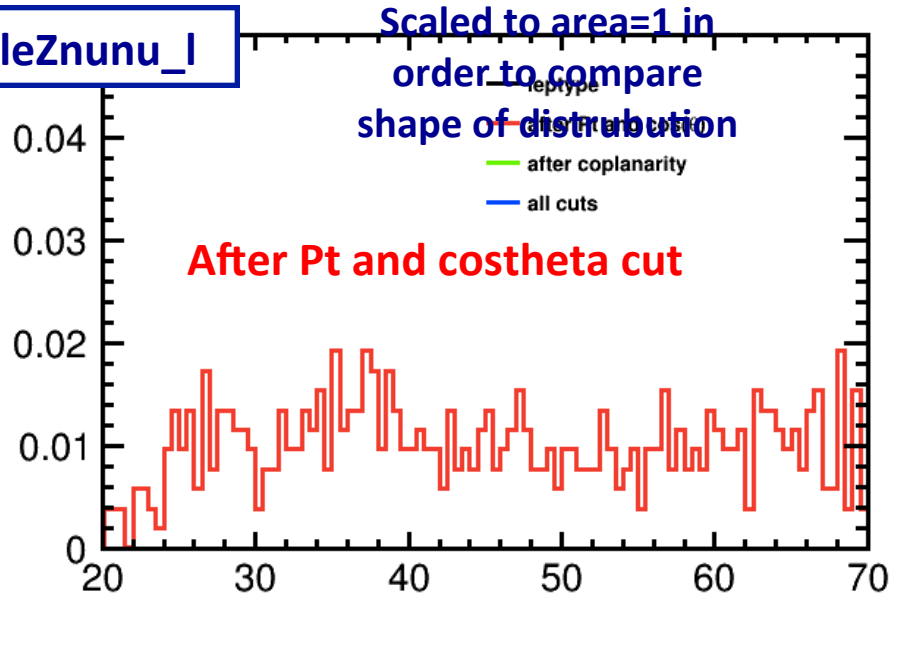


Compare bkg shape after 4 stages of cuts

- **After Lepton type selection**
- **After Pt and costheta cut**
- **After Coplanarity cut**
- **After all cuts**

Dip around 50 GeV seems apparent after coplanarity cut





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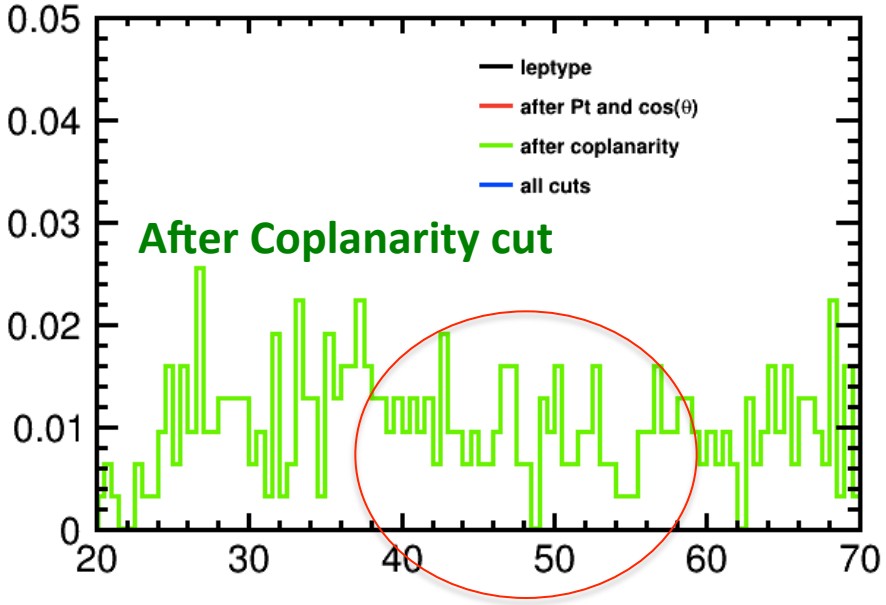
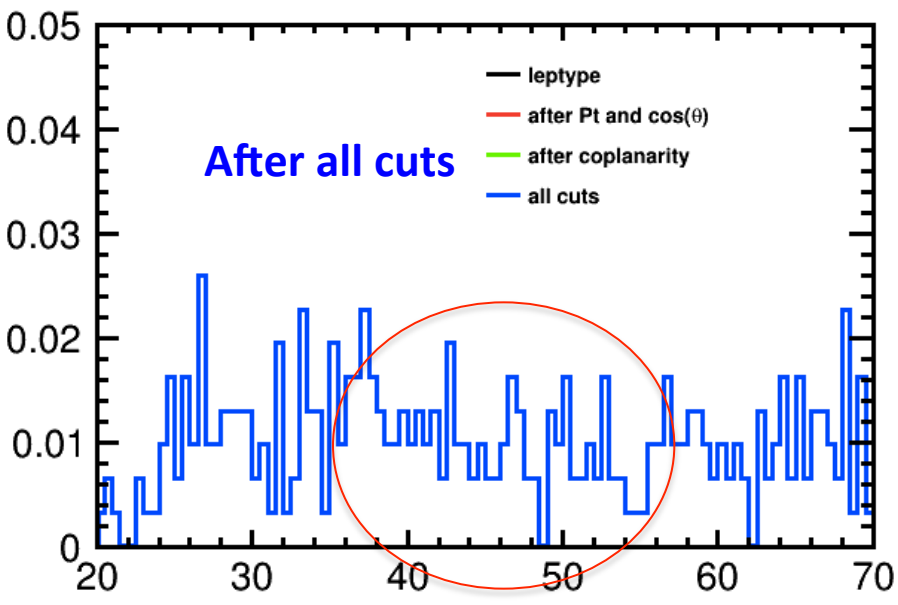




Plans for Higgsino Study

- Compare lepton selection efficiency between SGV samples and full sim samples
- Prepare materials for ICHEP presentation
- Pre-selection study for production of additional aa2f, ae3f bkg SGV samples
- Observe MC info for dilepton / dijet mass
- Study reliability of fit (dependence of on fitting range, bin width, etc…)
- Continue to work on edge extraction

Plans for Systematic Error Studies

Study effect of systematic errors on analysis results

(together with Yu Kato (Univ of Tokyo))

- **energy resolution :**

  change √s by 0.1% (0.3% for 3-sigma) : TDR 500 GeV 0.07%/0.12% for e+/e-

- **polarization errors**

  change P by 0.25% (polarimeter accuracy) or by 0.75% for 3-sigma

  personal view: not much point to do analysis without e+ polarization (unrealistic)

- **luminosity spectrum** **requires time**

Additional Material

Neutralino mixed production with leptonic decay

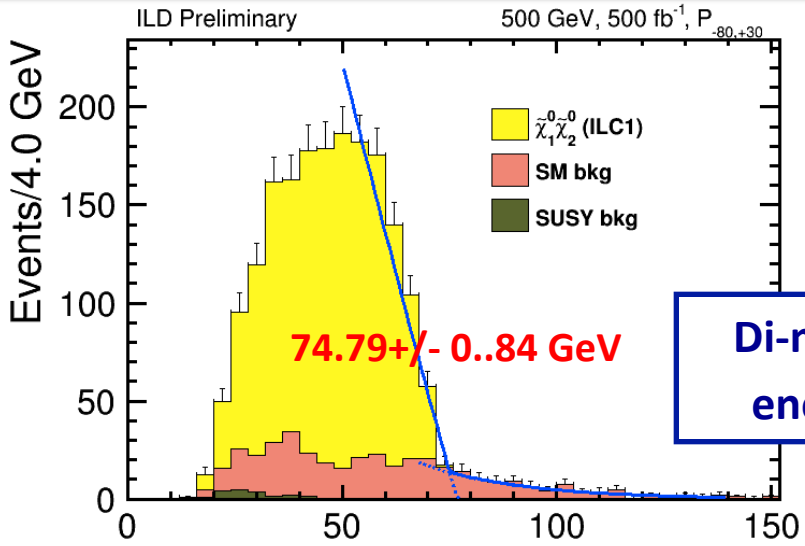
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

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

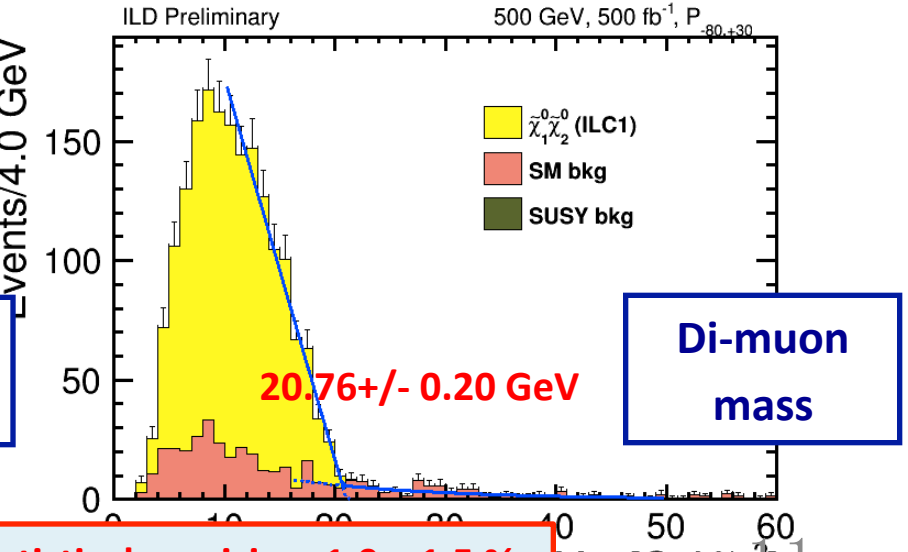
NEW

Replaced SGV with full sim for major bkg

preliminary

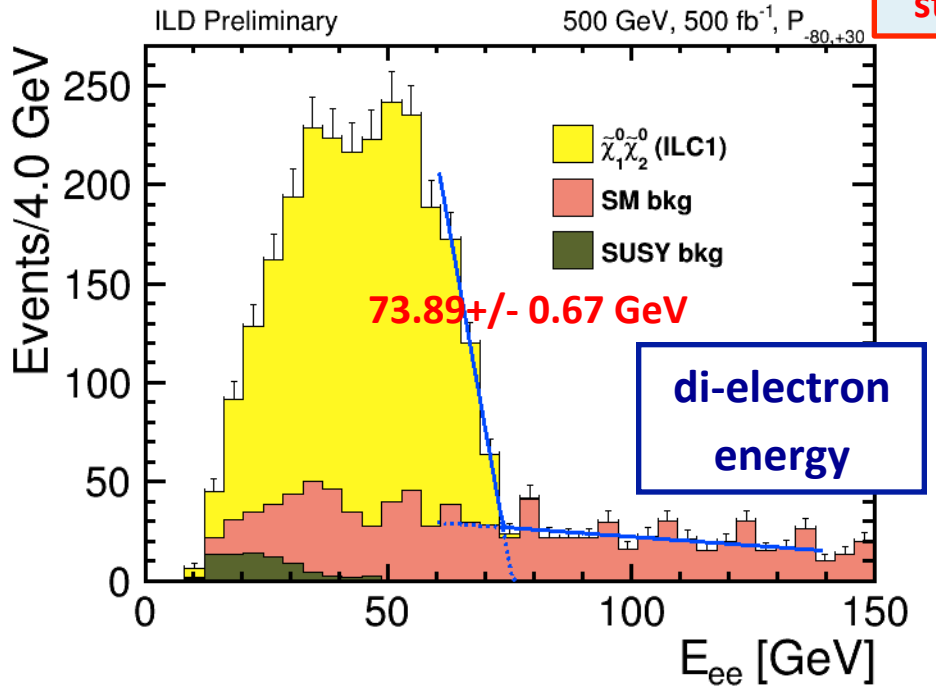


Di-muon energy

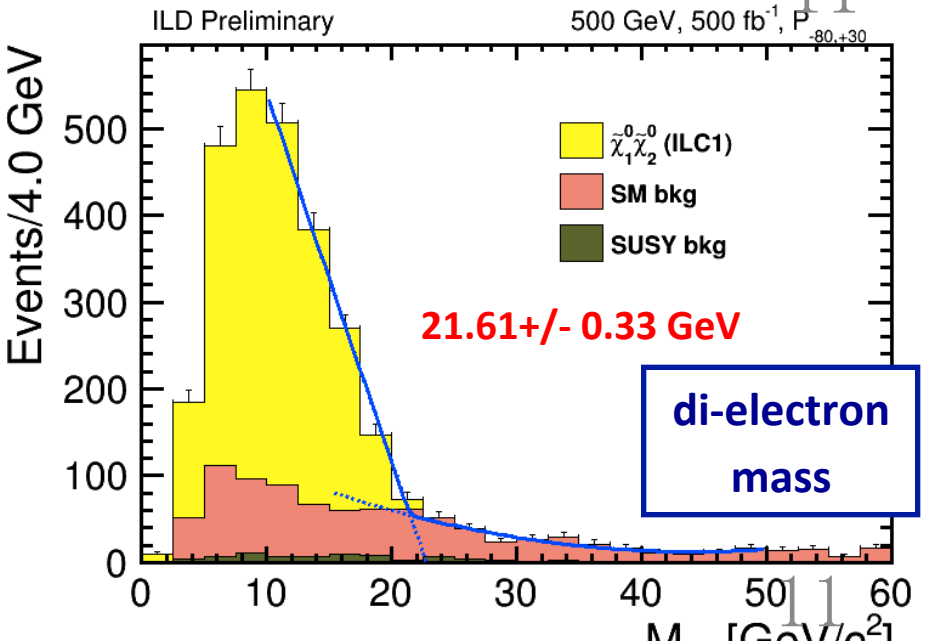


Di-muon mass

statistical precision 1.0 – 1.5 %



di-electron energy



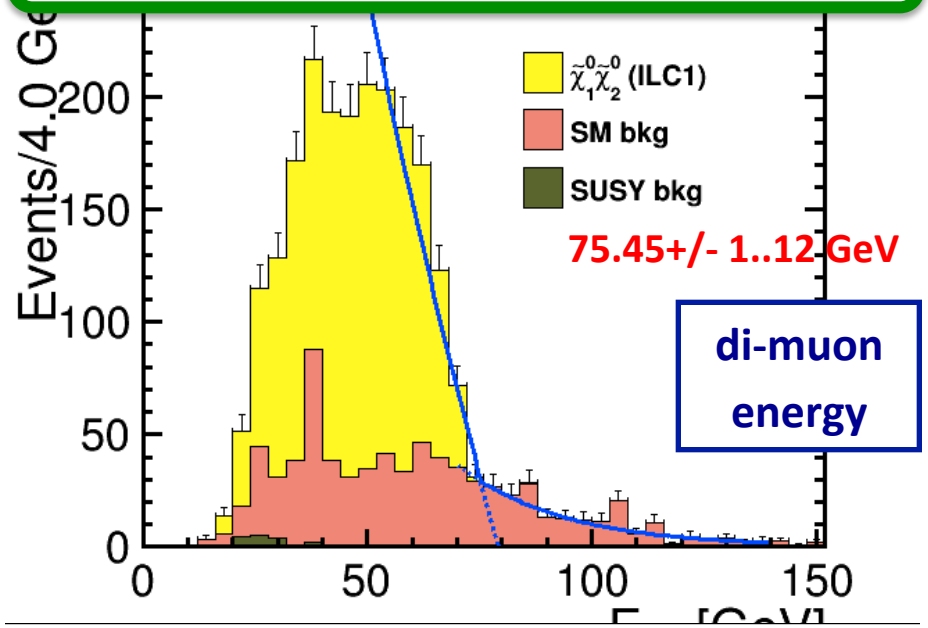
di-electron mass

Neutralino mixed production with leptonic decay

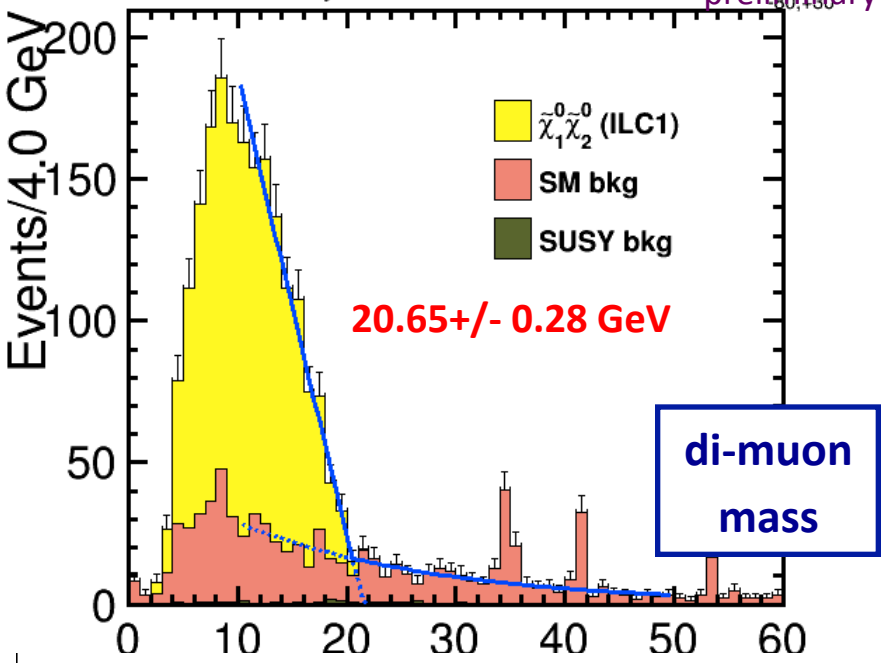
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

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

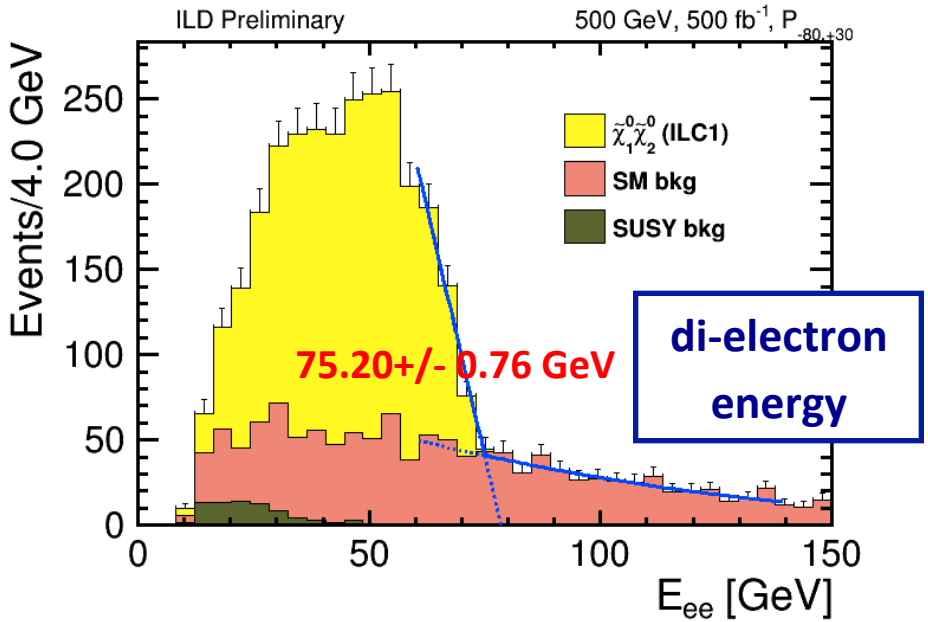
OLD



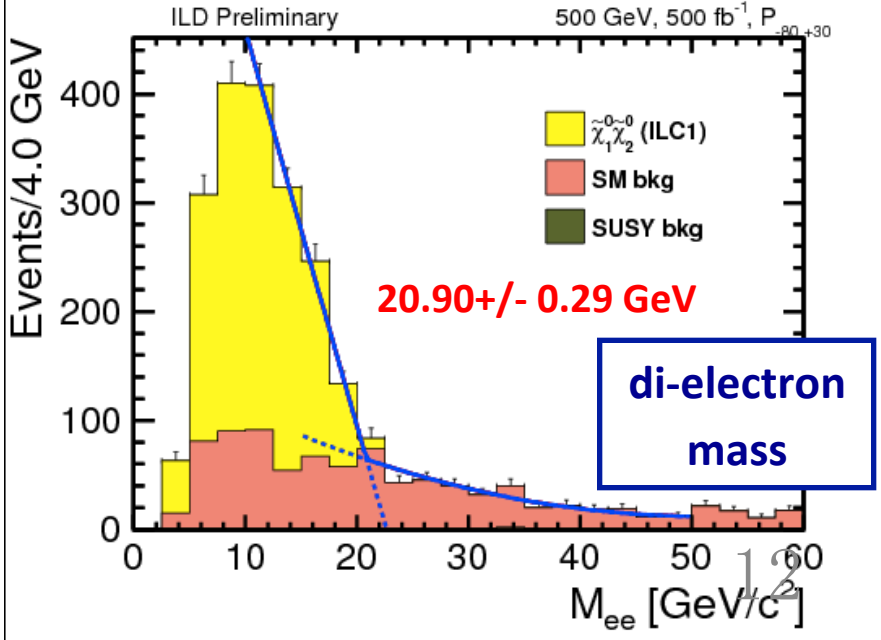
di-muon energy



di-muon mass



di-electron energy



di-electron mass

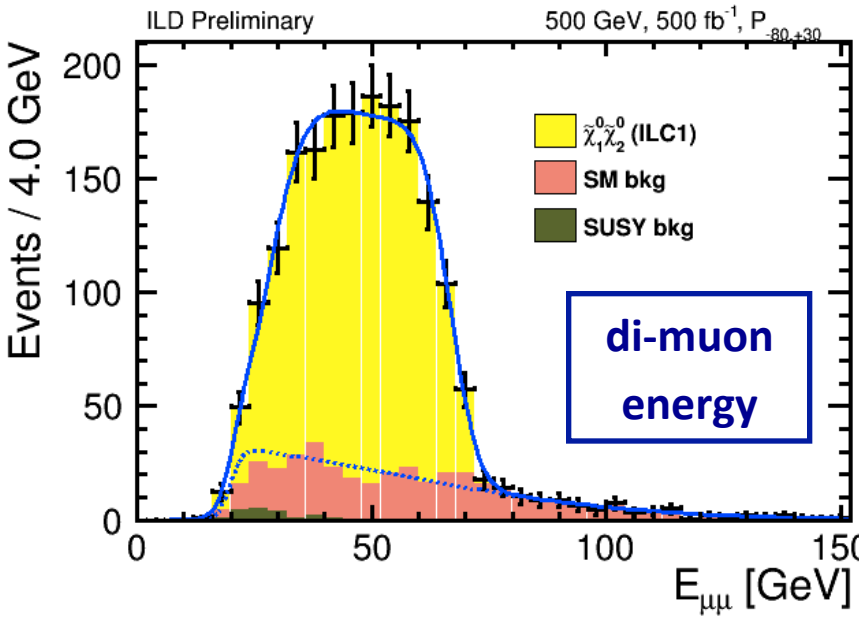
Extraction of Cross Section [work in progress]

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

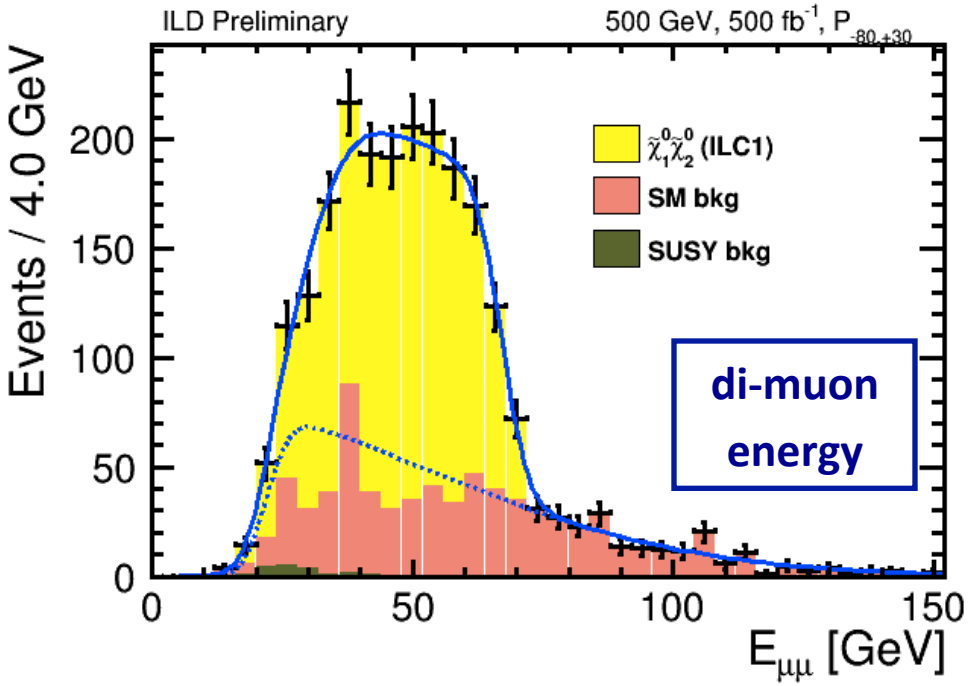
Neutralino mixed production with leptonic decay

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

new μμ result
(reported at ILD meeting on 7/13)



OLD μμ result
(reported at ILD meeting on 7/13)

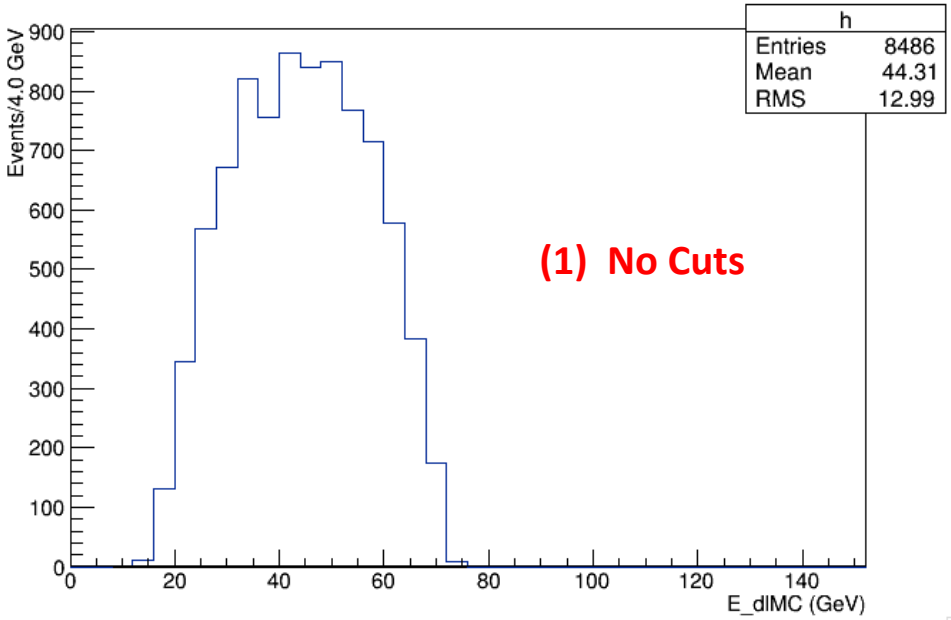


Still need to update xsec fit for ee channel

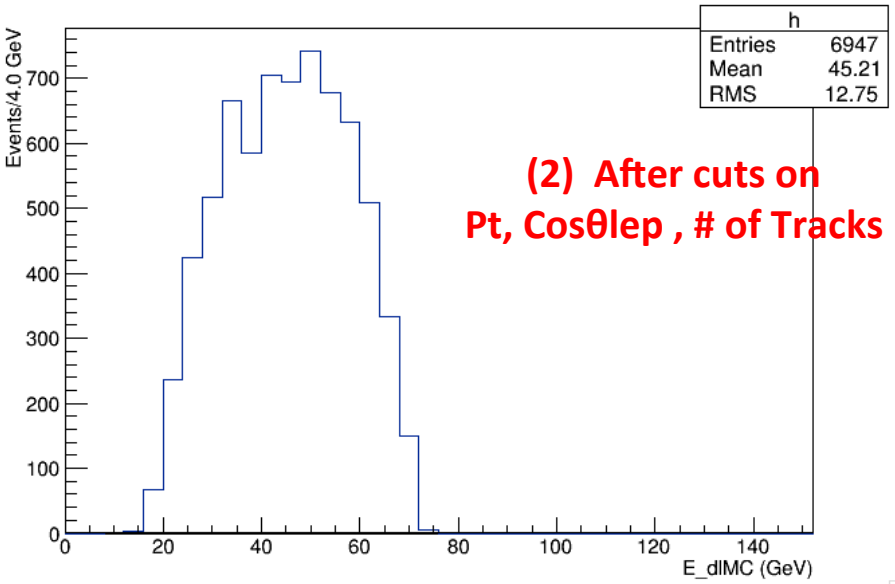
MC Truth of di-muon energy

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

Bin width : 4 GeV

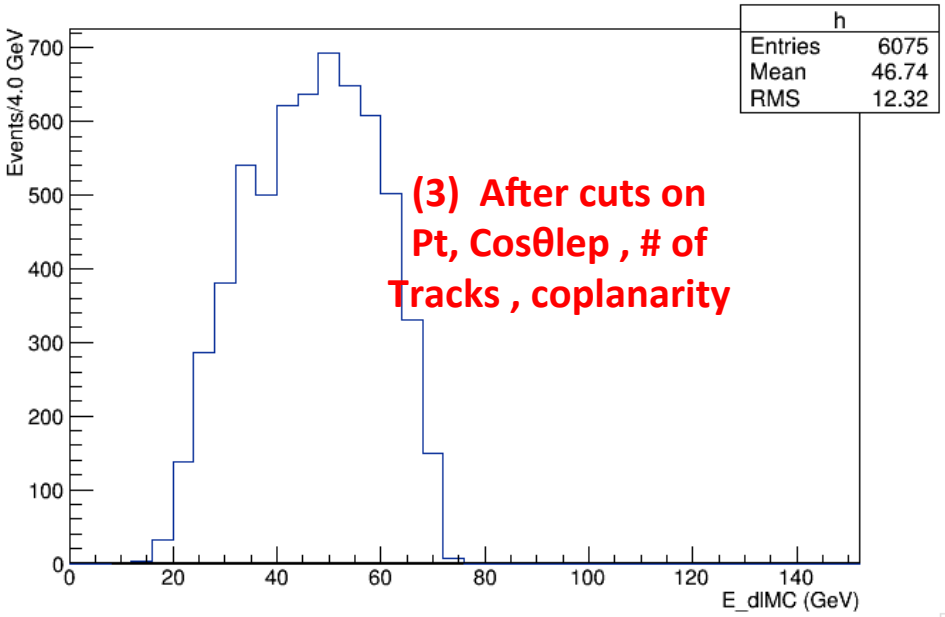


(1) No Cuts

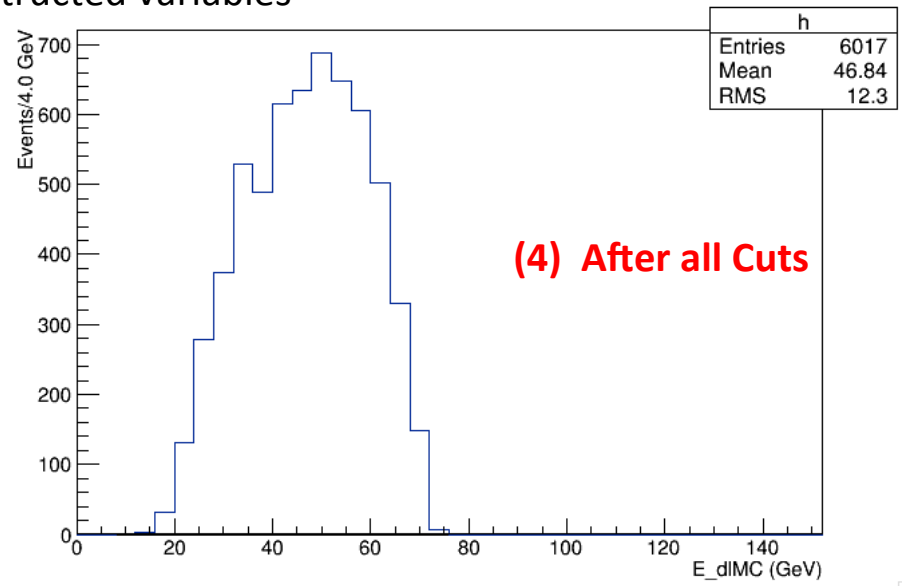


(2) After cuts on Pt, Cosθlep , # of Tracks

Cuts applied on Reconstructed variables



(3) After cuts on Pt, Cosθlep , # of Tracks , coplanarity

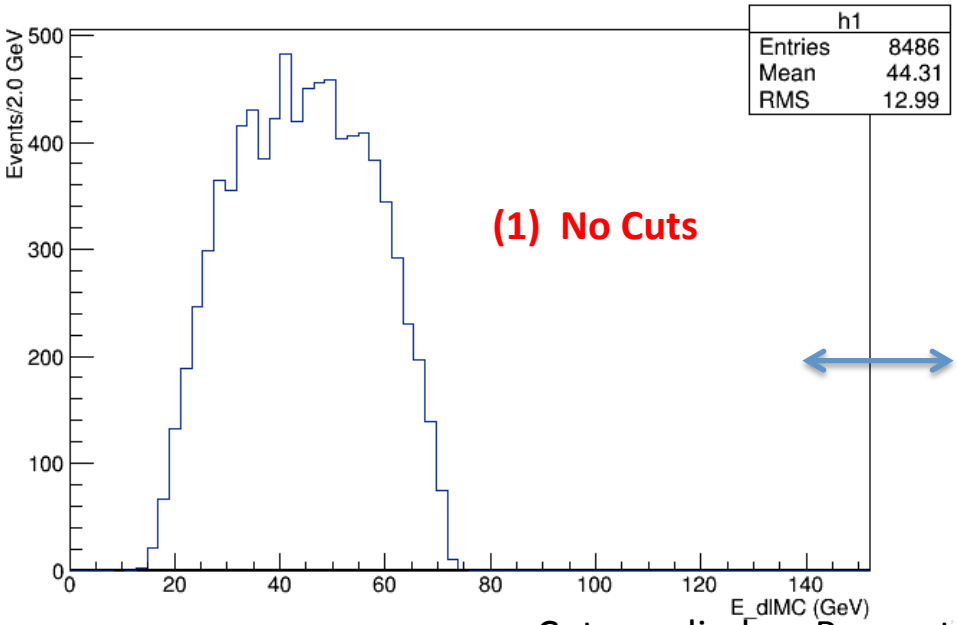


(4) After all Cuts

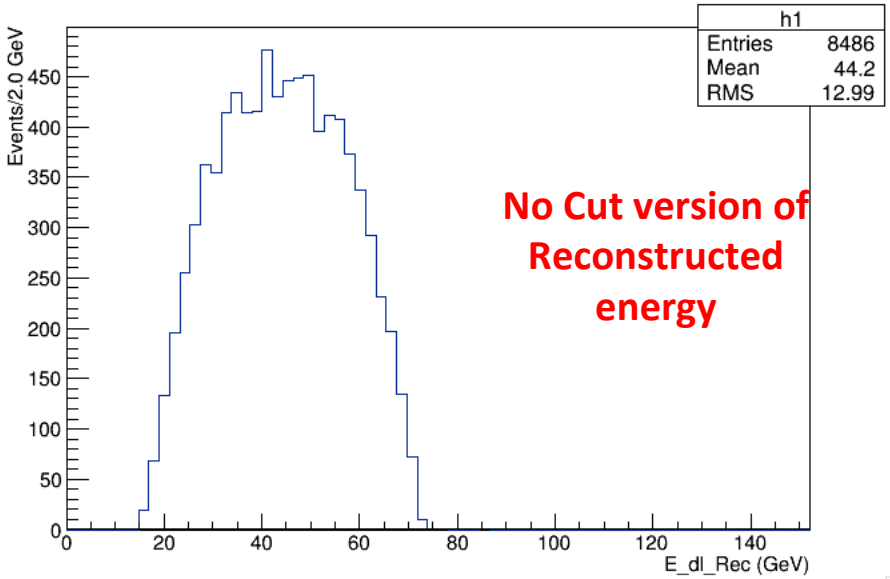
MC Truth of di-muon energy

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

Bin width : 2 GeV

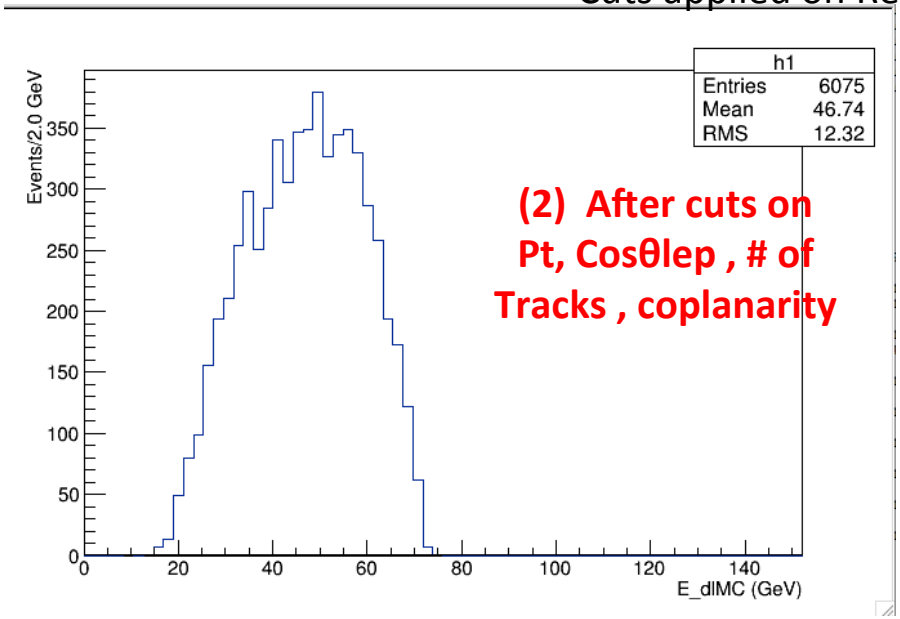


(1) No Cuts

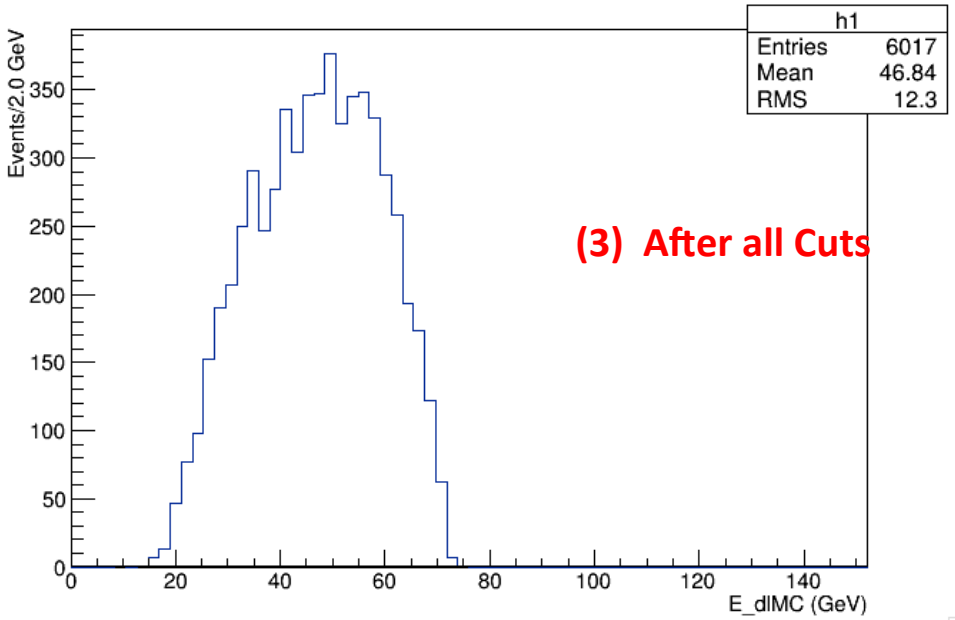


No Cut version of Reconstructed energy

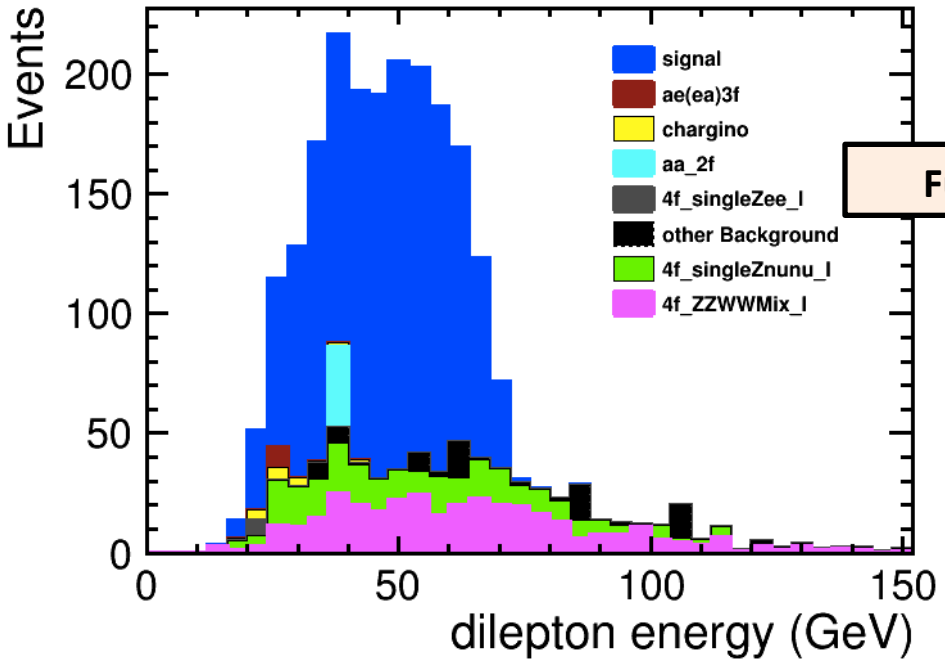
Cuts applied on Reconstructed variables



(2) After cuts on Pt, Cosθlep , # of Tracks , coplanarity



(3) After all Cuts



Increase in full sim samples

Full sim sample now

Replaced 4f_singleZnunu to new full sim

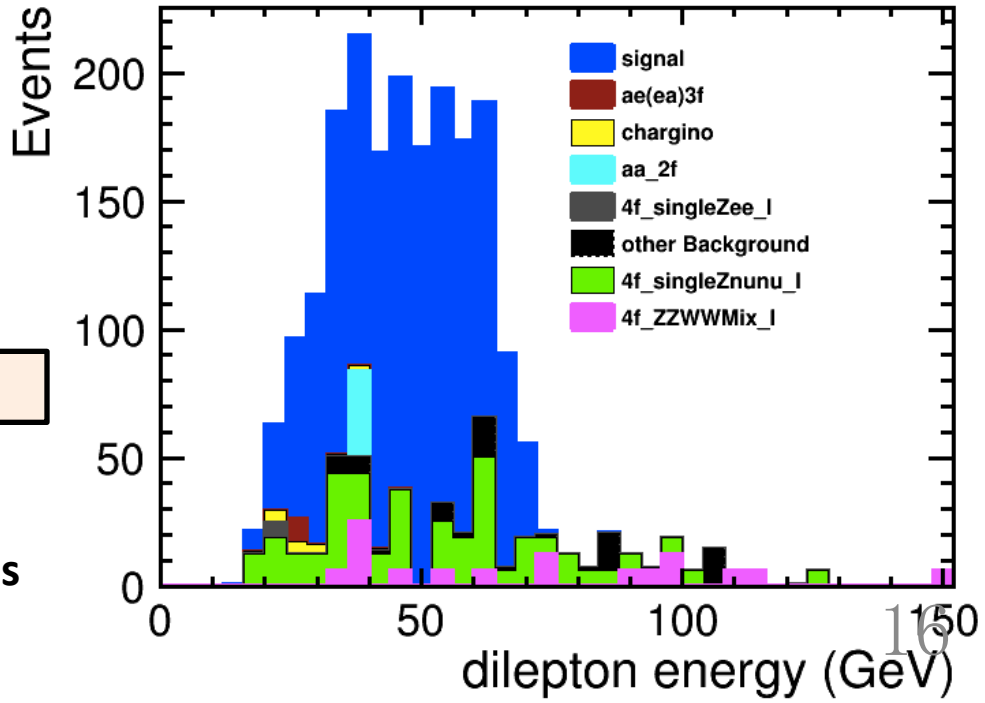
4f_ZZorWWMix is still SGV

E_μμ, left pol

Full sim sample, before

both 4f_singleZnunu and

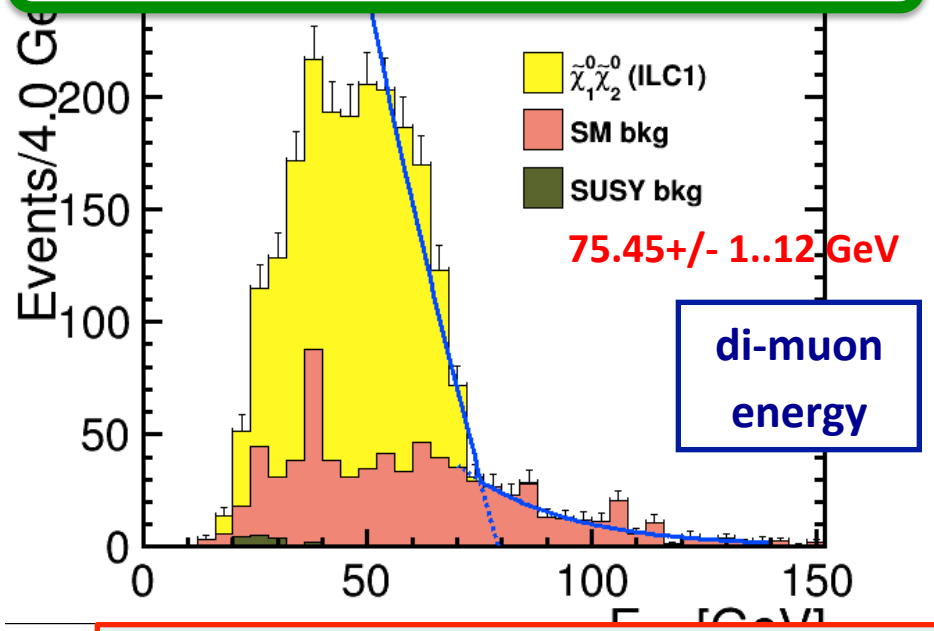
4f_ZZorWWMix are full sim samples

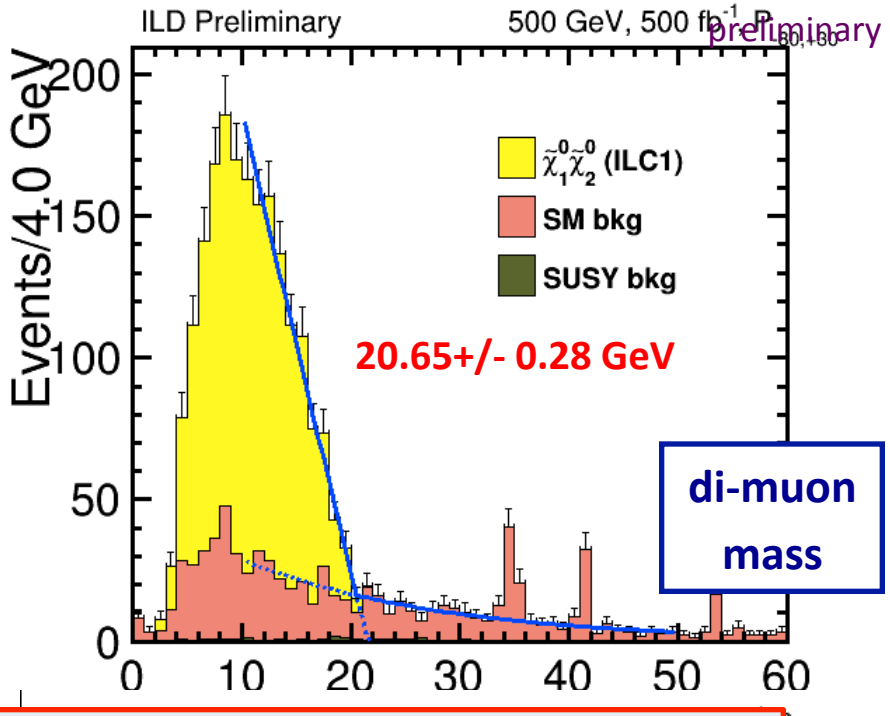


Neutralino mixed production with leptonic decay

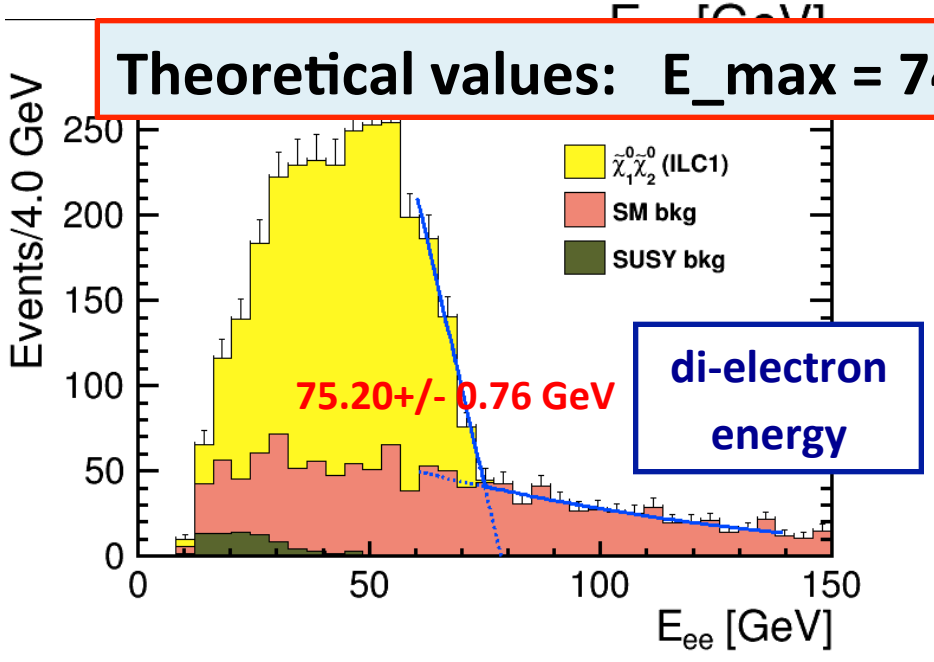
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+ \ell^-$$

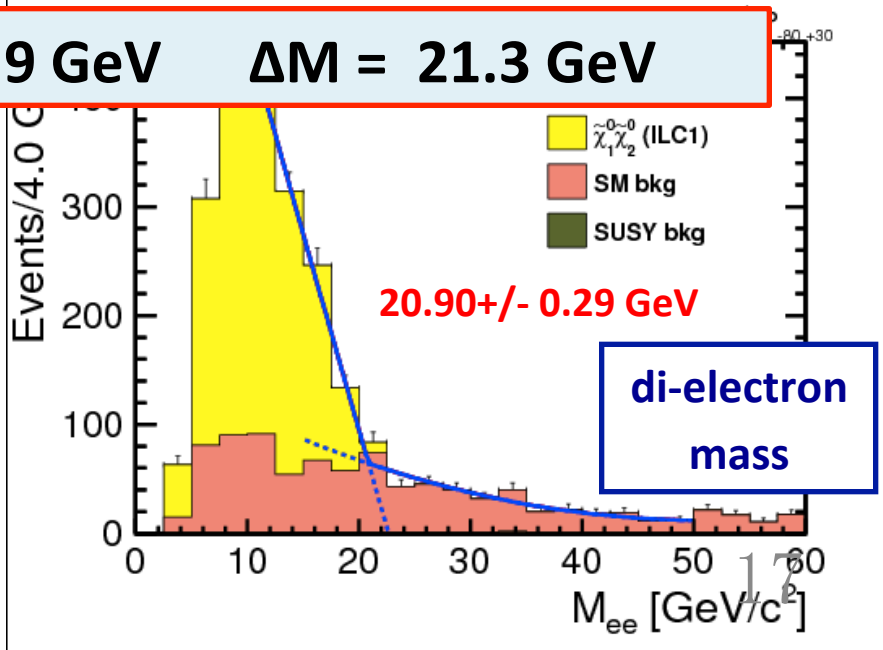
Polarization (Pe-,Pe+) = (-0.8, +0.3)





Theoretical values: E_max = 74.9 GeV ΔM = 21.3 GeV





Neutralino mixed production with leptonic decay

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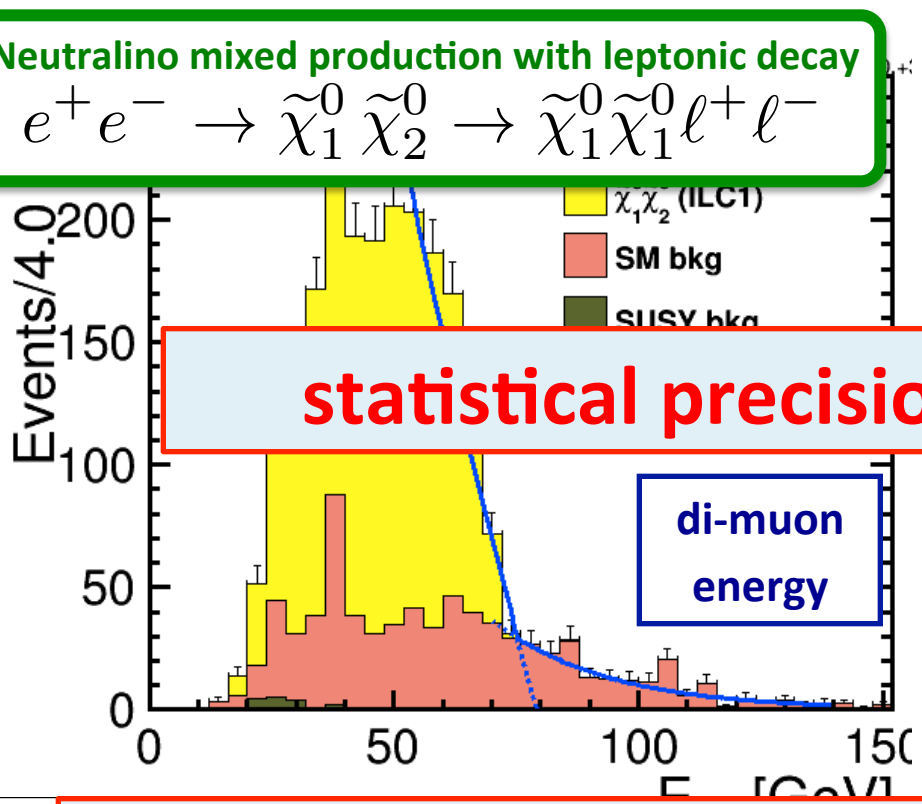
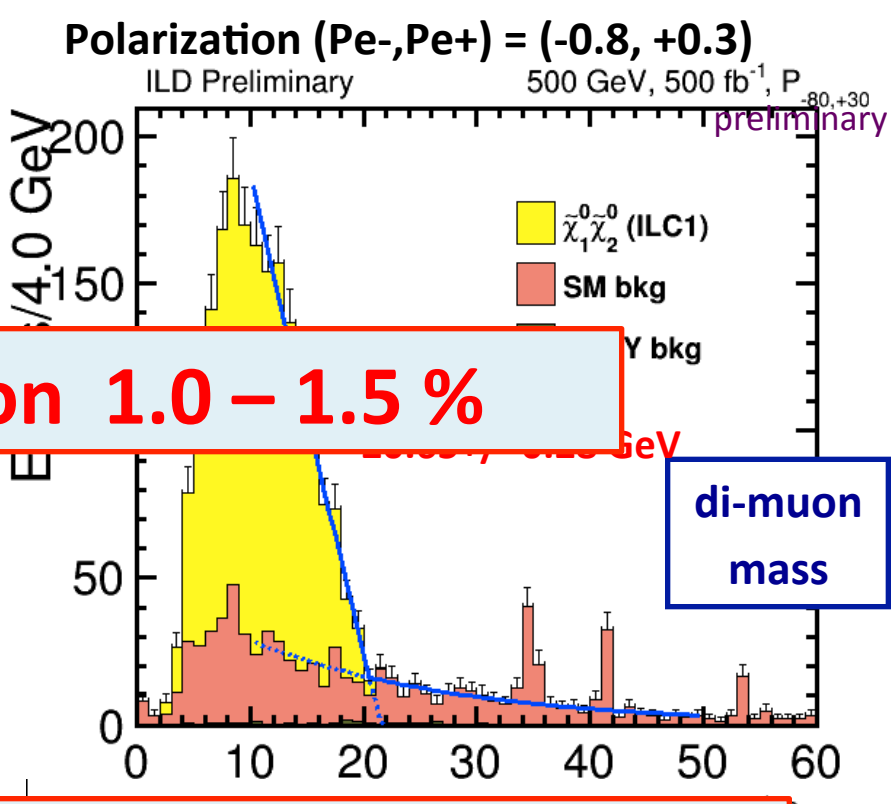


di-muon energy



di-muon mass

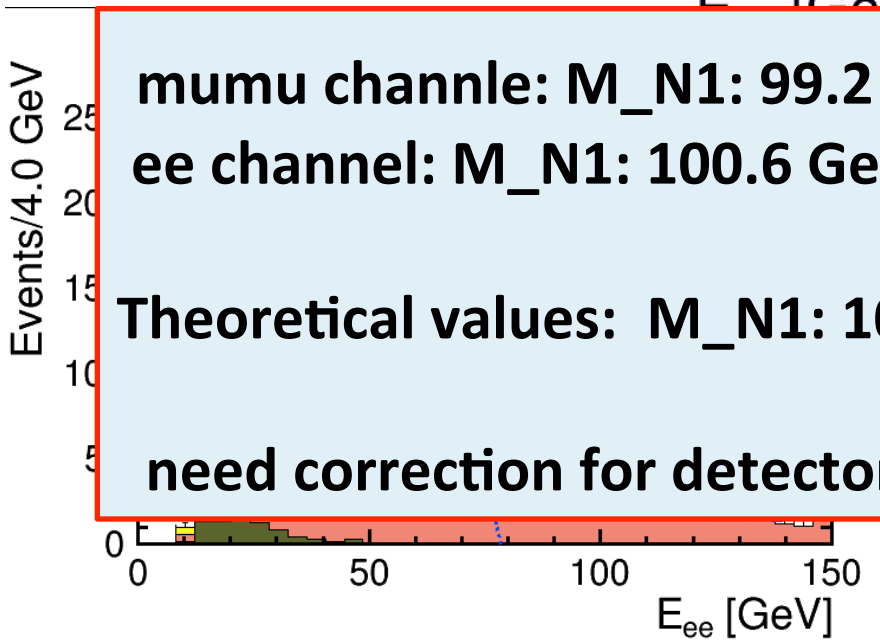
statistical precision 1.0 – 1.5 %

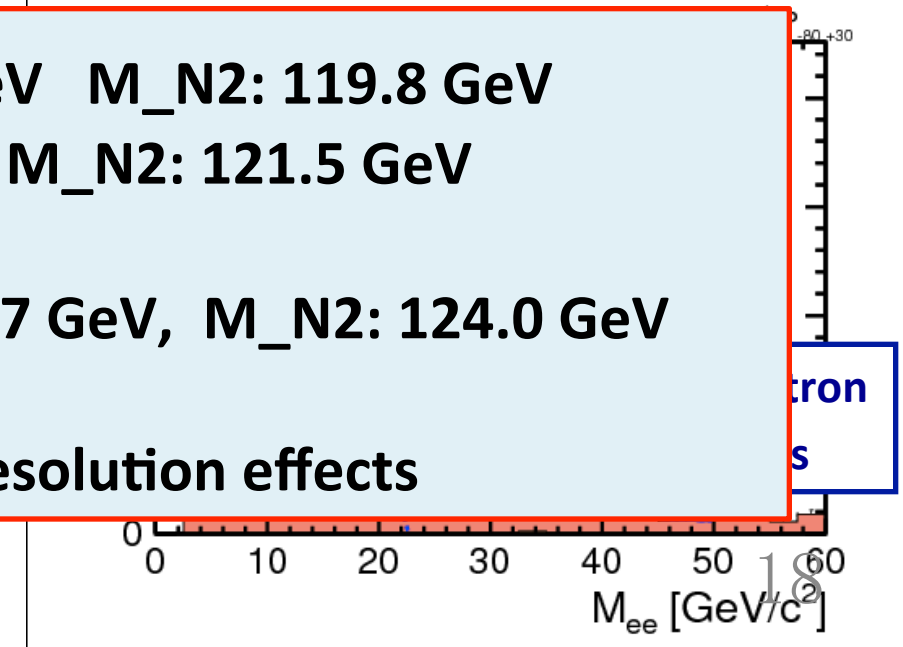
mumu channle: M_N1: 99.2 GeV M_N2: 119.8 GeV

ee channel: M_N1: 100.6 GeV M_N2: 121.5 GeV

Theoretical values: M_N1: 102.7 GeV, M_N2: 124.0 GeV

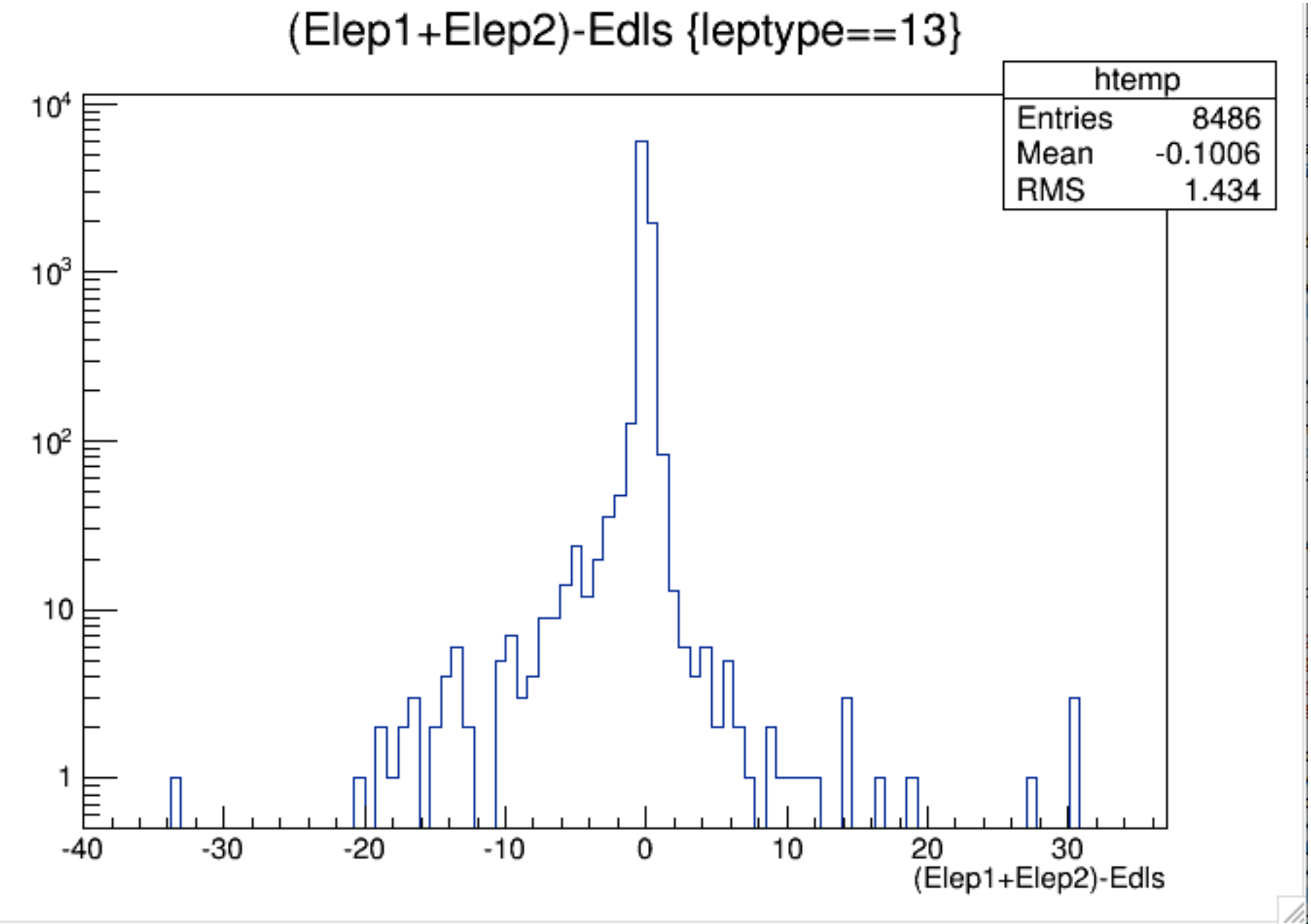
need correction for detector resolution effects





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

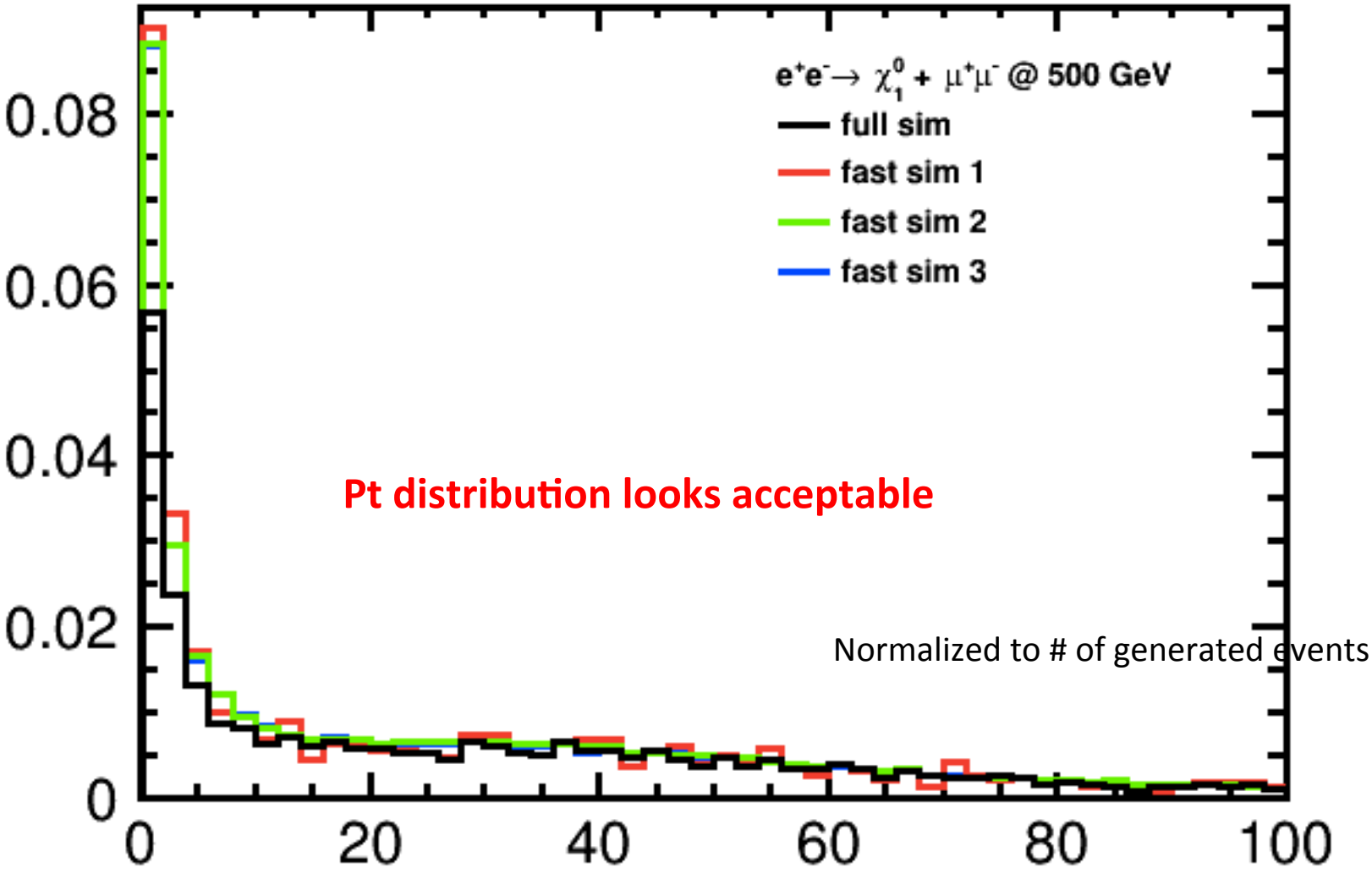
Difference in di-muon energy between MC truth and Reconstructed info



- **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

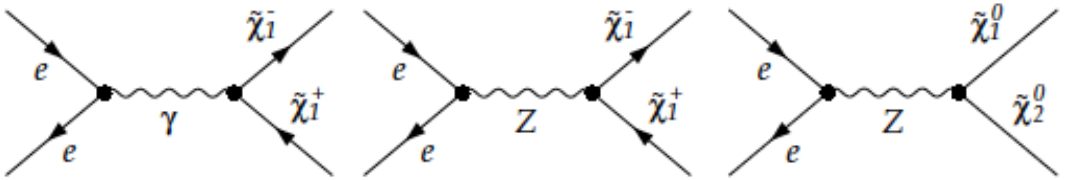
Muon Pt



Pt distribution looks acceptable

Normalized to # of generated events

Benchmarks in this Study



RNS model (Radiatively-driven natural SUSY)

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

- **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

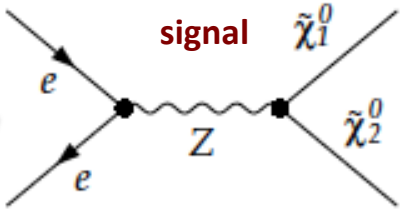
Defined at GUT scale
Defined at weak scale
Observables

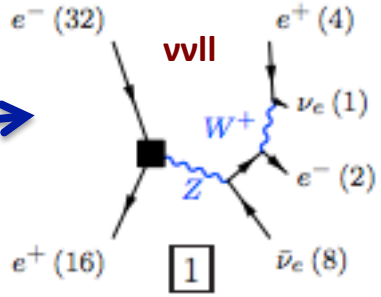
Event Selection

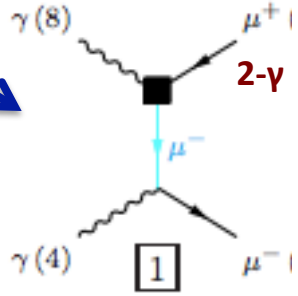
Neutralino mixed production with leptonic decay

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

- 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





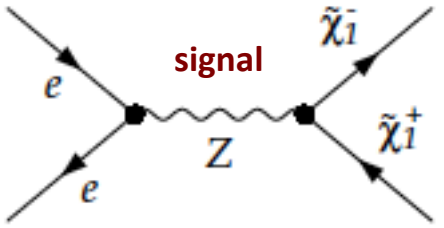


Chargino pair production with semileptonic decay

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

- 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)



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)
- Emis > 300 GeV : missing energy (very large for signal)
- |cosθmissing| < 0.98 : θ of missing energy events
- |cosθZ| < 0.98 : Z* production angle
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- 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

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- 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