LCFI CCD Vertex Detector Charm-Tagging and Mass Determination in Studies of Scalar Quarks

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Outline

- Introduction
- A CCD Vertex Detector (LCFI)
- A Charm Tagging Benchmark Reaction
- Event Selection
- Comparison of Detector Simulations
- Tagging Performance
- Varying Vertex Detector Design
- Mass Determinations
- Conclusions

Introduction

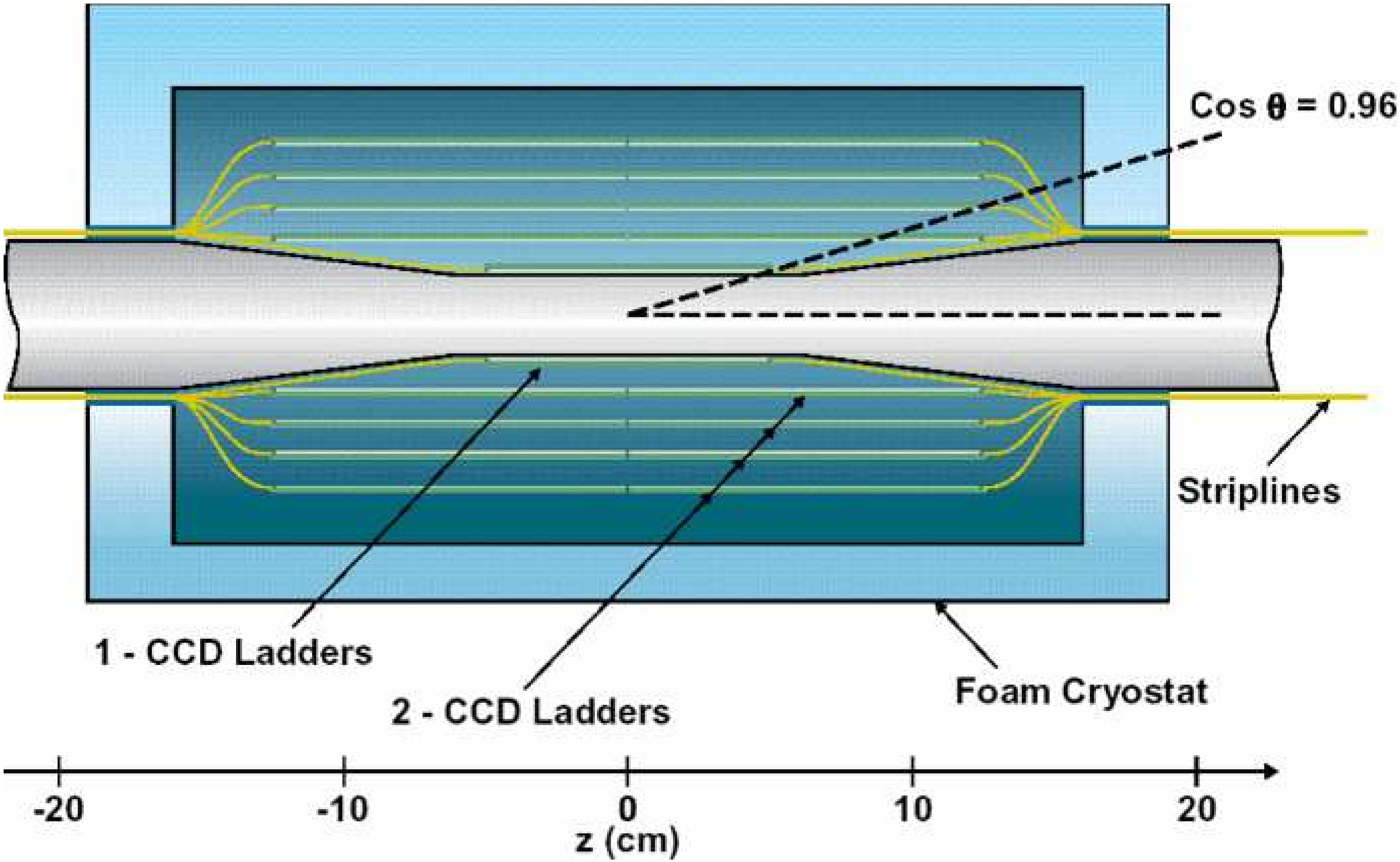
Large challenge to develop a vertex detector for a future LC.
Key aspects:

- Distance to interaction point of innermost layer (radiation hardness, beam background).
- Material absorption length (multiple scattering).
- Tagging performance.

While at previous and current accelerators (e.g. SLC, LEP, Tevatron) b-quark tagging has revolutionized many searches and measurements, c-quark tagging will be a very important tool at a future LC.

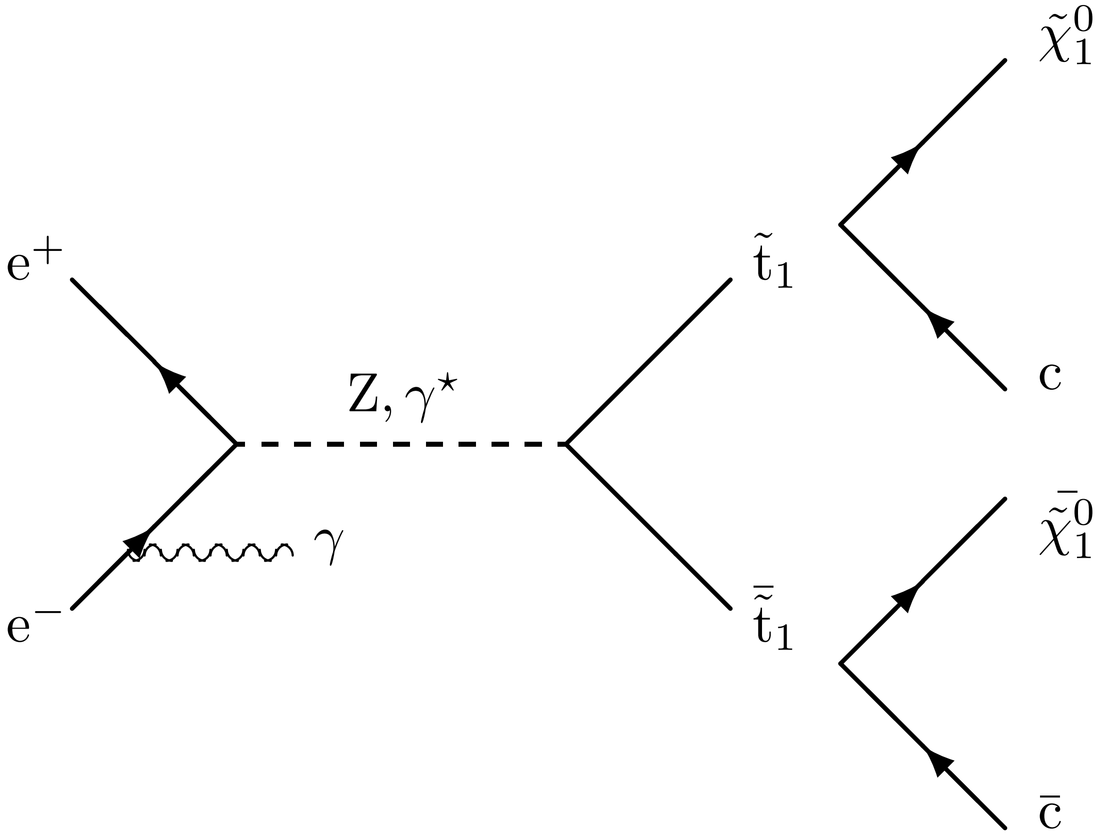
CDD Vertex Detector

LCFI Collaboration: Development of a CCD detector for a future LC.



5 CCD layers at 15, 26, 37, 48 and 60 mm. Each layer $< 0.1\%\ X_0$.

c-Quark Tagging: a Benchmark Reaction



Signal: Two charm jets and missing energy.

Benchmark reaction in the Supersymmetry framework: $e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1 \to c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$

(Other benchmark reactions, e.g. in Higgs sector, $H \to c\bar{c}$)

Signal and Background Cross Sections

Two scenarios:

1. Comparison previous SGV study: $m_{\tilde{t}_1} = 180\,\text{GeV}$, $m_{\tilde{\chi}_1^0} = 100\,\text{GeV}$
2. SPS-5 SUSY parameters: $m_{\tilde{t}_1} = 220.7$ GeV, $m_{\tilde{\chi}_1^0} = 120$ GeV

Decays mode (kinematics) $\tilde{t}_1 \rightarrow \tilde{\chi}_1^0 c$.

Signal and background cross section (pb):

$\tilde{t}_1\bar{\tilde{t}}_1$(180/220.7)	$We\nu$	WW	$q\bar{q}$	$t\bar{t}$	ZZ	eeZ
CALVIN32	GRACE	WOPPER	HERWIG	HERWIG	COMPHEP	PYTHIA
0.0532/0.0164	5.59	7.86	12.1	0.574	0.864	0.6

For this performance study: no beam polarization.

Analysis Strategy

- Signal and Background generated for 500 fb^{-1} and $\sqrt{s} = 500\text{GeV}$
- Detector Simulation: SIMDET 4.03 (J. Schreiber et al.)
- b/c tagging algorithm (T. Kuhl et al.)
- Iterative Discriminant Analysis (IDA) for selection optimization
- Different Vertex Detector configurations

SIMDET Detector Simulation (cf. SGV)

180 GeV $\tilde{t}_1 \to c\tilde{\chi}_1^0$ and 1000 fb $^{-1}$ Standard Model background simulated

Channel	Generated	Preselection/500 fb^{-1}	Previous SGV
$c\tilde{\chi}_1^0$	50 k	48%	47%
$q\bar{q}$	12169 k	64963	46788
$t\bar{t}$	620 k	32715	43759
eeZ	5740 k	24864	4069
ZZ	560 k	3100	4027
$We\nu$	4859 k	252367	252189
WW	6800 k	122621	115243
Total bg		500631	466075

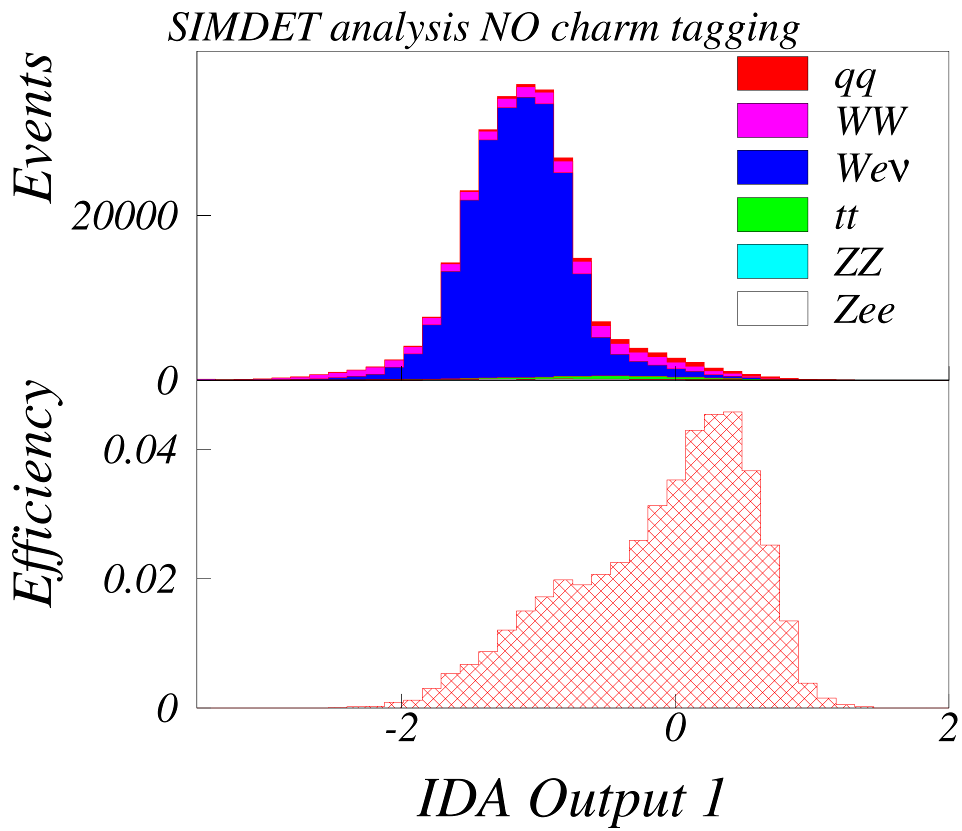
After additional preselection ($E_{\mathrm{vis}}/E_{\mathrm{cms}} < 0.52$, $P_{\mathrm{t}}/E_{\mathrm{vis}} > 0.05$):

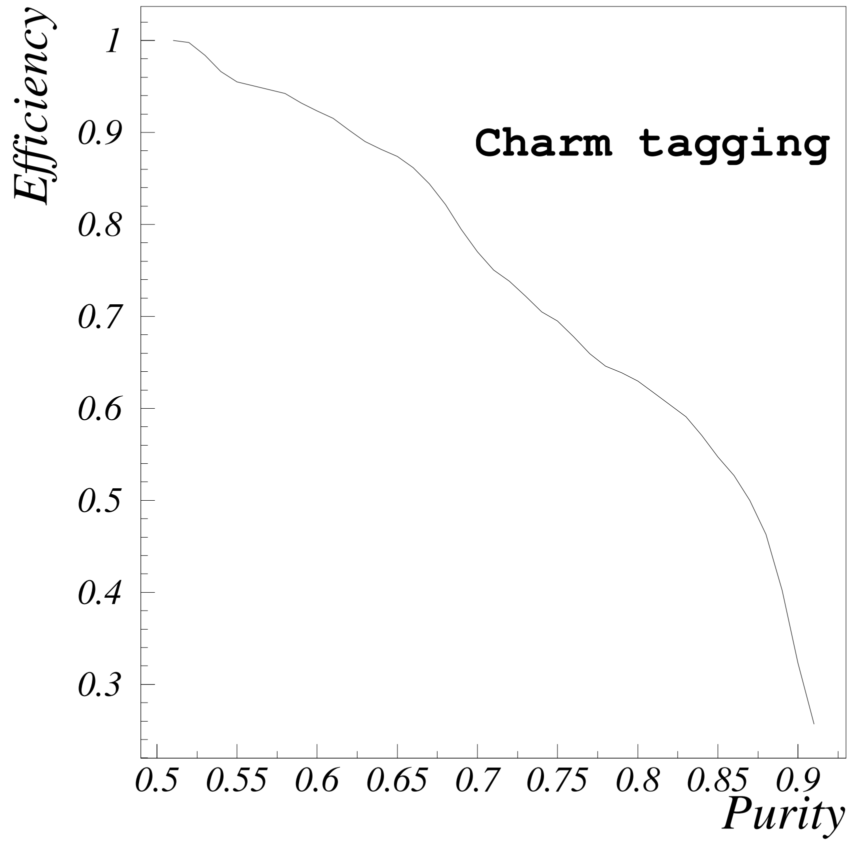
Channel	$q\bar{q}$	WW	$We\nu$	$t\bar{t}$	ZZ	eeZ	Total
	6801	23278	226070	5267	125	2147	263691

(cf. SGV: 278377 events).

Iterative Discriminant Analysis (IDA)

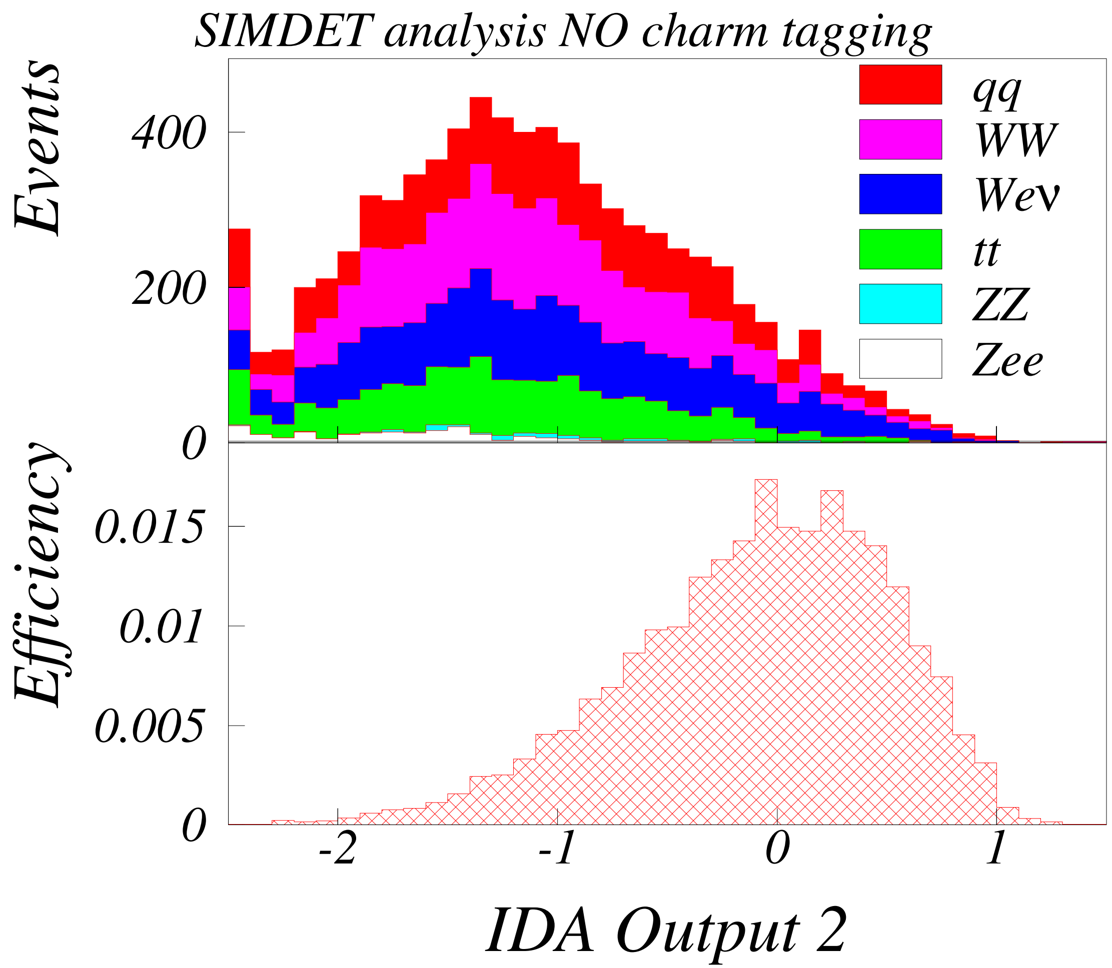
- First half-sample for training.
  Second part for signal efficiency and backgrund rate determination.
- Two step process: IDA 1: signal reduced to 50% efficiency; IDA 2: fine-tuning





Without charm tag 7815 (cf. SGV 7265). With charm tag 3600 background events.

Signal vs. Background: c-Quark Tagging



After second IDA step, remaining backgrounds for 12% efficiency (180 GeV):

Without charm tag 680 (cf. SGV 400 events),

With charm tag 165 events.

SPS-5 Results (220.7 GeV)

Events remaining after 1st Iteration of IDA (25% efficiency):

Signal	Background	Charm Tagging
3800	5400	No
3800	2500	Yes

Events remaining after 2nd Iteration of IDA (12% efficiency):

Signal	Background	Charm Tagging
1800	170	No
1800	68	Yes

Varying Vertex Detector Design

Vertex detector absorption length:

- Normal thickness (TESLA TDR)
- Double thickness

Number of vertex detector layers:

- 5 layers - innermost layer at 15 mm (like TDR)
- 4 layers - innermost layer at 26 mm (Layer 1 removed)

For SPS-5 parameters (220.7 GeV):

Thickness	Layers	Remaining background events (12% Signal)	Remaining background events (25% Signal)
Normal	5	68	2300
Normal	4	82	2681
Double	5	69	2332
Double	4	92	2765

Four Different Methods of Mass Determination

- ‘IDA’ based selection -

  Optimum Signal/Background ratio:

  – Cross section with different polarizations

  – Threshold dependence of cross section

- Cuts based selection -

  Minimum distortion of final state observables

  – Endpoint of jet energy spectrum

  – Minimum Mass of jets

Iterative Discriminant Analysis - 'IDA'

A method to weight each event to optimize signal / background separation using n discriminant variables.

Construct: vector x containing the n variables and
$(n^2 - n)/2$ products of those variables.

Calculate:	V	Variance matrix
	$\Delta\mu$	Difference in the mean values between signal and background
	$a = V^{-1}\Delta\mu$	
	$D^0 = x^T \cdot a \cdot x$	provides the maximum separation between Signal and Background.

Weighted such that signal and background have equal importance.

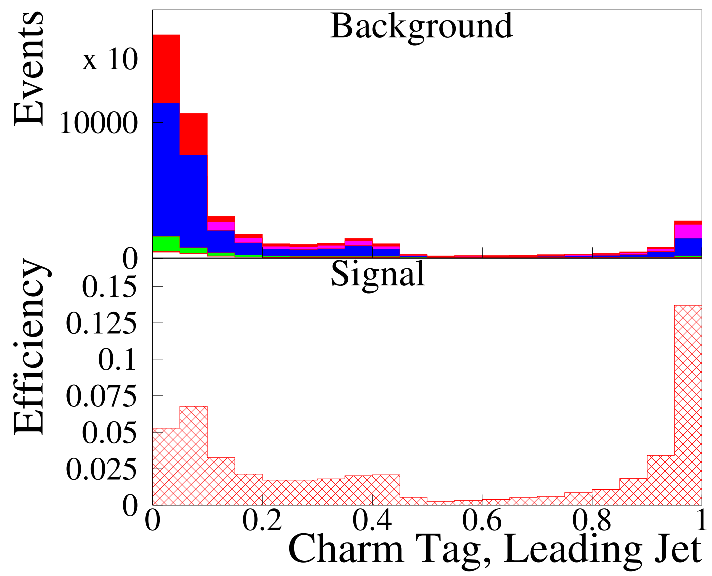
Find the value of D^0 which selects a predetermined fraction of the signal (e.g. 50%), and cut on it.

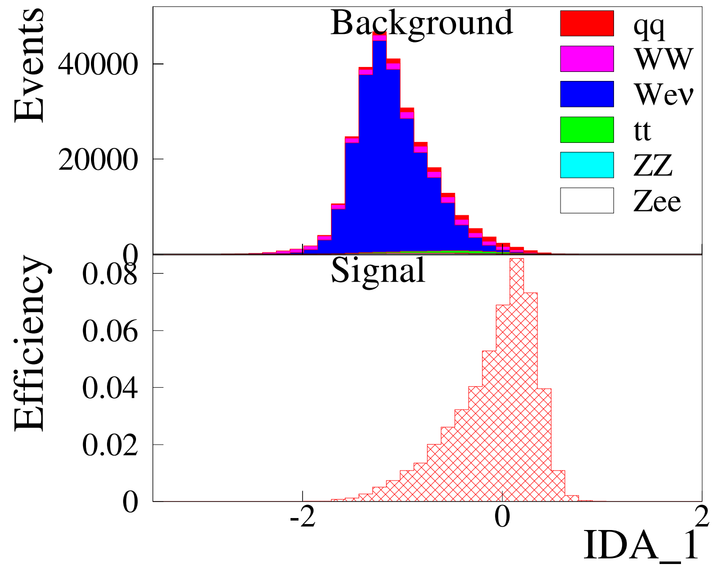
Do this process once again for events passing the cut.

IDA Analysis

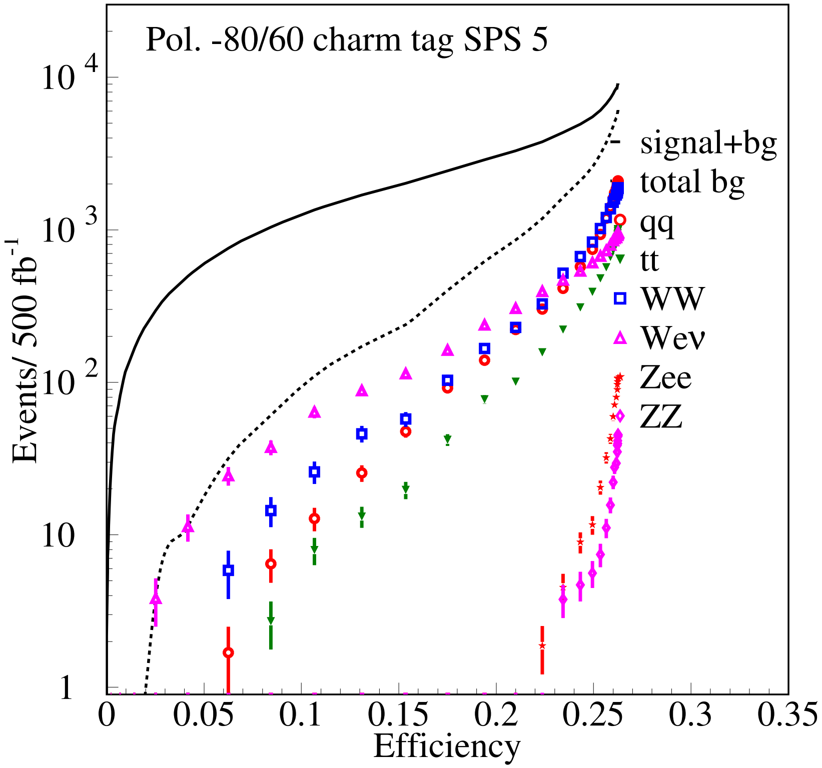
Discrimination Variables

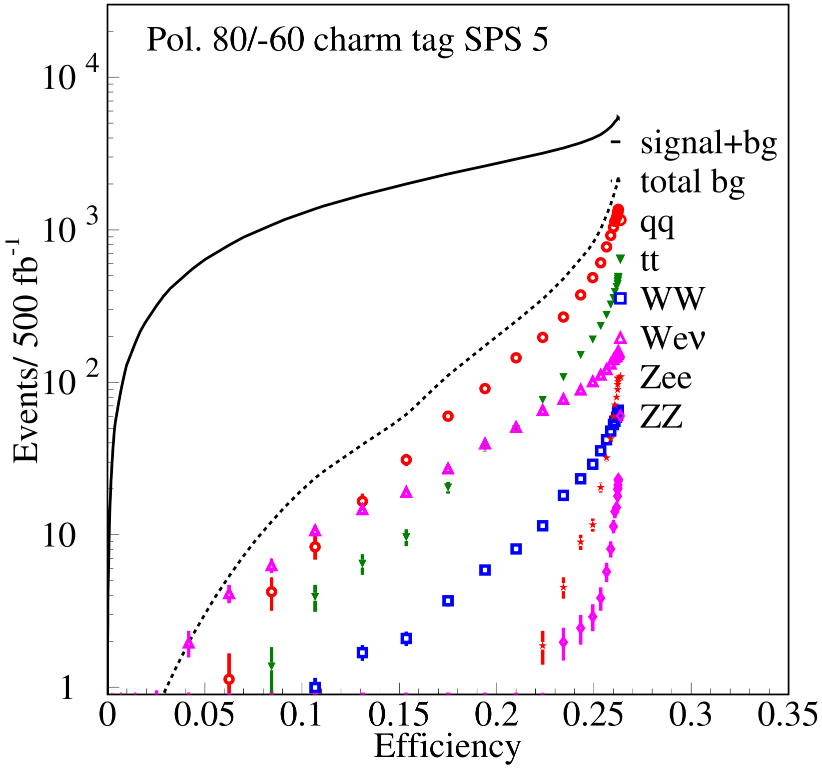
- visible energy
- number of jets
- thrust value
- thrust direction
- number of energy flow objects
- transverse momentum imbalance
- parallel momentum imbalance
- acoplanarity of the two highest energy jets.
- invariant mass of the two highest energy jets.
- Charm Tag of Jet 1
- Charm Tag of Jet 2





Selection Efficiency for Different Beam Polarizations

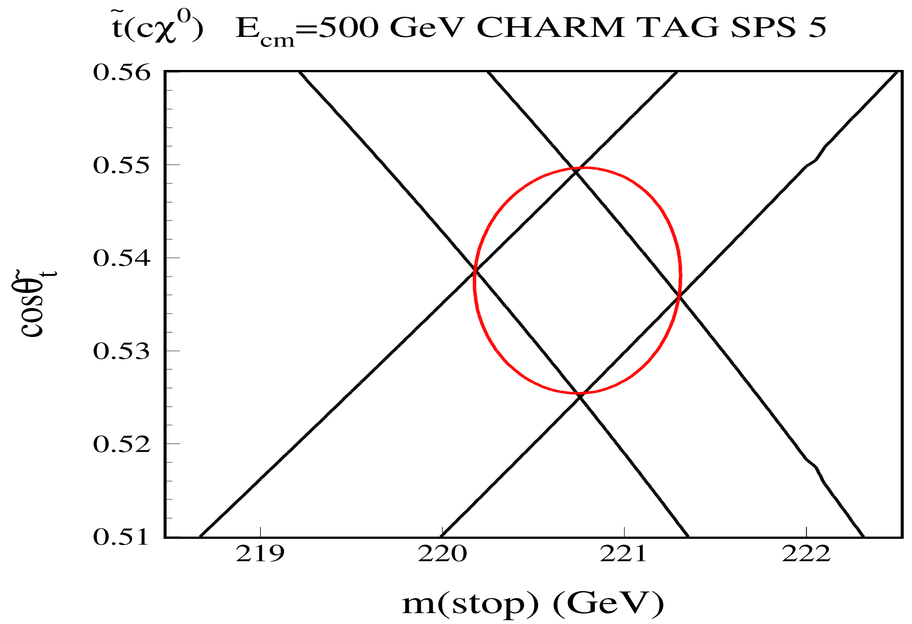




		Pol. -80/60	Pol. 80/-60
At 12% Efficiency {	Signal:	1350	1500
	Background:	145	32

Results Using Polarization Method

Dependence of cross section on scalar top mass and mixing angle:



$$\Delta m_{\tilde{t}_1} = \pm 0.57 \text{GeV}$$
$$\Delta \cos\theta_{\tilde{t}} = \pm 0.012$$

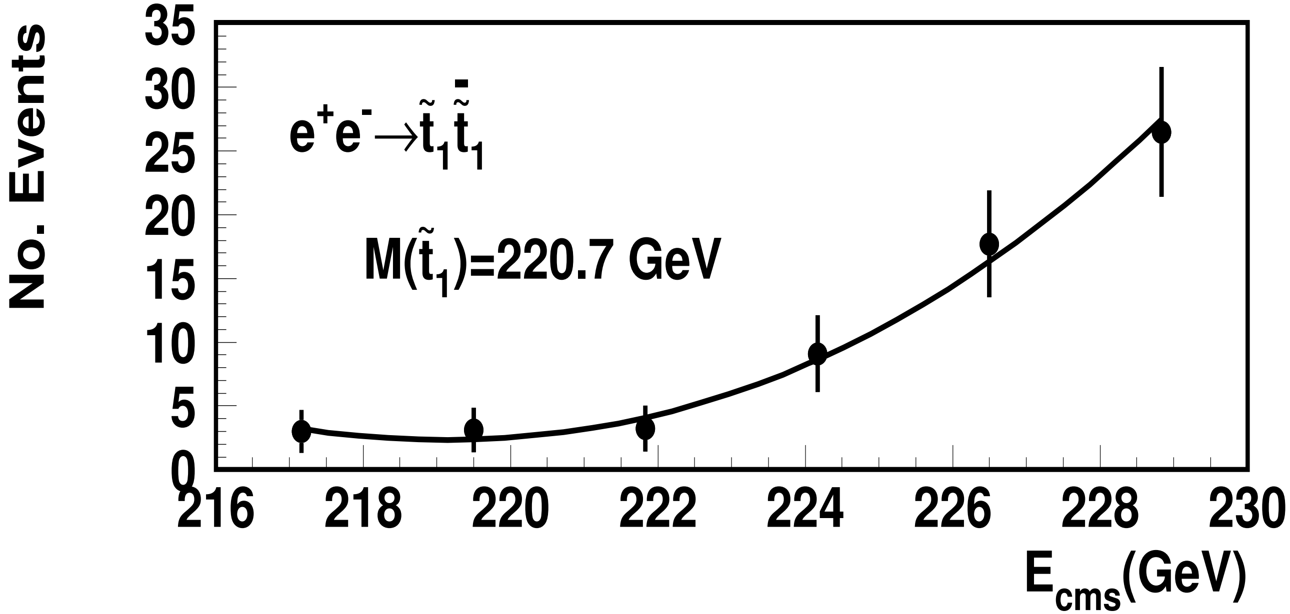
Note $500\,\text{fb}^{-1}$ for each polarization

Threshold Scan Method

Use 'Right Handed Polarization' to reduce backgrounds

Measure Cross Section Close to Threshold

6 points with 50 fb^{-1} per point.

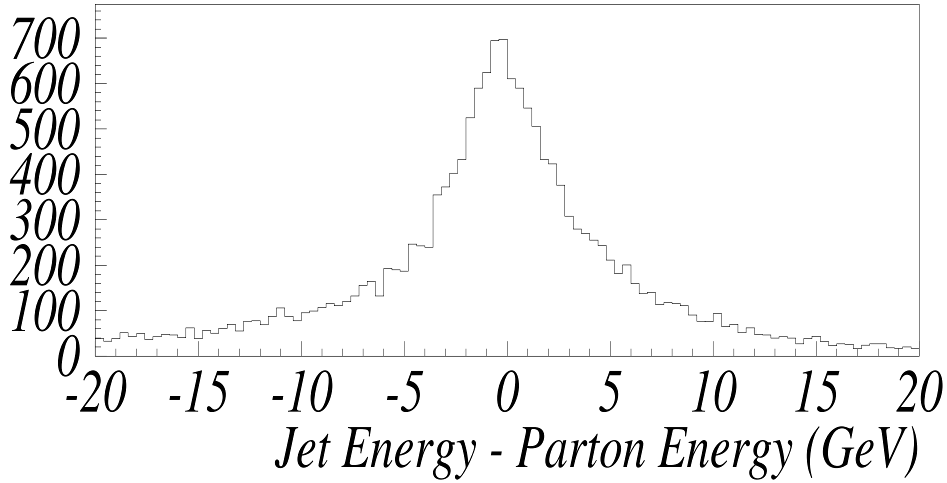


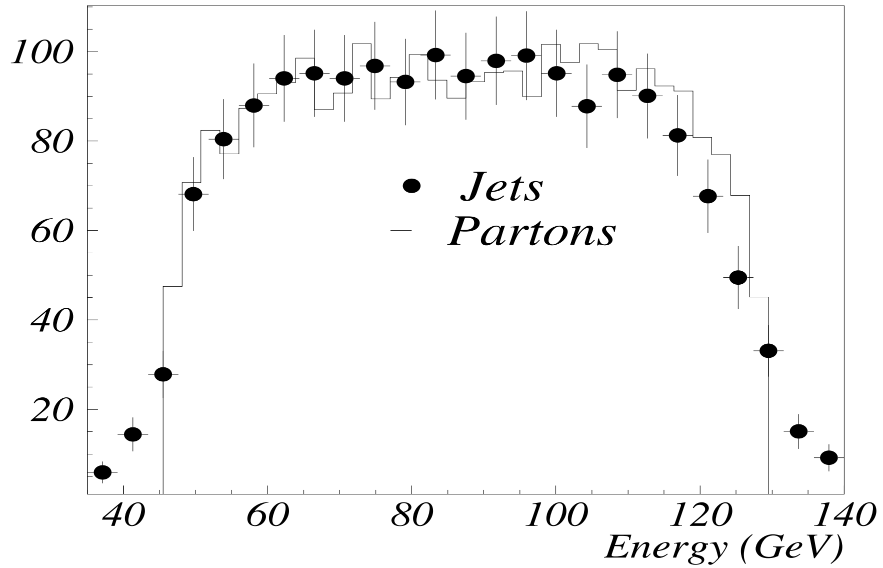
Mass from Fit to shape: 220.9 ± 1.2 GeV

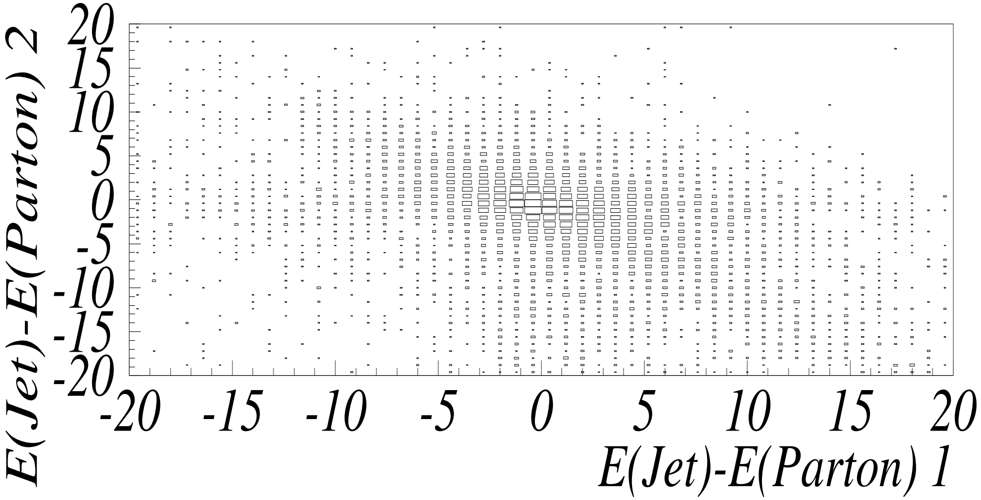
Direct Measurments from Jet Energies

'End Point Method' and 'Minimum Mass Method'

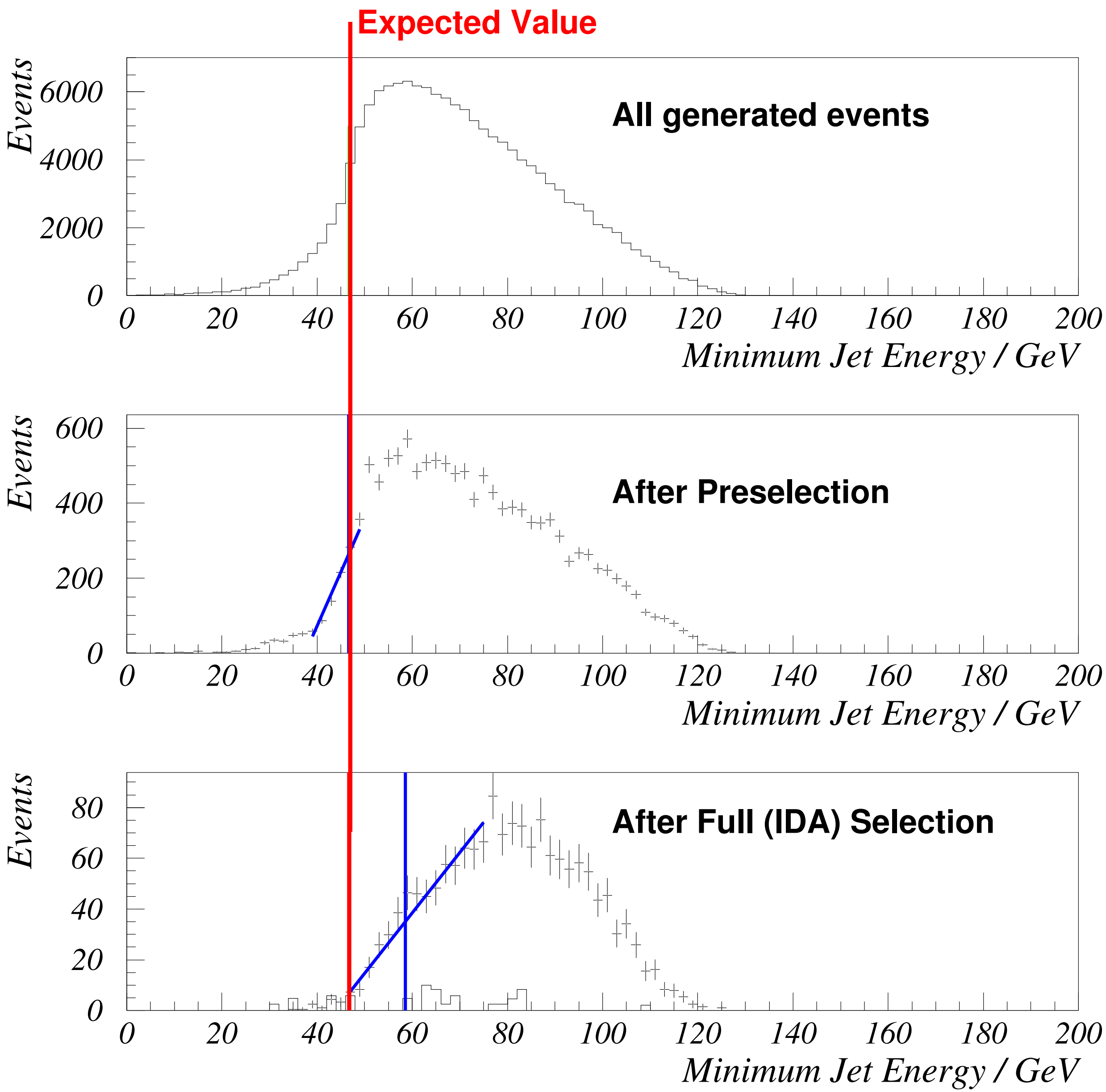
Require quark energies, but one measures jets...







Effect of IDA Selection on Min. Jet Energy

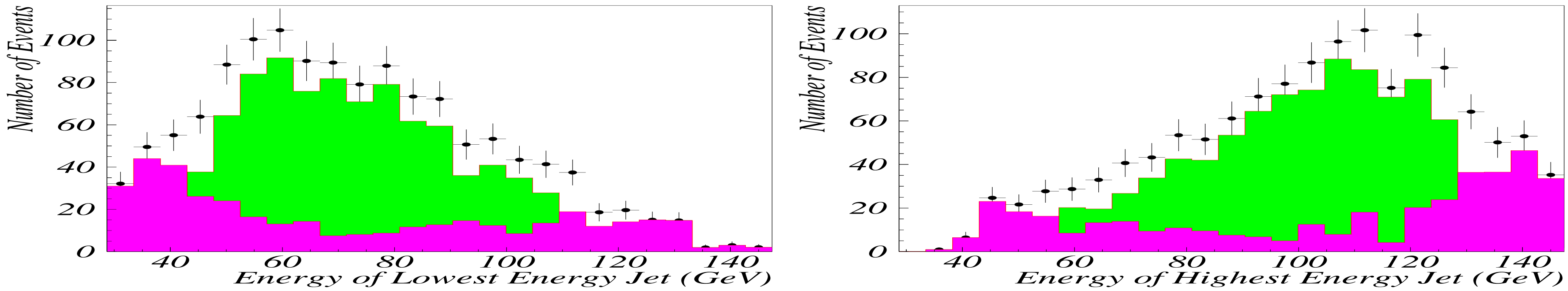


Cuts Based Selection to Reduce Distortions

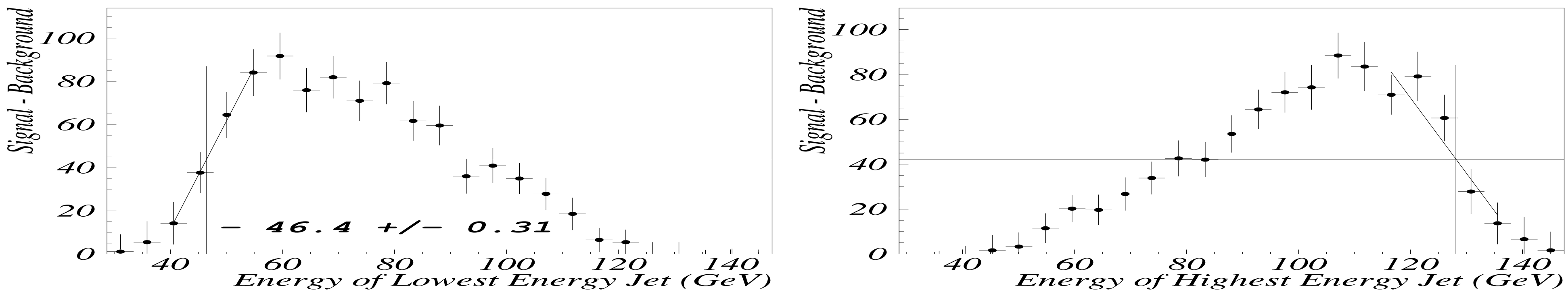
- 20 < Number of Energy Flow Objects < 90
- Visble Energy $< 0.8\sqrt{s}$
- Measured Longitudinal Momentum < 0.5 Visible Energy
- Thrust < 0.95
- Cosine of Thrust Axis relative to Beam Direction < 0.95
- Both Jet Charm Tags > 0.3
- At Least One Jet Charm Tag > 0.4
- Number of Jets < 4.
- Lowest Energy Jet > 35 GeV
- Highest Energy Jet < 140 GeV

Number of Signal Events Selected = 900 (=11 % efficiency)
Number of Background Events Selected = 390 (=70% purity)

Jet Energy Using Cuts Selection at SPS5



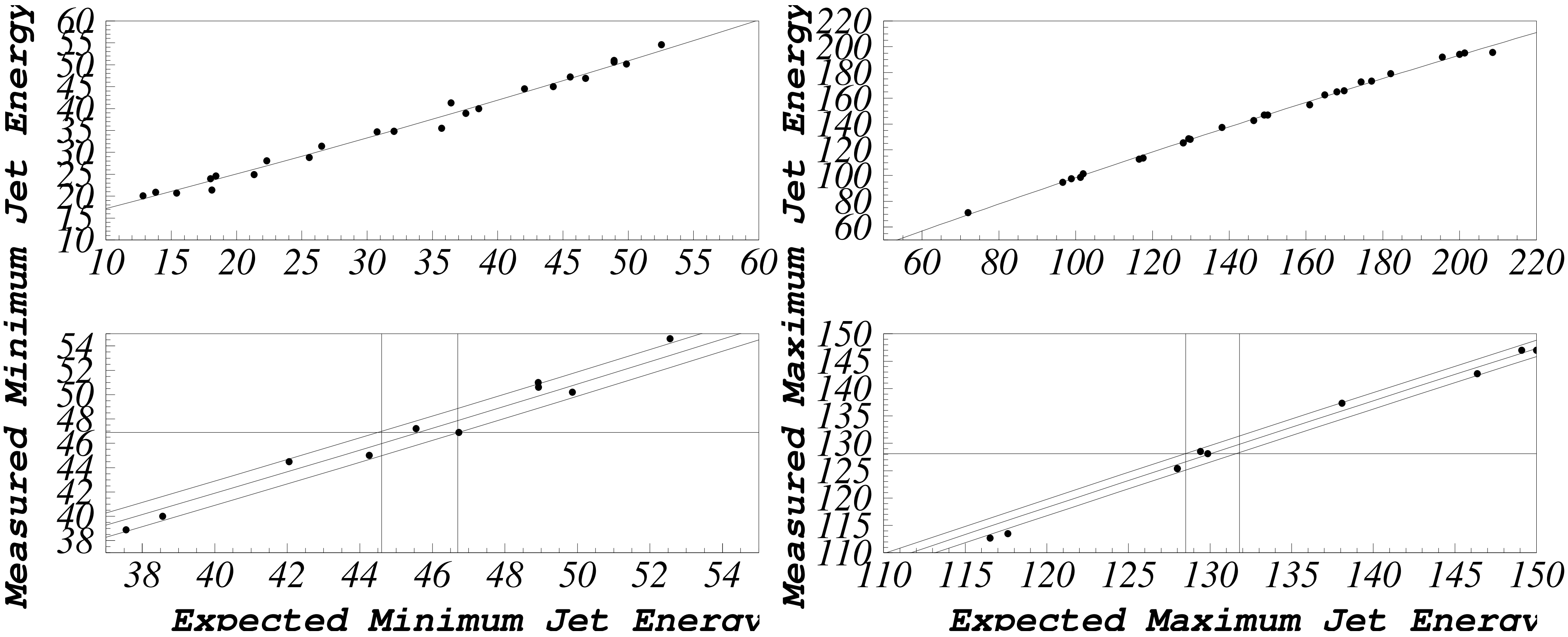
Subtract Background. Straight line fit to decreasing and increasing slopes.



Measure Endpoints at Half Height Position (statistical uncertainty is small).

Jet Energy Using Cuts Selection at SPS5

Generate several samples to obtain 'calibration curves'



Minimum Jet Endpoint $= 45.7 \pm 1.0$ GeV

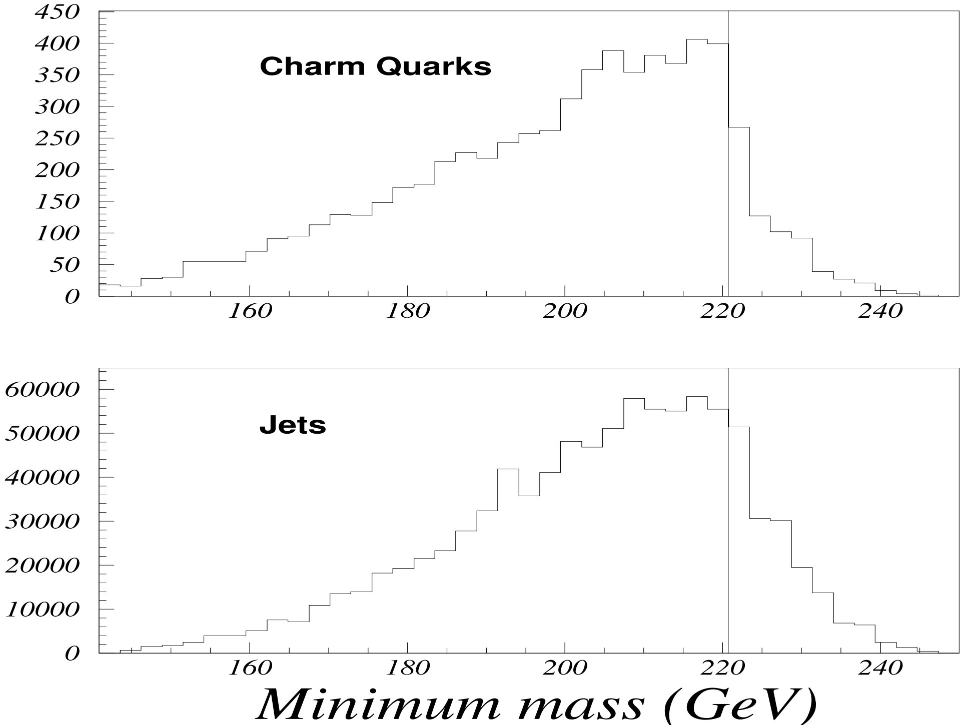
Maximum Jet Endpoint $= 130.2 \pm 1.5$ GeV

$m_{\tilde{t}_1} = 219.3 \pm 1.7$ GeV

$m_{\tilde{\chi}_1^0} = 119.4 \pm 1.6$ GeV

Minimum Mass Method

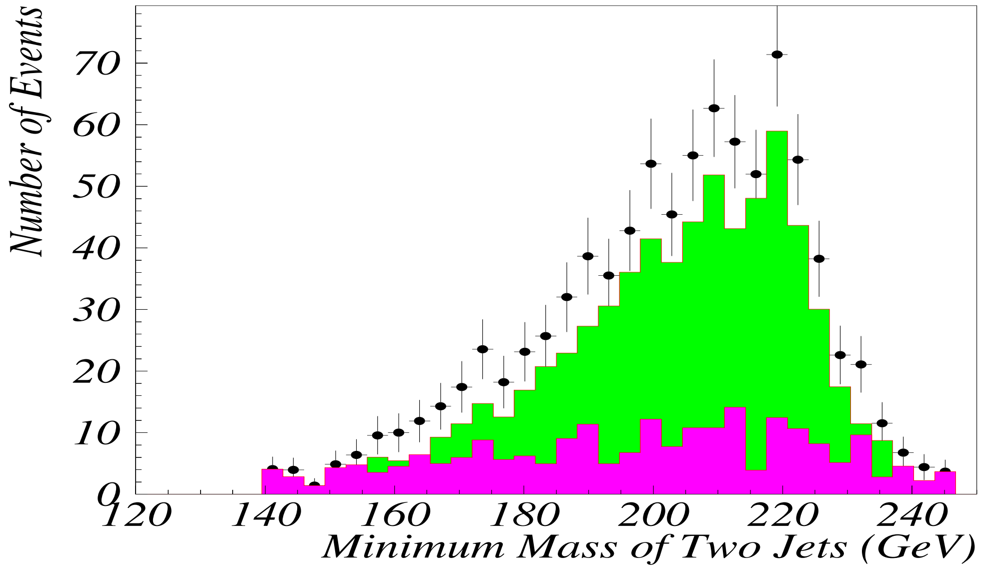
If $m_{\tilde{\chi}_1^0}$ is known: calculate minimum allowed mass of the two jets; it peaks at $m_{\tilde{t}_1}$



At SPS5,

additional cut -

$p_t^{\mathrm{Event}}/\mathrm{Visible\,Energy} > 0.1$

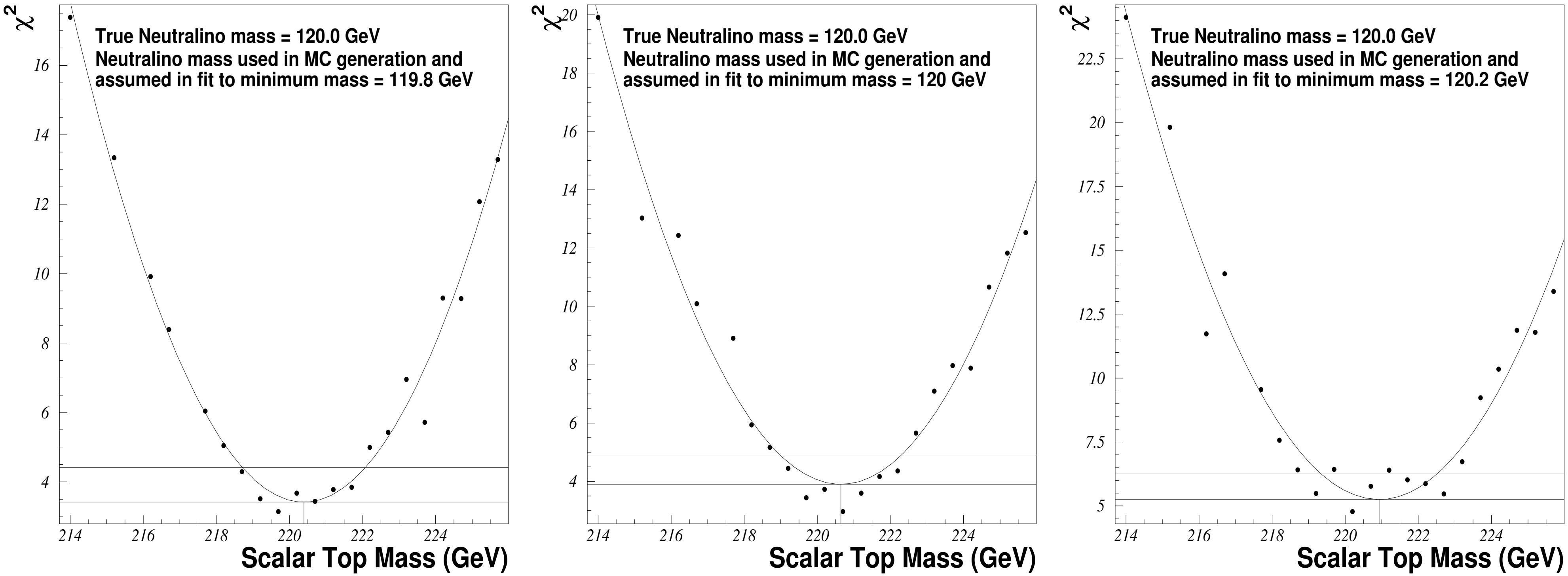


Signal: 650 Events,

Background: 190 Events

Fit to Find Error on Mass

- Generate several Monte Carlo samples - varying $m_{\tilde{t}_1}$
- Fit shape of minimum mass distribution to 'data'
- Plot χ^2 versus $m_{\tilde{t}_1}$. Fit a parabola.
- Find where χ^2 increases by 1.0 above minimum
- Check effect of uncertainty on $m_{\tilde{\chi}_1^0}$ (200 MeV, from $e^+e^- \rightarrow \tilde{\mu}\tilde{\mu}$)
- Result: $m_{\tilde{t}_1} = 220.5 \pm 1.5$ GeV



Summary of Mass Determinations

- IDA selection provides high purity and efficiency.
- Allows $m_{\tilde{t}_1}$ measurement via:
  1. Combining Different Beam Polarizations
  2. Threshold Scan
- Cuts selection reduces distortions of Jet Energy Spectrum
- Allows $m_{\tilde{t}_1}$ measurement via:
  1. End Point Method
  2. Minimum Mass Method

Method	Δ_m (GeV)	luminosity	comment
Polarization	0.57	2×500 fb^{-1}	no theory errors included
Threshold Scan	1.2	300 fb^{-1}	right hand polarization
End Point	1.7	500 fb^{-1}	
Minimum Mass	1.5	500 fb^{-1}	assumes $m_{\tilde{\chi}_1^0}$ known

Conclusions

- c-quark tagging as a benchmark for vertex detectors.
  In Supersymmetry: Scalar top quarks
- SIMDET detector simulation: LCFI vertex detector.
- SIMDET and previous SGV kinematic distributions largely agree.
- c-tagging reduces background by about a factor 3 for $\tilde{\chi}_1^0 c \tilde{\chi}_1^0 \bar{c}$.
- Dedicated simulation with SPS-5 parameters:
  Possibility to compare with other vertex detector projects
- Background depends on vertex detector design.
- Simulations for SPA parameters started.
- Simulations for small stop-neutralino mass difference started (with Caroline Milstene).