SUSY analysis (smuon and chargino/neutralino 4-jet)

Taikan Suehara

ICEPP, The Univ. of Tokyo

Topics

- Overview
- Smuon analysis (very quick analysis)
  - Event characteristics
  - Result of mass determination
- Chargino/neutralino 4-jet analysis
  - Event characteristics
  - Background suppression (SM 4-jets)
  - Chargino/neutralino separation by W/Z mass
  - Result of mass determination
- Performance of each geometry

Overview

Physics process for optimization

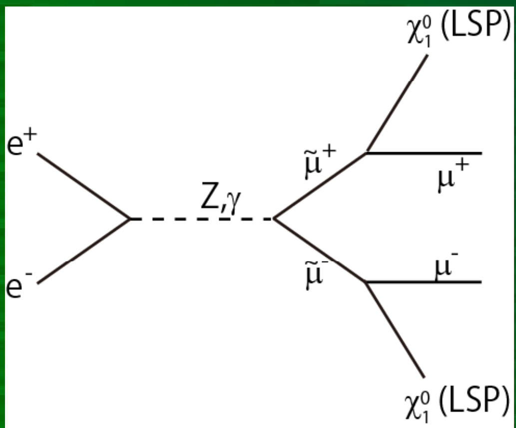
Benchmark processes:

Processes ($e^+e^- \rightarrow$)	$\sqrt{S}$ (GeV)	Observables	Comments
ZH, ZH→e^+e^-X,	250	σ, m_H	m_H=120GeV, test materials and γ_{ID}
→$\mu^-\mu^+X$	250	σ, m_H	m_H=120GeV, test $\Delta P/P$
ZH, H→cc, Z→$\nu\nu$	250	Br(H→cc)	Test heavy flavour tagging and anti-tagging of light quarks and gluon
, Z→qq	250	Br(H→qq)	Same as above in multi-jet env.
$Z^* \rightarrow \tau^+\tau^-$	500	σ, A_{FB}, Pol(τ)	Test π^0 reconstruction and τ rec. aspects of PFA
tt, t→bW, W→qq'	500	σ, A_{FB}, m_{top}	Test b-tagging and PFA in multi-jet events. m_{top}=175GeV
$\chi^+\chi^-$, $\chi_2^0\chi_2^0$	500	σ, $m\chi$	Point 5 of Table 1 of BP report. W/Z separation by PFA

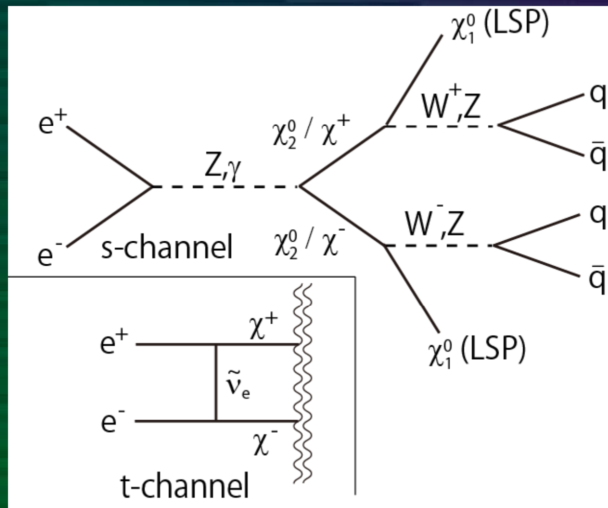
SUSY parameters

Point	Ref.	m_0 GeV	$m_{1/2}$ GeV	$\tan\beta$ GeV	A	μ GeV	M_{top} GeV	$M_{\tilde{\chi}_1^0}$ GeV	$M_{\tilde{\tau}_1}$ GeV	$M_{\tilde{\chi}_2^0}$ GeV	$M_{\tilde{\chi}_3^0}$ GeV	$M_{\tilde{e}_R}$ GeV	M_A GeV	$M_{\tilde{\chi}_1^+}$ GeV	$M_{\tilde{\chi}_2^+}$ GeV
1	SPS1a' [5, 6]	70	250	10	-300	389	175	96.1	109.2	185	393	124	421	185	408
2	LCC2 [6]	3280	300	10	0	178	175	107.7	3251	166	190	3270	3242	159	287
3	D' [7]	110	525	10	0	654	175	211.3	220.8	408	658	228	744	409	671
4	LCC4 [6]	380	420	53	535	0	178	169.1	195	327	540	412	419	328	553
5	α [8]	206	293	10	0	375	178	113	213	215	380	216	265	215	399
6	ϵ [8]	20	440	15	-25	569	178	175	153	339	574	171	622	340	587

Analyzed processes:



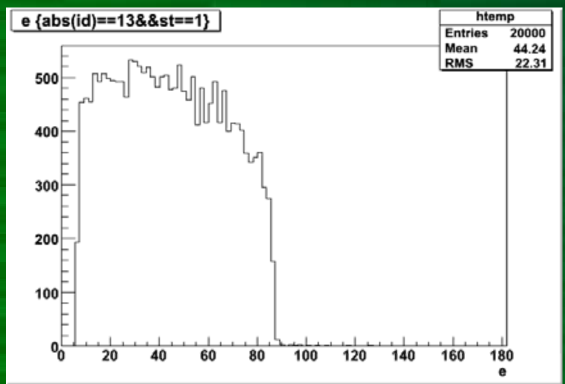
Smuon – point1

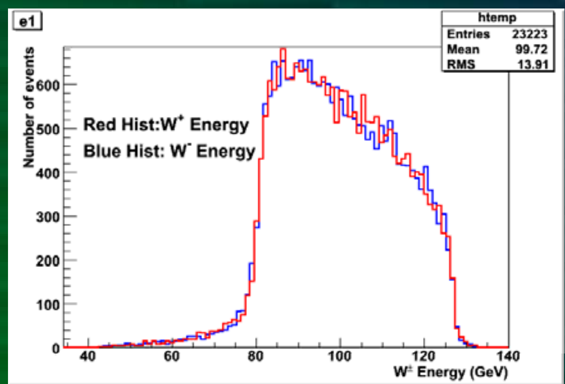


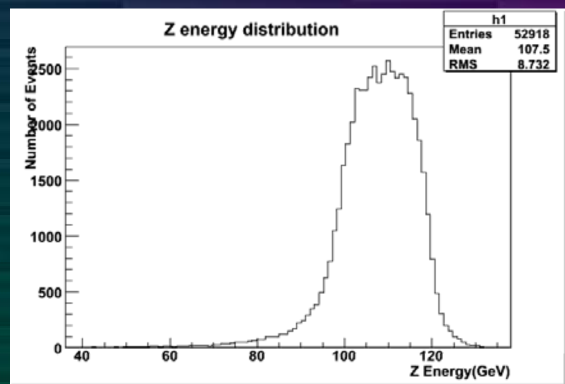
Chargino/neutralino – point5

Event topology

- Similar for all processes in this talk
- Visible W/Z/μ pair + missing LSP pair
- 2-body decay – monochromatic in decay frame
- Nearly flat distribution with sharp edges in lab. frame
- Edge positions can be translated to SUSY masses
  - Energy resolution at edges is essentially important
- Generator distributions







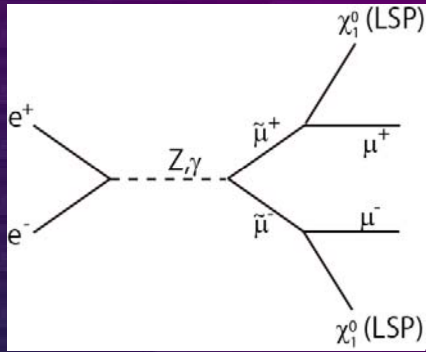
Muon energies in smuon events

Ws in charginos

Zs in second neutrinos

Smuon mode

Smuon-pair overview



- Events
  - Smuon mass: 122.98 GeV
  - LSP mass: 97.44 GeV
  - Cross sections: 28.53 fb (e_L), 121.56 fb (e_R)
  - GLD, GLD' and J4LDC each 500 fb^{-1}
  - SM $\nu\nu\mu\mu$ sample for BG, Mokka/LDC', 500 fb^{-1}
    - Currently ν_μ sample was only analyzed.
    - 80 fb in 80% right polarization
  - No SUSY background, BG separation cuts.
- Concerning detector performance
  - Muon tracking resolution

Energy spectrum of muons

- Sharp edges.
- No difference between geometries and MC truth.
- BG is not critical.
- Differential spectra are fitted by Gaussian to obtain SUSY masses.

SUSY mass determination

	GLD			GLD’			J4LDC			MC truth fit			input	unit
left edge	6.097	±	0.017	6.103	±	0.023	6.088	±	0.018	6.05	±	0.01	6.019	GeV
left width	0.059	±	0.016	0.076	±	0.021	0.055	±	0.018	0.044	±	0.018		GeV
left chi2	26.02	/	36	25.98	/	36	23.95	/	36	30.51	/	36		
right edge	86.9	±	0.088	86.78	±	0.122	86.84	±	0.098	86.83	±	0.048	87.04	GeV
right width	0.51	±	0.073	0.68	±	0.105	0.607	±	0.078	0.339	±	0.04		GeV
right chi2	27.98	/	26	30.42	/	26	36.17	/	26	21.73	/	26		GeV
smuon mass	123.8	±	0.159	123.88	±	0.214	123.71	±	0.171	123.38	±	0.092	122.98	GeV
LSP mass	98.07	±	0.135	98.21	±	0.18	98.06	±	0.144	97.81	±	0.075	97.44	GeV

- ~ 200 MeV mass resolution of smuon/LSP.
  - Obtained LSP mass can be used for other SUSY modes.
- Essentially no difference between 3 geometries.
  - GLD’ seems slightly worse,
    but it might be just a statistical effect.

SUSY 4-jet-mode

Chargino/neutralino2 4-jet mode

- Events
  - Chargino/neutralino2/LSP mass (point 5): 210.21 / 210.67 / 117.36 GeV
  - Cross sections: 157.61 fb (chargino, e_L), 29.24 fb (neutralino2, e_L)
    - Cross sections in e_R are negligibly small (<1 fb)
  - GLD, GLD' and J4LDC each 500 fb^{-1}
  - 10fb^{-1} SM 4jets (uddu/cssc/udsc) in LDC'
    - Total cross section: about 10000 fb (e_L)
- Concerning detector performance
  - Jet energy resolution
    - To separate W(80.4 GeV) and Z(91.2 GeV) invariant mass
    - Sharpness of the edge of W/Z energy distribution
  - Flavor tagging for W/Z separation (not implemented yet)

Analysis flow

- Detector simulation (Jupiter(signal) / Mokka(BG))
- Reconstruction (MarlinReco & PandoraPFA)
- 4-jet clustering (DurhamNJet)

SM separation cuts

- Lepton veto
- Jet angle cut
- Visible energy cut

W/Z jet association

- Using χ^2 values of invariant masses
- W/Z best candidate is independently chosen

Chargino / neutralino separation

- χ^2 cut for W/Z separation
- Acoplanarity cut (chargino only)

Mass fit

- Obtain SUSY masses by energy distribution of W/Z

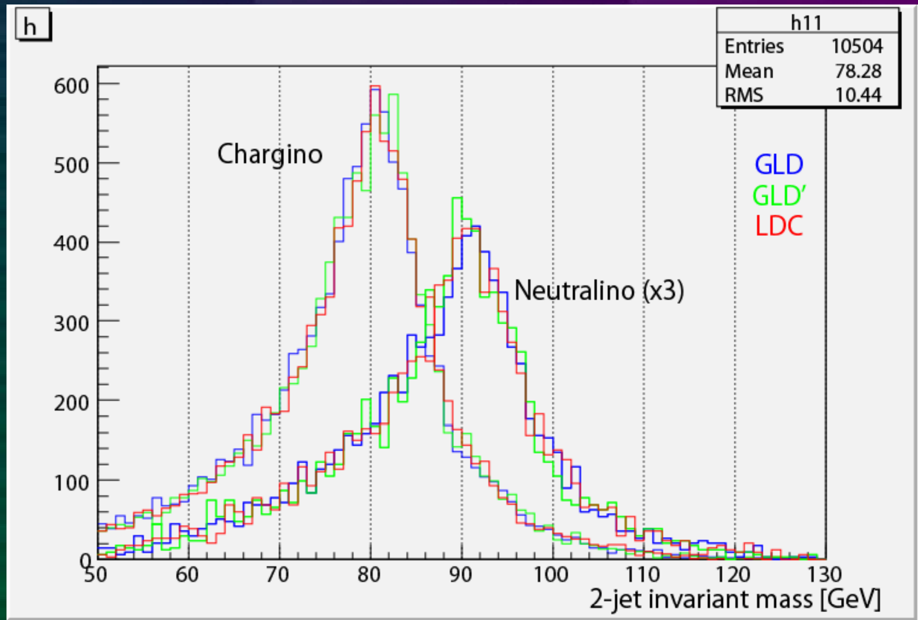
SM separation cuts

Process	Chargino			Neutralino			SM 4jet
Geometry	GLD	GLD'	J4LDC	GLD	GLD'	J4LDC	LDC'
Cross section	158 fb			29 fb			10000 fb
Luminosity	500 fb-1						10 fb-1
Jet events	73310	72572	73263	13923	13930	13929	101905
MC 4jet events	36546	36206	36550	7948	7948	7948	-
eL < 20GeV	47700	46591	46893	11604	11602	11586	83968
jet angle <0.9	36748	35921	35937	9295	9287	9225	21419
all jet > 5GeV	34935	34480	34436	8711	8706	8663	21413
Evis < 300GeV	34935	34480	34436	8711	8706	8663	682

- # of SM events becomes comparable to chargino after these cuts.
- No difference between geometries in this stage.

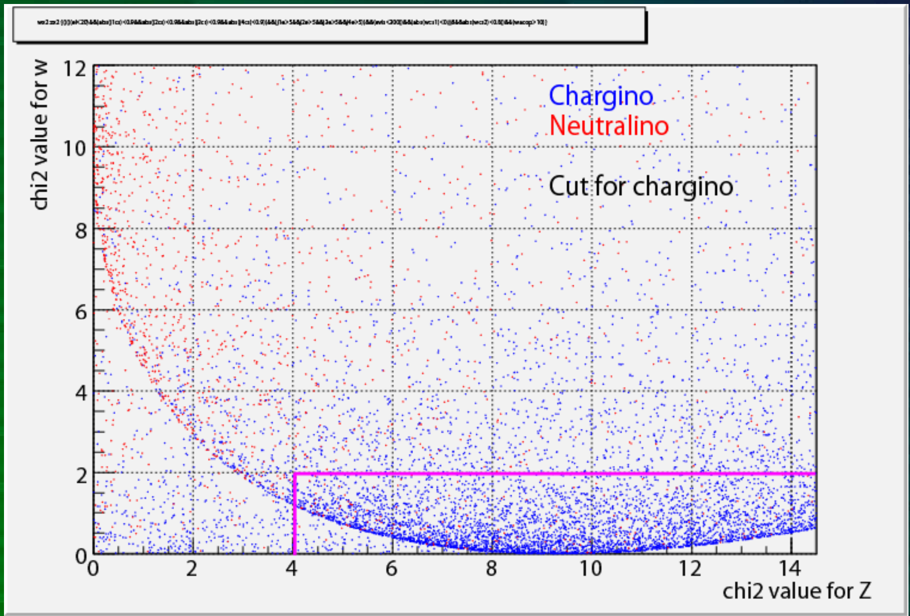
W/Z jet association

- Select 2+2 jet combination which gives minimum χ^2 :
  $\chi^2(W) = (m_1-m_W)^2/\sigma_{mW}^2 + (m_2-m_W)^2/\sigma_{mW}^2$
  $\chi^2(Z) = (m_1-m_Z)^2/\sigma_{mZ}^2 + (m_2-m_Z)^2/\sigma_{mZ}^2$
  ($\sigma_{mW} = \sigma_{mZ} = 5$ GeV)
- Peak of W/Z is corrected by shifting every jet energy (0.9 GeV in current analysis)
- W/Z separation can be efficiently performed.
- No significant difference in W/Z mass peak width.

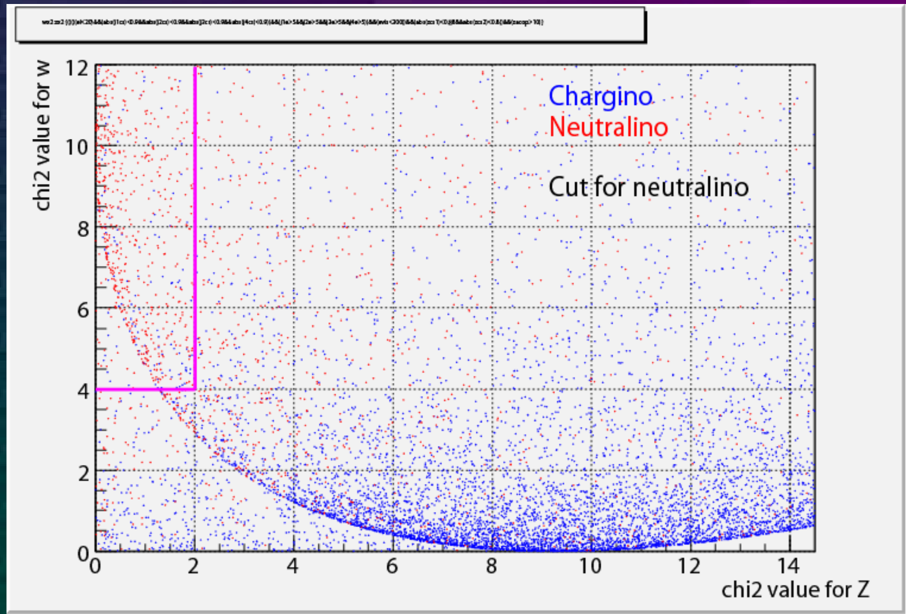


Invariant mass distribution of selected W/Z of chargino/neutralino2

χ^2 distribution / mass cut



Events in bottom area are selected as chargino



Events in left area are selected as neutralino2

χ^2 value of 2 W/Z candidates in the event is summed for the criteria.

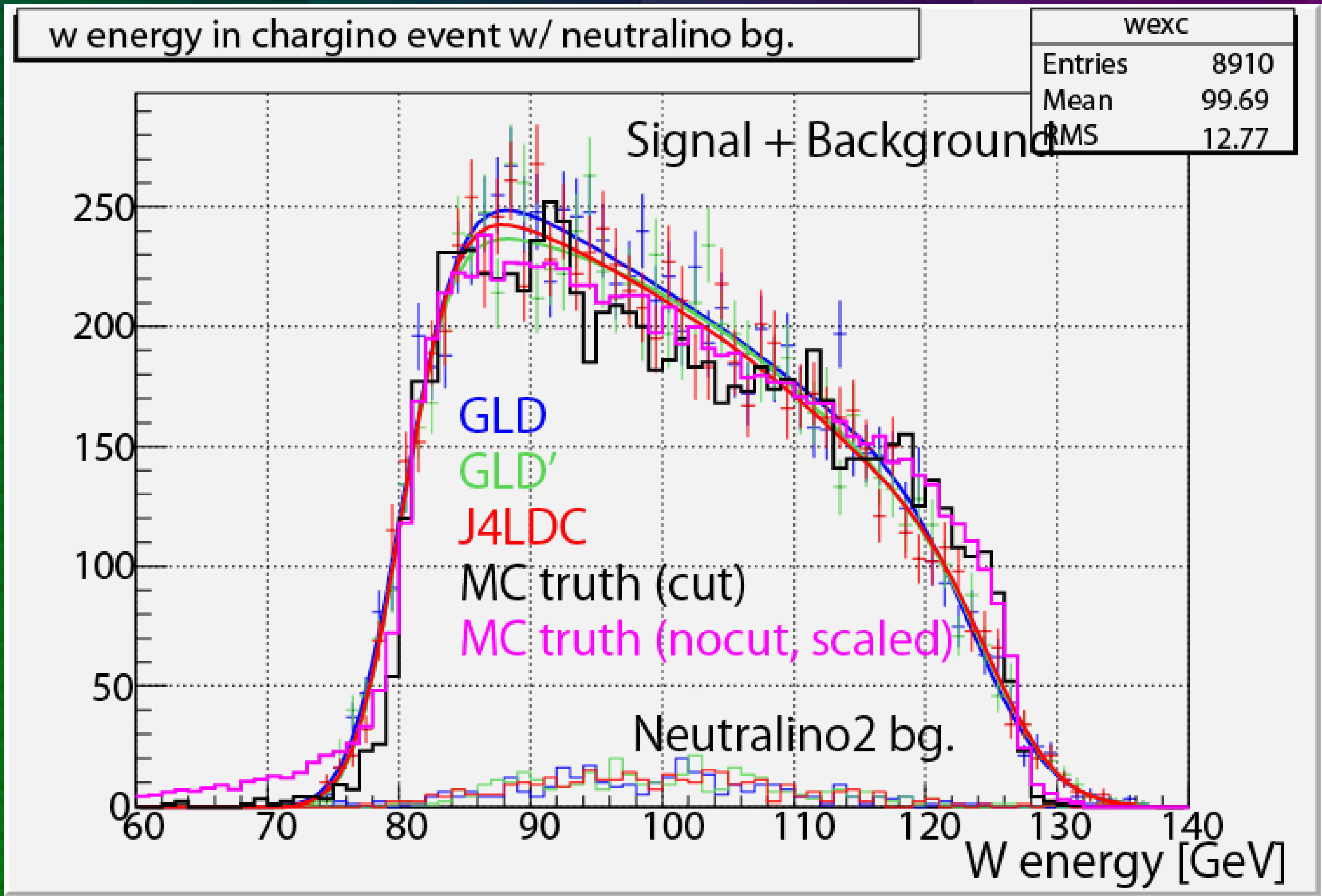
- The cut requires both χ^2(W) and χ^2(Z) within desired values.

Cut statistics (2)

	Process	Chargino			Neutralino			SM 4jet
	Geometry	GLD	GLD'	LDC	GLD	GLD'	LDC	LDC'
	Cross section	158 fb			29 fb			10000 fb
	Luminosity	500 fb-1						10 fb-1
	Jet events	73310	72572	73263	13923	13930	13929	101905
	MC 4jet events	36546	36206	36550	7948	7948	7948	-
chargino	Cuts after (1)	34935	34480	34436	8711	8706	8663	682
	cos(theta_W)<0.8	24897	24595	24672	7069	7100	7068	170
	acop_w > 10deg	21293	20977	21043	5003	4985	4990	35
	(MC 4jet in it)	15980	15889	15903	-	-	-	-
	W mass cut	5022	4908	4985	180	199	189	2
	(MC 4jet in it)	4999	4897	4972	-	-	-	-
	MC 4jet efficiency	13.68%	13.53%	13.60%	-	-	-	-
	BG acception	-	-	-	1.29%	1.43%	1.36%	0.00%
neutralino	Cuts after (1)	34935	34480	34436	8711	8706	8663	682
	cos(theta_Z)<0.8	24648	24342	24425	7034	7108	7045	171
	(MC 4jet in it)	-	-	-	4870	4946	4896	-
	Z mass cut	187	210	210	1308	1364	1346	8
	(MC 4jet in it)	-	-	-	1303	1360	1339	-
	MC 4jet efficiency	-	-	-	16.39%	17.11%	16.85%	-
	BG acception	0.26%	0.29%	0.29%	-	-	-	0.01%

- BG separation is efficient (see W/Z mass cut rows)
- Slightly better BG separation performance in GLD but almost within statistical fluctuations.

Chargino mass fit



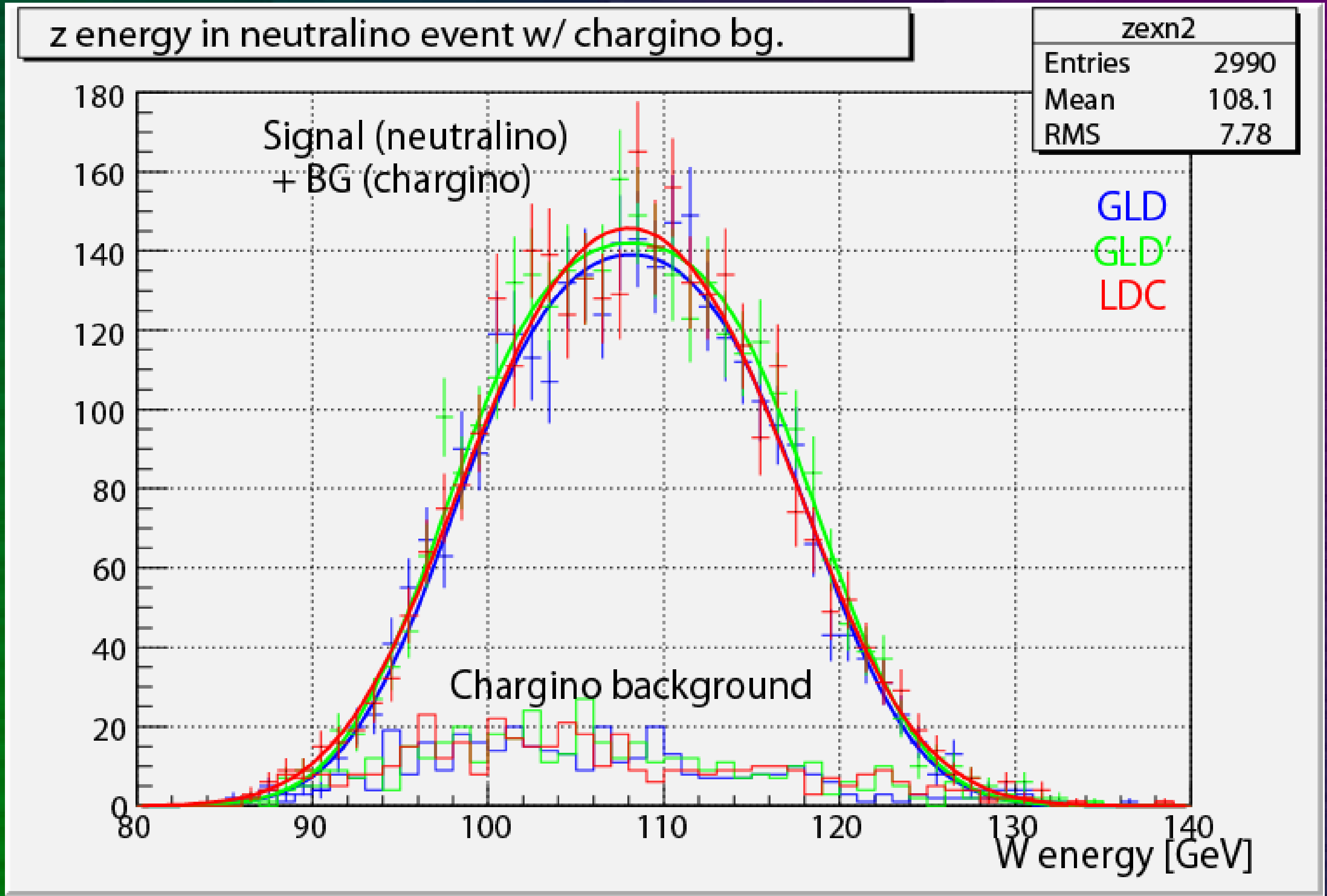
MC cut and nocut shape is almost the same (wo left edge).
No significant difference between geometries can be seen.

Chargino mass fit results

	GLD	GLD'	J4LDC	input	unit
Chargino mass	215.41 ± 1.15	216.29 ± 1.55	214.99 ± 1.20	210.21	GeV
LSP mass	121.59 ± 0.72	120.78 ± 0.89	120.40 ± 0.76	117.36	GeV
Chargino (cheat)	210.51 ± 0.56	210.67 ± 0.51	210.46 ± 0.52	210.21	GeV
LSP (cheat)	117.59 ± 0.58	117.61 ± 0.47	117.49 ± 0.46	117.36	GeV
Width L (cheat)	3.59 ± 0.11	3.30 ± 0.08	3.46 ± 0.12		GeV
Width R (cheat)	3.79 ± 0.21	3.69 ± 0.17	3.67 ± 0.19		GeV

- Fitting function:
  3rd polynomial (4 param) (center) / 0 (edge) convoluted with a Gaussian with σ as linear function of energy (2 param)
  edge position: 2 param, total # of parameters = 8
- Cheat fitting:
  1. fix edge positions at true value, fit other 6 parameters.
  2. fix those 6 parameters and fit edge positions.
- No significant difference between geometries.

Neutralino mass fit



Distribution in LDC is slightly broader (worse resolution).
Chargino background might not be negligible for lower edge.

Neutralino mass fit results

	GLD	GLD'	J4LDC	input	unit
Xn2 mass	214.61 ± 0.50	215.31 ± 0.46	214.04 ± 0.63	210.21	GeV
LSP mass	120.51 ± 0.33	120.88 ± 0.32	120.40 ± 0.36	117.36	GeV
Xn2 (cheat)	214.06 ± 0.36	214.67 ± 0.36	214.14 ± 0.39	210.21	GeV
LSP (cheat)	120.34 ± 0.31	120.78 ± 0.31	120.42 ± 0.34	117.36	GeV
Width (cheat)	7.42 ± 0.20	7.20 ± 0.22	8.04 ± 0.21		GeV

- Fitting function:
  Error function (left) x Complementary error function (right)
  Width of left and right is the same, # of parameters = 4
- Cheat fitting:
  Same as chargino
- J4LDC gives slightly larger width than other two.
  Corresponding fitting error is enhanced.

Performance Summary

Geometry	GLD	GLD’	J4LDC	Related to
Smuon fit	○	△?	○	Tracking performance
Jets selection	◎?	○	○	W/Z separation
Mass fit chargino	○	○	○	Jet energy resolution
Mass fit neutralino	○	○	△	Jet energy resolution
Overall	○	○	△?	

- Performance is almost identical.
- Slight hint of worse energy resolution in J4LDC.
  - Might be corresponding to PFA performance.
- Difference of smuon fit and W/Z separation might be random effect.

Comments

- Mass fit of chargino/neutralino is problematic: practically we might need a kind of “template fit” for accurate estimation.
  - Templates of various SUSY masses are needed for the template fit.
- Mass cut of W/Z might be too tight. We can earn efficiency by looser mass cuts.
  - Need to be optimized.
- LDC’ SUSY events can be analyzed in the same framework, can be checked in a week.

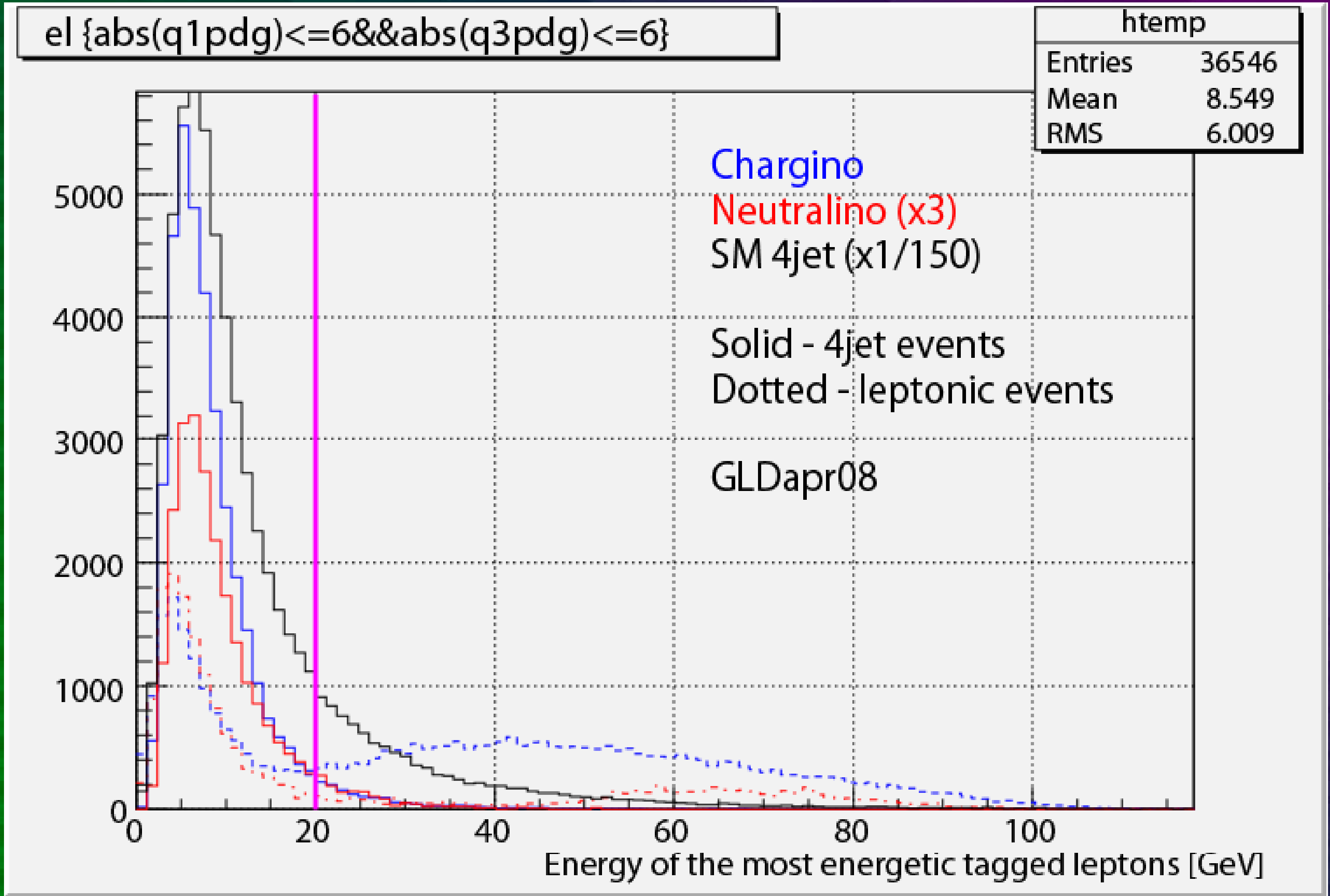
Thank you for your attention again!

Backup

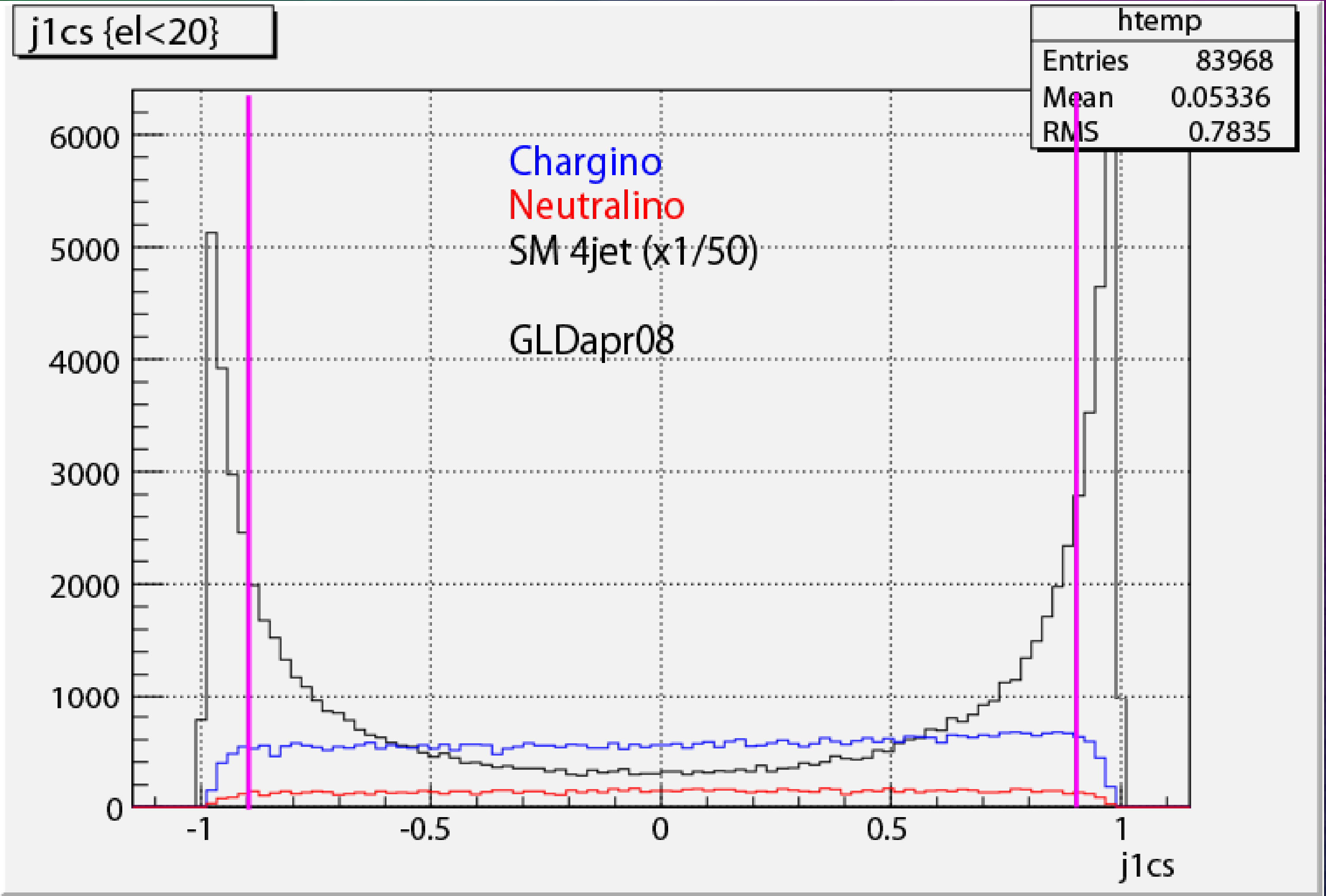
Cuts(1)

1. Jet clustering (njet=4)
2. Lepton ID/veto
   - Electron by Ecal/total deposit >0.9 or tagged by PandoraPFA
   - Muon by calo/track energy < 0.5
   - Currently no tau-ID
   - Events with >20GeV leptons are cut
3. |Cos(theta)|<0.9 for all jets
4. E>5GeV for all jets
5. Visible energy < 300 GeV
6. Combining W/Z using remaining events

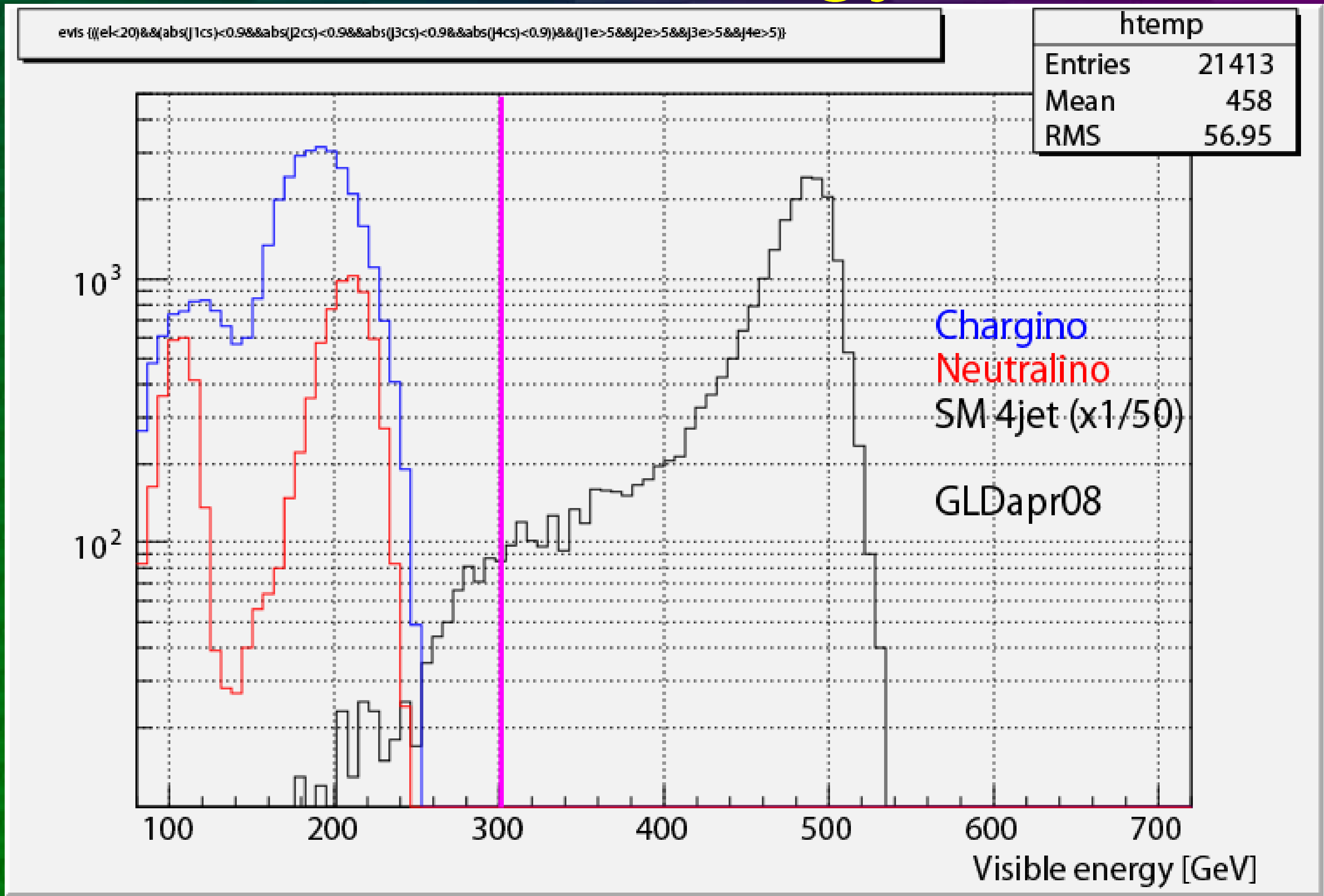
Lepton veto


el {abs(q1pdg)<=6&&abs(q3pdg)<=6}
htemp
Entries 36546
Mean 8.549
RMS 6.009
Chargino
Neutralino (x3)
SM 4jet (x1/150)
Solid - 4jet events
Dotted - leptonic events
GLDapr08
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
Energy of the most energetic tagged leptons [GeV]

Jet angle cut

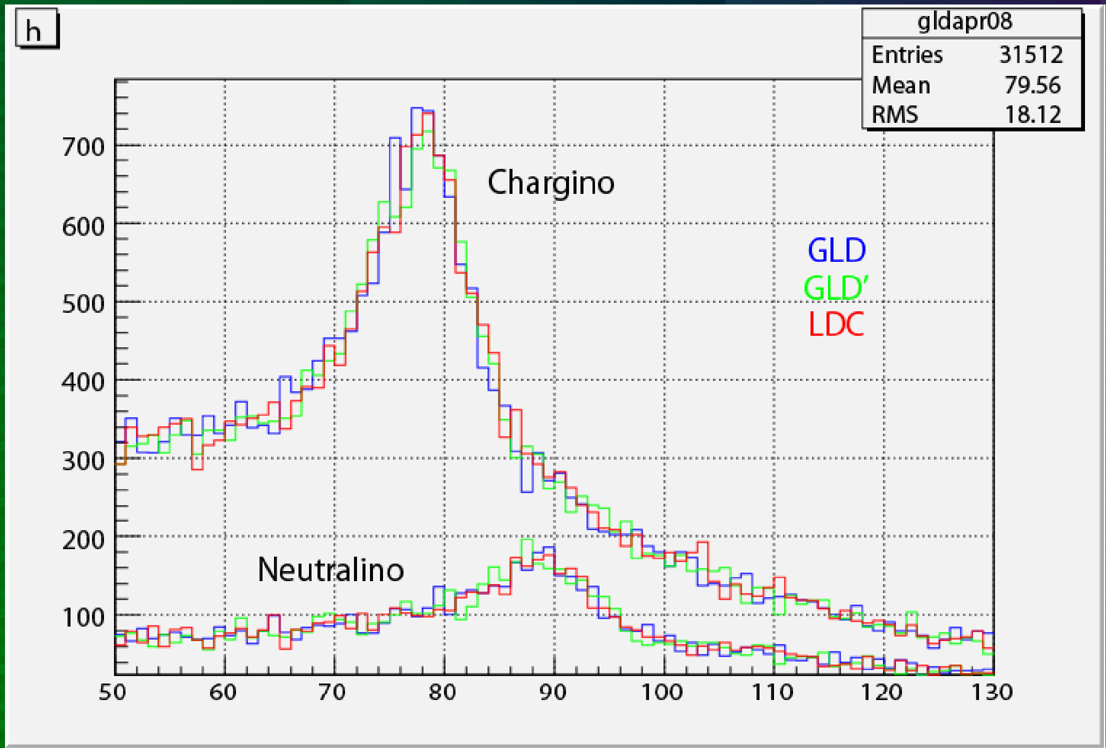


Visible energy cut



Loose cut (300 GeV) is for accepting lighter SUSY particles (LSP to 100 GeV)

W/Z mass peak – all combination



Cut condition

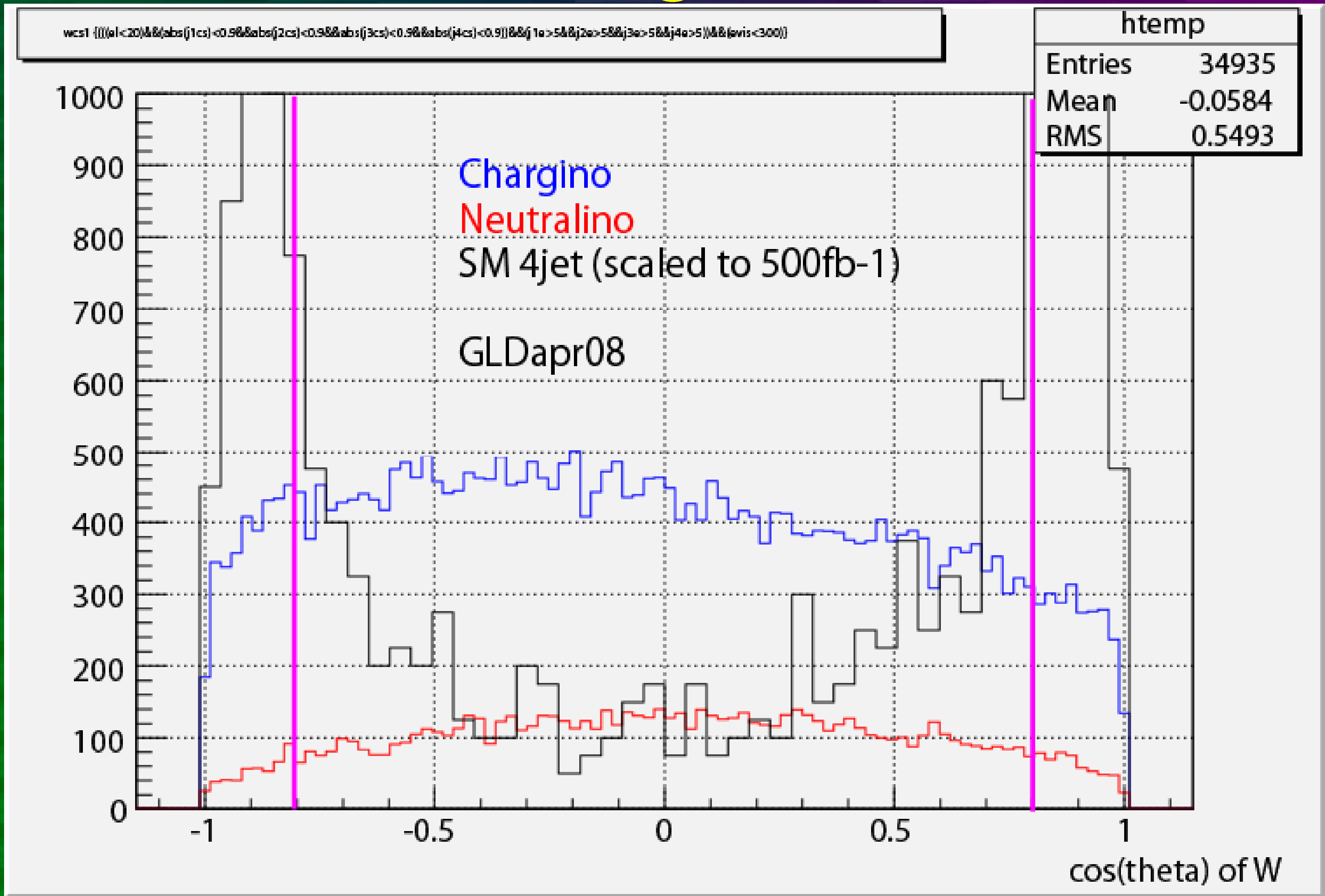
- 4 jet clustering
- Lepton veto (<20GeV)
- All jet angle < 0.6 (Barrel only)
- No Evis cut
- No Ejet cut
- All combination

- Energy peak is shifted – need correction
  - All jet energy is shifted (0.8GeV) to fit the peak
- No difference between geometries again

Cuts(2)

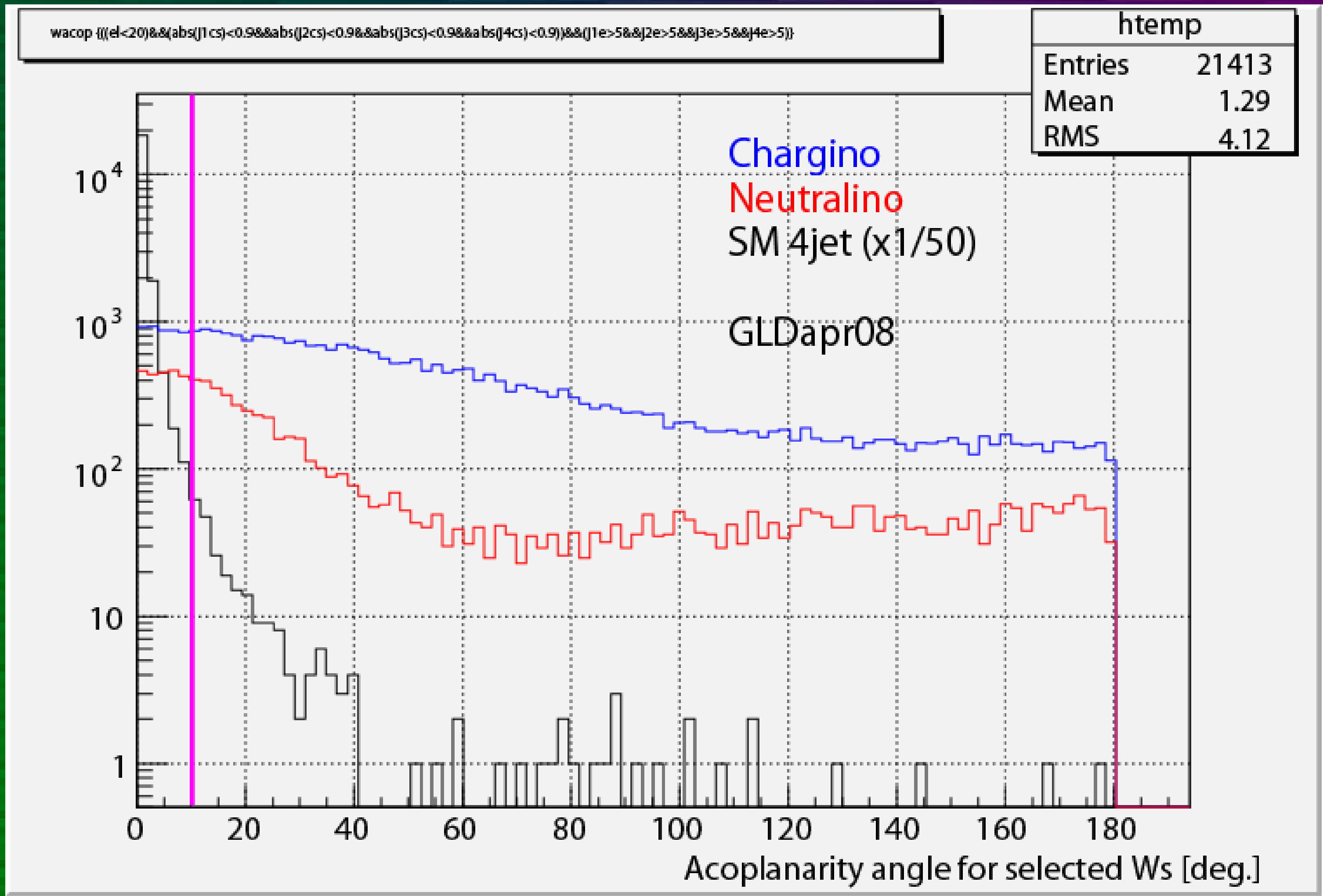
7. Select best-W and best-Z combination by χ^2
   $\chi^2 (W) = (m_1-m_W)^2 + (m_2-m_W)^2$
   $\chi^2 (Z) = (m_1-m_Z)^2 + (m_2-m_Z)^2$
   Minimum χ^2 (W) pair is selected for W analysis
   and minimum χ^2 (Z) pair is selected for Z analysis.
   1σ width of W and Z mass resolution is 5 GeV for both.
8. Angular cut of best-combined W/Z
   |cos(theta_WorZ)| < 0.8
9. Acoplanarity cut
   >10deg for chargino, no cut for neutralino
10. Mass cut using χ^2 values
    Chargino cut: $\chi^2(W) < 2$ and $\chi^2(Z) > 4$
    Neutralino cut: $\chi^2(Z) < 2$ and $\chi^2(W) > 4$

W/Z angular cut



W angular distribution is shown (Z is similar).

Acoplanarity cut



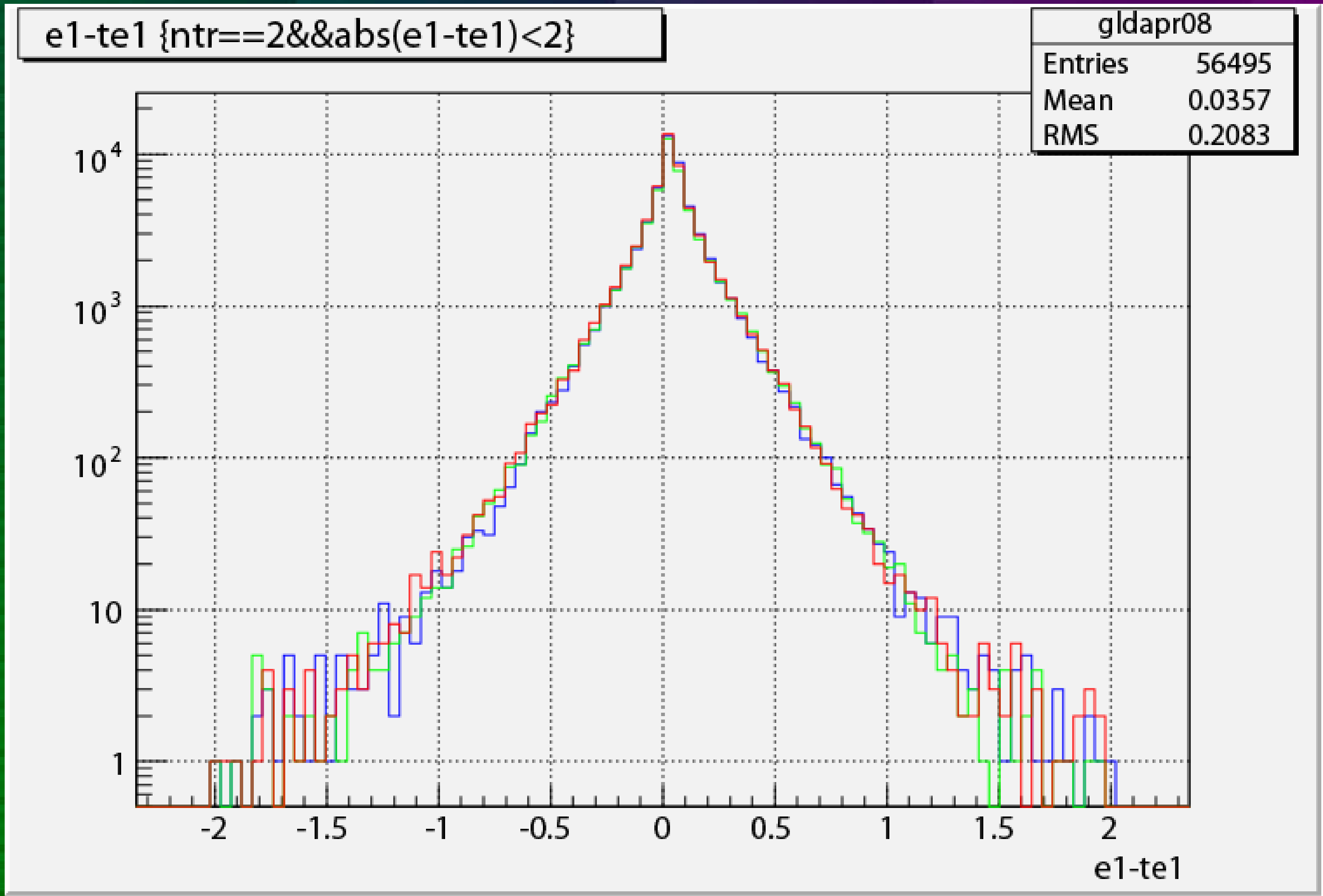
This cut is for chargino only.
SM is plotted without Evis and W/Z angular cut

Result of mass fit

	GLD	GLD'	LDC	input	unit
chargino mass	221.7 ± 3.44	219.1 ± 2.73	220.8 ± 1.8	210.21	GeV
LSP mass	124.2 ± 1.32	122.4 ± 1.21	122.6 ± 0.62	117.36	GeV
width (left)	0.645 ± 0.02	0.603 ± 0.03	0.576 ± 0.02		GeV/sqrt(E)
width (right)	0.56 ± 0.05	0.517 ± 0.05	0.507 ± 0.03		GeV/sqrt(E)
lower edge	80.32 ± 0.17	80.47 ± 0.16	80.14 ± 0.16	81.739	GeV
higher edge	124 ± 0.73	125.1 ± 0.73	125.6 ± 0.79	126.86	GeV
neutralino mass	214.6 ± 0.49	214.9 ± 0.44	214.4 ± 0.51	210.67	GeV
LSP mass	120.6 ± 0.31	120.6 ± 0.29	120.7 ± 0.31	117.36	GeV
width	6.83 ± 0.4	6.61 ± 0.36	7.84 ± 0.49		GeV

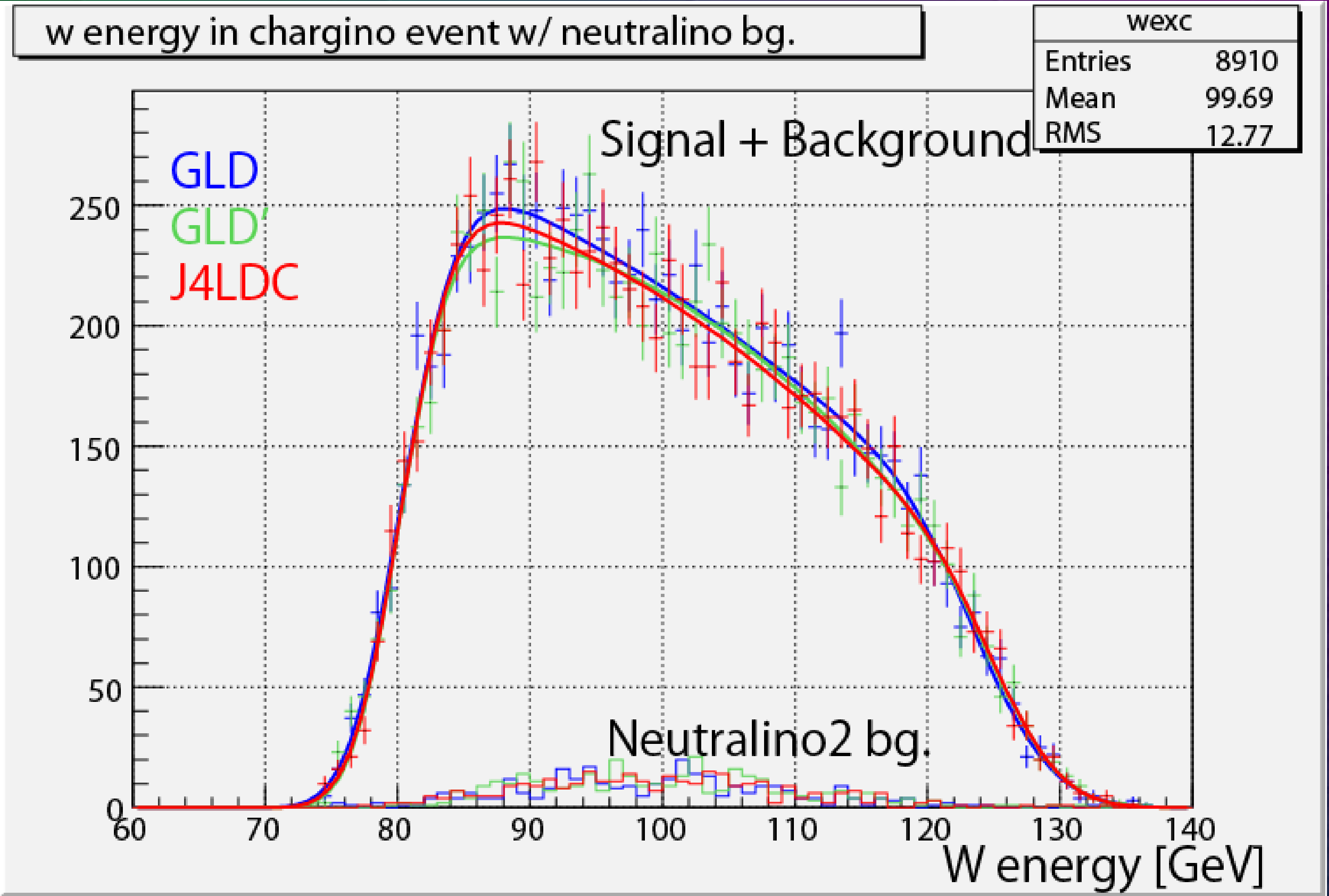
- Input and fitted masses are largely deviated
  - Need to check the reasons
  - Previous fitting gave better consistency
    - Jet energy correction is revised: using MC jet energy -> using W/Z peak
    - Various cuts are changed, mass cut is looser in previous analyses
- Chargino higher edge has poor resolution
- LDC has larger width in neutralino fitting

Muon track – reco - MC

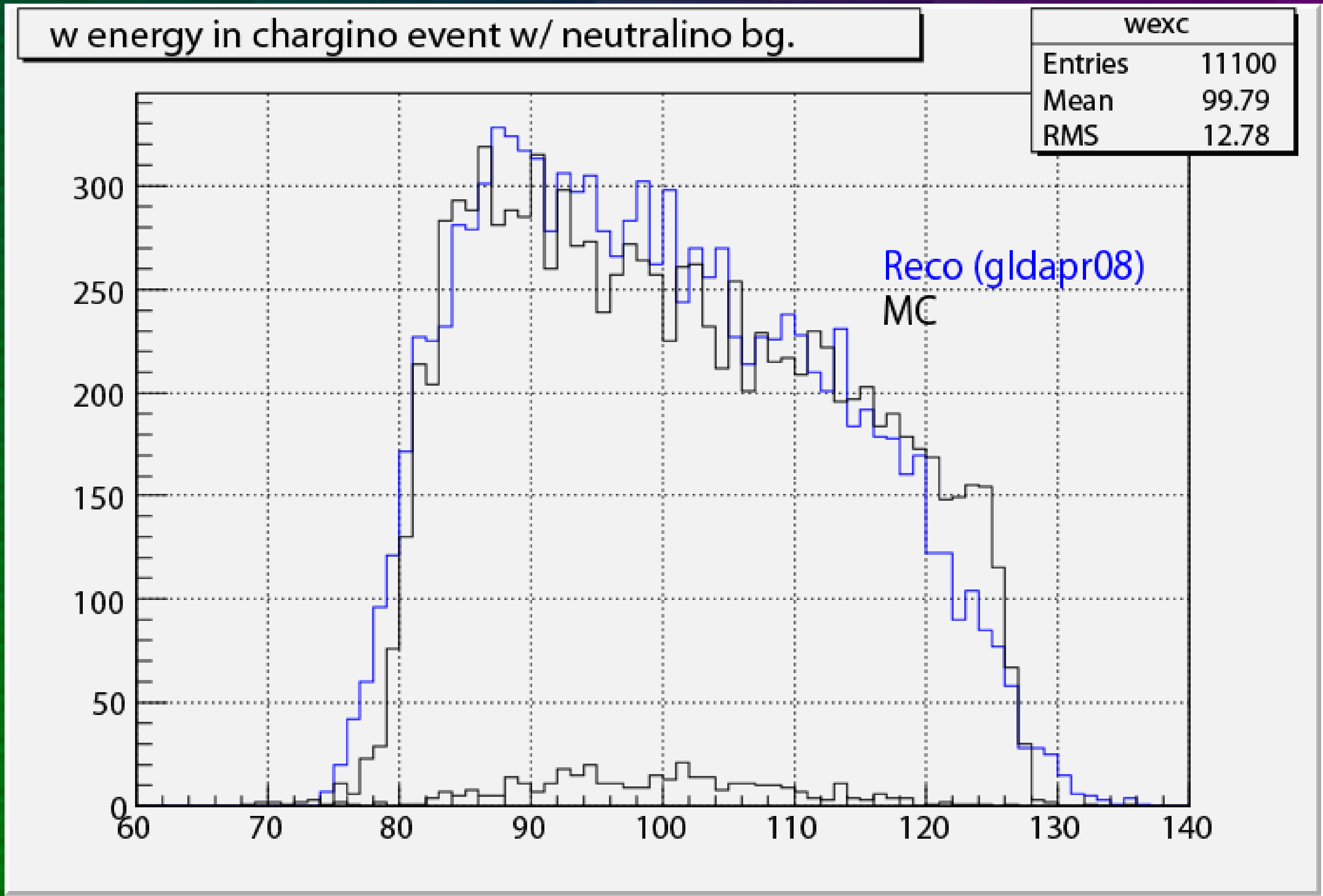


- No difference (RMS ~ 200MeV).

Chargino mass fit (wo. MC)



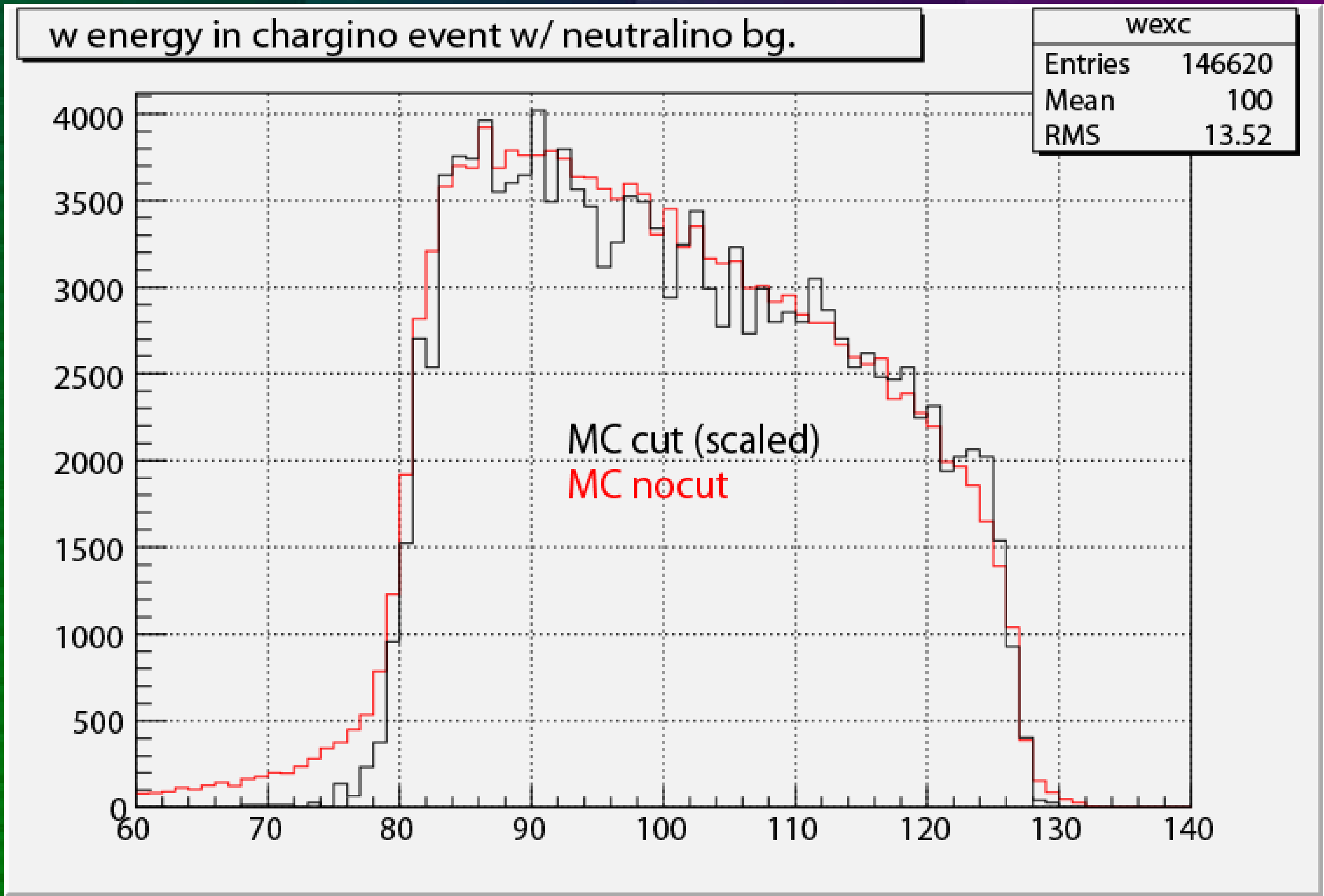
Chargino MC vs Reco



Mass cut by 80 GeV W

Slightly shifted?

Chargino MC cut vs nocut



Very slight shift (left edge?)