Stop Searches at ILC - Status and Critical Rewiew

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Outline

- **Searching for Stop Particles: Topologies and Strategies**
- **LEP and Fermilab Limits, LHC Expectations**
- **Stops at Linear Collider**
  - **A Stop near the Top Mass**
  - **SPS 5**
  - **SPA: A Stop with 400 GeV Mass**
- **Summary and Outlook**

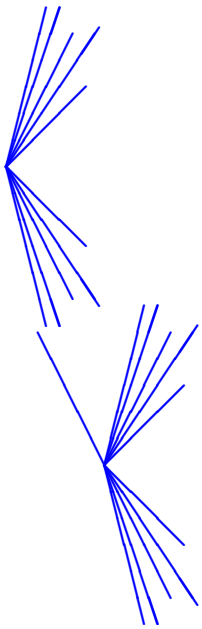
Topologies and Strategies

Common features of any signal topology:

- **missing momentum p_{miss} with no preferred direction**
- **missing mass M_{miss}**
- **acoplanar leptons and/or**
- **acoplanar jets in the final state**

a given signal topology depends on :

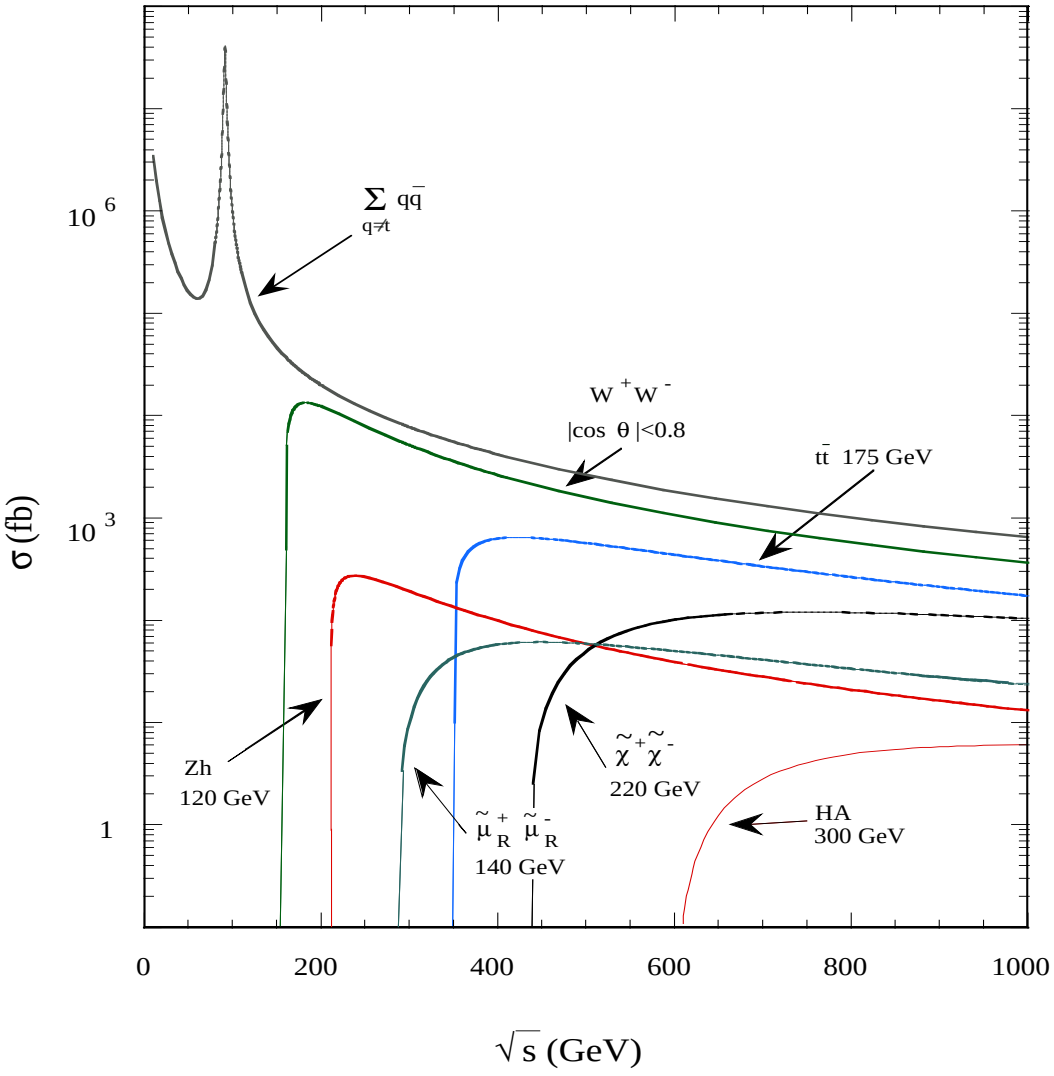
- **the nature of the signal**
- **the mass difference between a sparticle and LSP called ΔM**
- **the nature of the decay , e.g. direct decays, cascade decays, higher order processes**



topology : 2 acoplanar jets $+E_{miss}$
signature for : neutralino,squark

topology : 2 jets + lepton $+E_{miss}$
signature for : chargino,squark

SM Backgrounds



- $q\bar{q}$ **cross section 12 pb**
- **cross section for WW 7.9 pb**
- **cross section for 180 GeV** $\tilde{t}_1$ **53 fb**

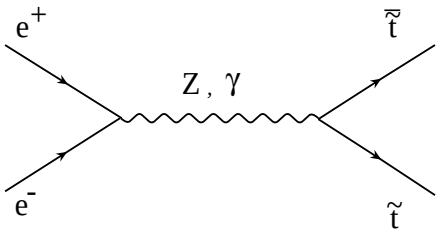
Squarks -

- **SUSY partners of the helicity states of each quark**
- **large mixing, large mass splitting for the third generation**

$$\tilde{t}_1 = \tilde{t}_L \cos\theta_{LR} + \tilde{t}_R \sin\theta_{LR}$$

- $\tilde{t}_1$ **,** $\tilde{b}_1$ **(**$\tan\beta > 10$**) light stop possible**

Production via s-channel Z, γ **exchange**
free parameters : mass and $\cos\theta_{LR}$
if vanishing coupling to Z cross section has its minimum



decays: three-body decay preferred if kinematically allowed

- **two-body decays :**$\tilde{t}_1 \to t\tilde{\chi}_1^0$ **,** $\tilde{t}_1 \to c\tilde{\chi}_1^0$ **,** $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$ **,** $\tilde{b}_1 \to b\tilde{\chi}_1^0$
- **three-body decays** $\tilde{t}_1 \to bl\tilde{\nu}_l$ **, for high** $\tan\beta$ $l = \tau$ **preferred but not studied**

Squarks

Searching for squarks:

- 2 jets + E_{miss} with and without b-tagging
- 2 jets + 2 (1) leptons + E_{miss} with b-tagging

main backgrounds - depending from ΔM

- low ΔM (5...10 GeV) : 2 photon collision processes
- medium ΔM (20 ...40 GeV): 2f processes
- high ΔM (50 ... 70 GeV): 4f processes (WW, ZZ)

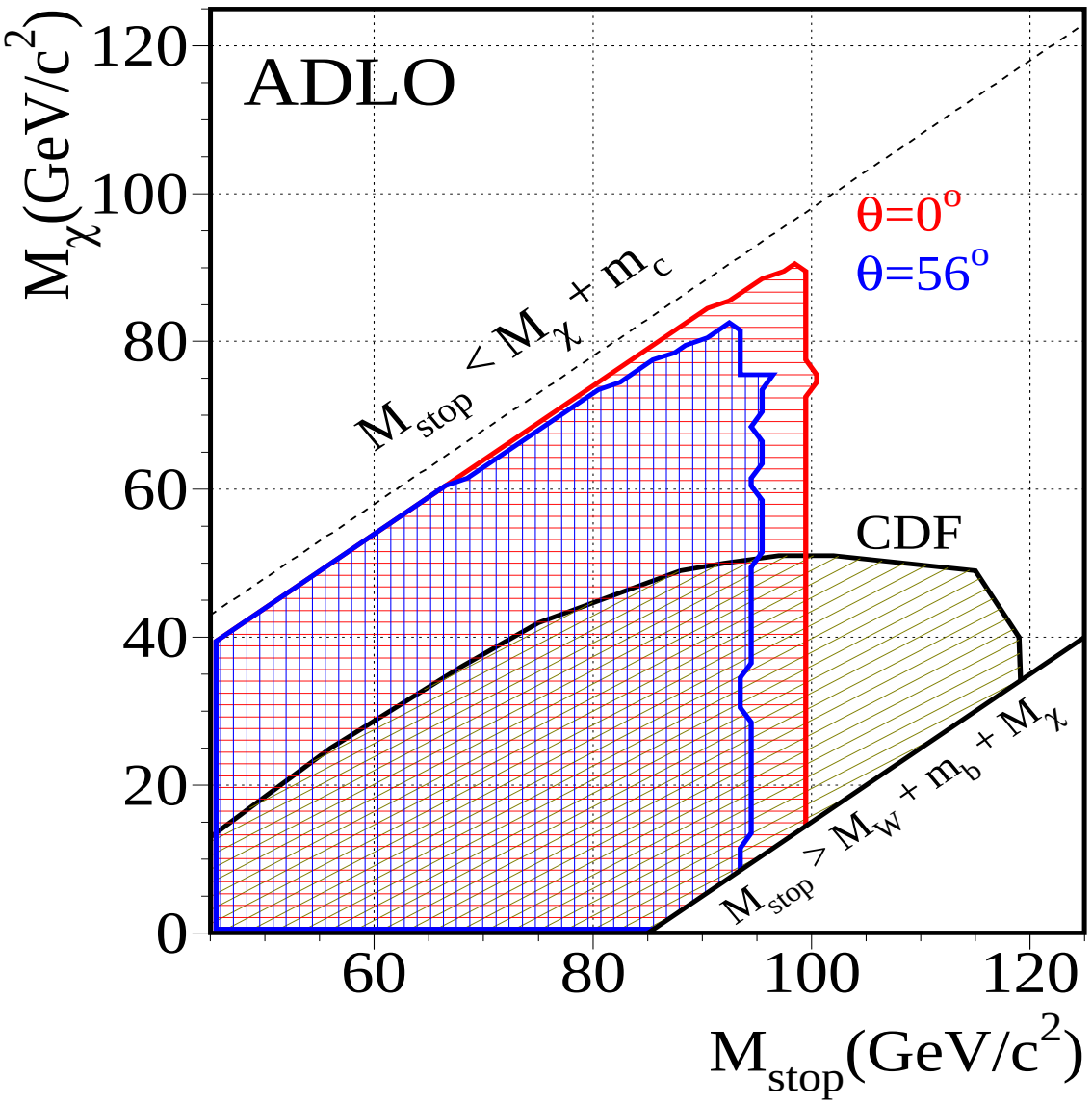
LEP and FERMILAB have searched for $\tilde{t}_1$ and $\tilde{b}_1$:

No evidence for any squark was found
$\rightarrow$ limits at 95% C.L.

LEP compilation of the LEP working group
Systematics is taken into account with
100% correlation between the experiments
Fermilab results included

One plot:
— mass limits for
$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

Squarks


ADLO
θ=0°
θ=56°
CDF
$M_{stop} < M_\chi + m_c$
$M_{stop} > M_W + m_b + M_\chi$
$M_\chi (GeV/c^2)$
$M_{stop} (GeV/c^2)$
0
20
40
60
80
100
120
60
80
100
120

Cross Sections at 500 GeV

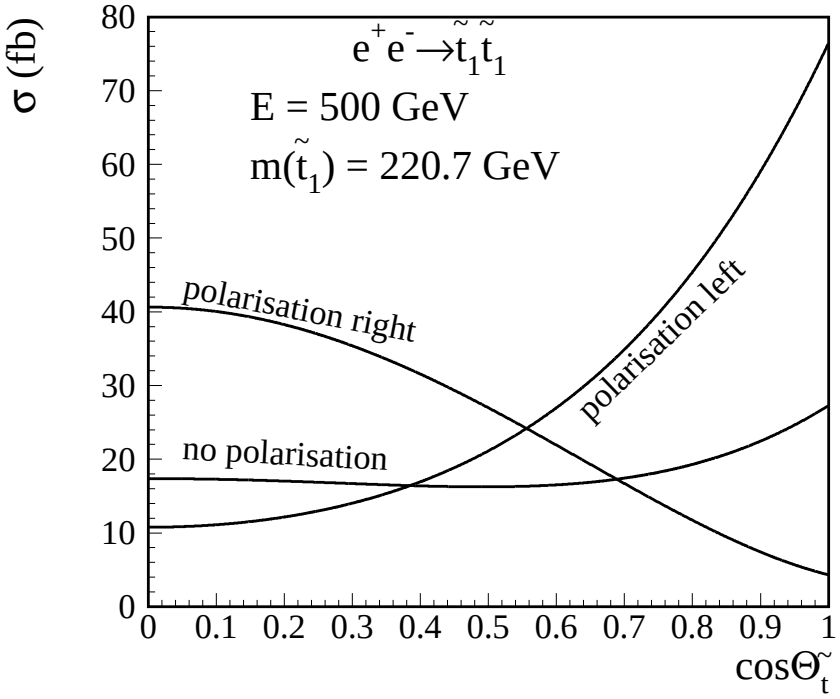
Polarization states : e^-/e^+ -80/60 versus 80/-60

minimum cross section (γ exchange only)

Pol.	$\tilde{t}_1\bar{\tilde{t}}_1$	$We\nu$	WW	$q\bar{q}$	$t\bar{t}$	ZZ
e^-/e^+	fb	pb	pb	pb	pb	pb
-.8/.6	23.15	10.72	22.64	21.49	1.113	0.909
-.9/0	15.67	6.86	14.9	14.4	0.771	1.17
0/0	16.29	5.59	7.86	12.1	0.574	0.864
.9/0	16.97	4.61	0.906	9.66	0.376	0.554
.8/-.6	25.16	1.780	0.786	13.99	0.542	0.464

better signal/background ratio for 0.8/-0.6

use this polarization state in case of low cross sections for parameter determination



Light Stop

Light stop - near the top mass favoured from Baryogenesis

high x-sec : we have studied it in any detail (see our old 180 GeV study) for both decay modes : charm neutralino and bottom chargino

now used for detector studies (see ICHEP'04 contribution 12-0438 and Andre's talk in Paris)

$e^+e^- \to \tilde{t}_1 \bar{\tilde{t}}_1 \to c\tilde{\chi}_1^0 \bar{c}\tilde{\chi}_1^0$ **benchmark reaction used for studying the charm tagging and the vertex detector performance**

for comparison with previous 'SGV'studies M(stop) = 180 GeV $m_{\chi_1^0} = 100$ **GeV no beam polarization**

Light Stop

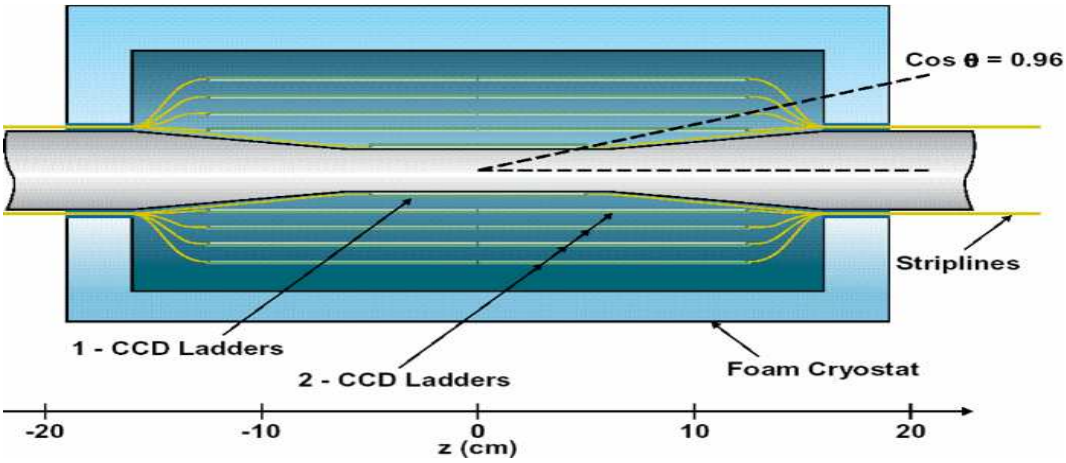
Channel	Generated events	Preselection/500 fb^{-1}	Previous SGV
$c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$	**50 k**	**48%**	**47%**
$q\bar{q}$	**12169 k**	**64963**	**46788**
$t\bar{t}$	**620 k**	**32715**	**43759**
eeZ	**5740 k**	**24864**	**4069**
ZZ	**560 k**	**3100**	**4027**
Weν	**4859 k**	**252367**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

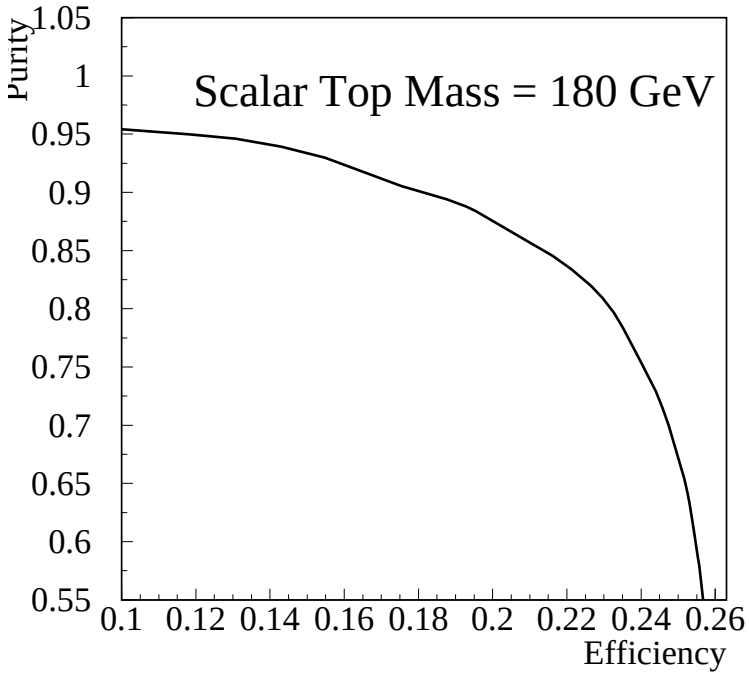
After additional cuts, $E_{\rm vis}/\sqrt{s} < 0.52$ and $P_{\rm t}/E_{\rm vis} > 0.05$, the following numbers of events are obtained:

Channel	$q\bar{q}$	WW	Weν	$t\bar{t}$	ZZ	eeZ	Total
Total background	**6801**	**23278**	**226070**	**5267**	**125**	**2147**	**263691**

compare 263691 with previous 278377 event with SGV — o.k.

Light Stop





studies continue

SPS 5 Stop at 220 GeV

SPS 5 is the only scenario with a light stop

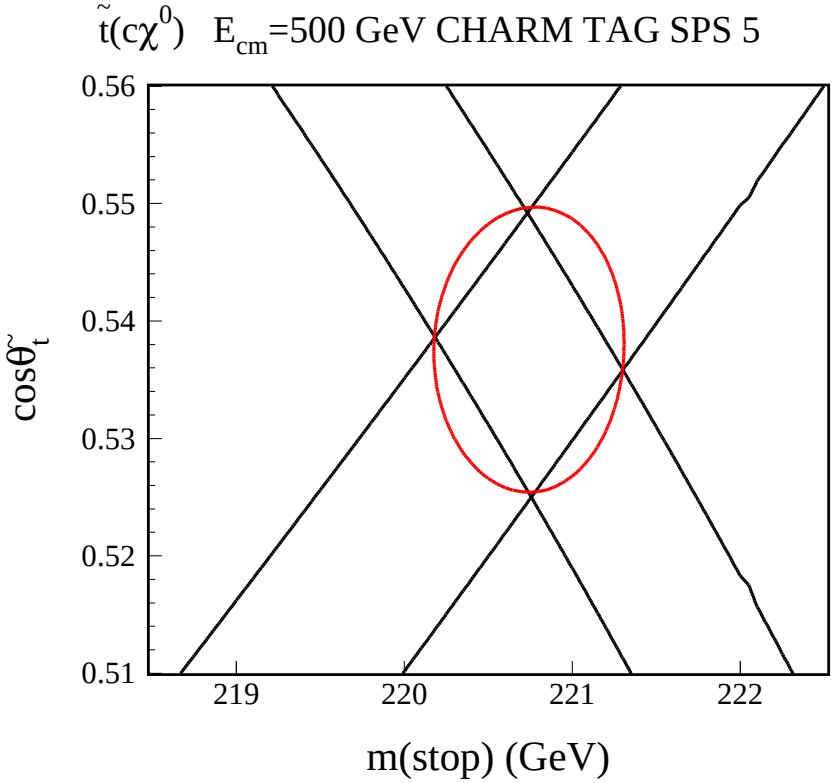
four different methods of mass determination
see Alex's talk at Paris
see also ICHEP'04 contribution 12-0438

all for $e^+e^- \rightarrow \tilde{t}_1\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$
M(stop) = 220.7 GeV and $m_{\chi_1^0} = 120$ **GeV with beam polarization**

The Analysis in Brief

- **500** fb^{-1} **for each polarization state at 500 GeV cms energy**
- **Detector simulation with SIMDET 4.03**
- **Thorsten's b/c tagging**
- **Either IDA selection**
- **or cut based selection**

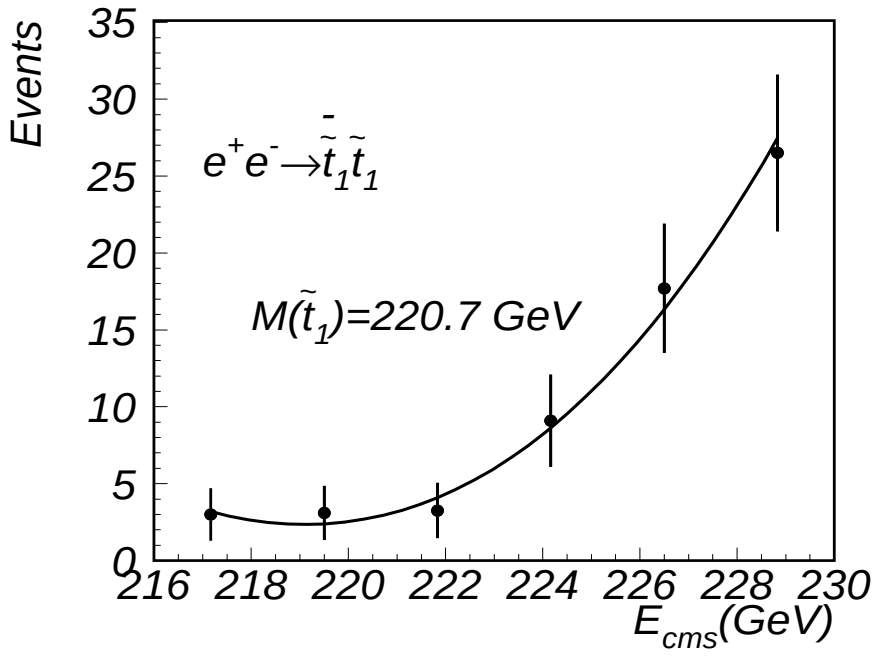
IDA Analysis



knowing dependence of the cross section from the stop mass, the mixing angle and the polarization state (CALVIN32 from the Vienna SUSY group)

$$\Delta M(stop) = 0.57\,GeV \;\; and \;\; \Delta\cos\theta_{LR} = 0.012$$

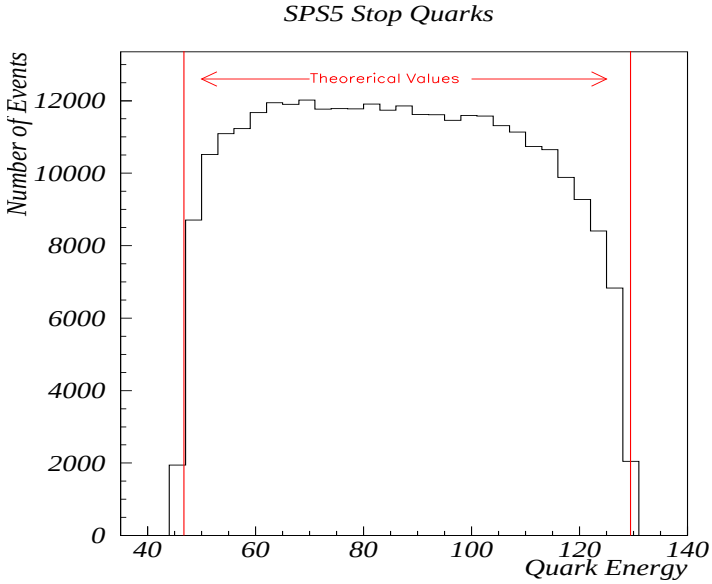
Threshold Scan

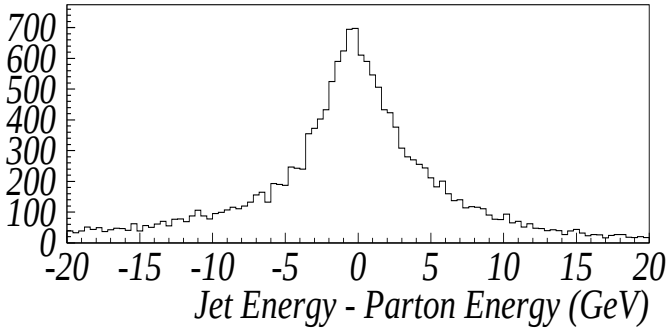


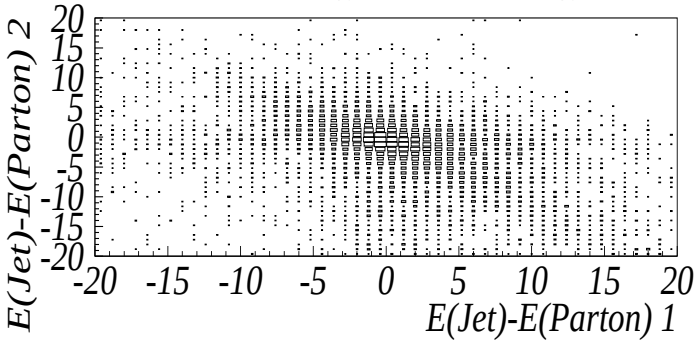
50 fb^{-1} per point - right handed polarization (lowest backgrounds)

$\Delta M(stop) = 1.9$ GeV from fit to the "data"

Cut Based Analysis - end point method - requires quark energies but one measures jets







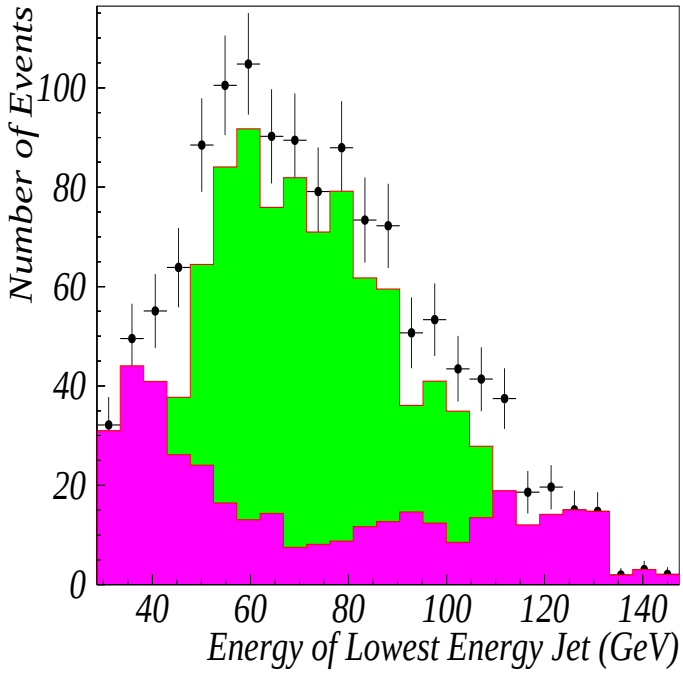
jets have a finit resolution - jet algorithm and hadronization must be studied

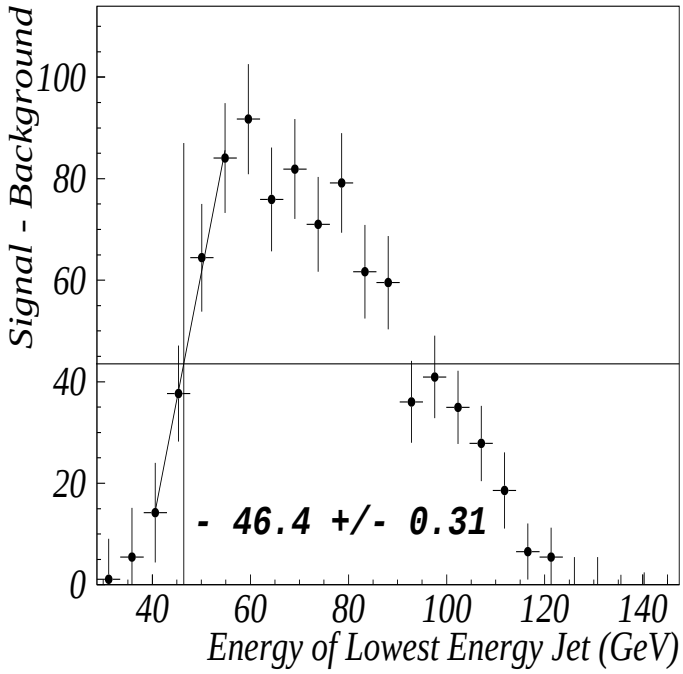
IDA is disturbing the energy spectrum

use cut selection, substract the background and measure

SPS 5 Stop at 220 GeV

endpoints at the half hight position, calibrate the method

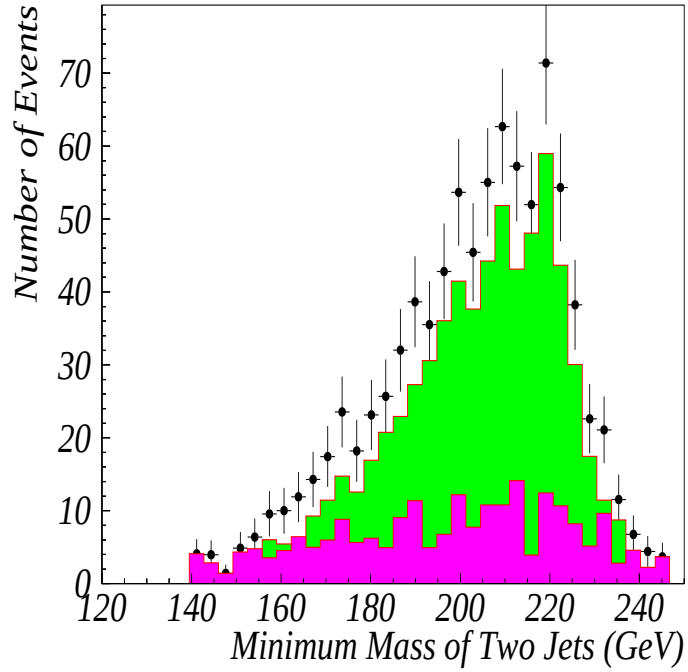


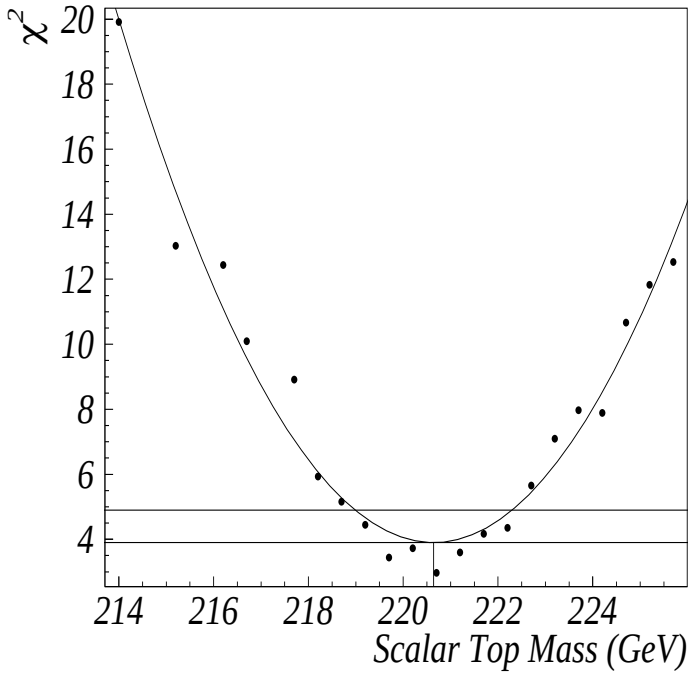


$$\Delta M(stop) = 1.7\ \mathbf{GeV}$$

Cut Based Analysis Minimum Mass Method

the minimum allowed mass of the two jets peaks at M(stop)





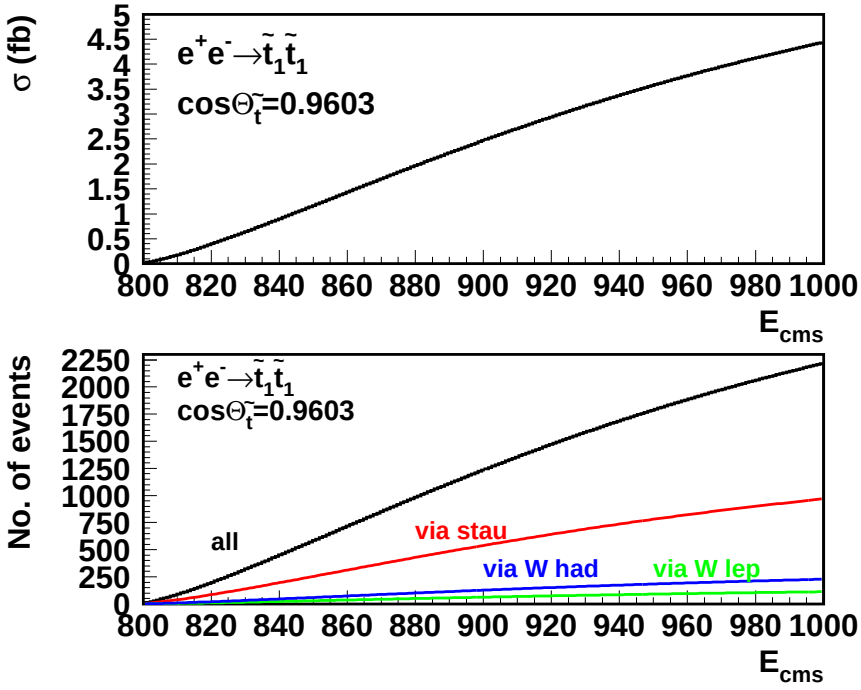
$\Delta M(stop) = 1.5$ **GeV**

SPS1a Stop at 400 GeV

SPA Scenario - high stop mass

needs 1 TeV and more dedicated analysis
- other decay modes and SUSY backgrounds

stop decays via stau or chargino



dependence of the cross section from the stop mass, the mixing angle and no polarization CALVIN32 from the Vienna SUSY group) - study at 1 TeV possible but hard to do

Generation of background and signal just started

Summary and Outlook

- **mass determination with four different methods**
- **charm tagging reduces the background up to a factor of 3**
- **continue the study of the vertex detector performance**
- **first look at SPS1a for a high stop mass**
- **other interesting stop decays ????**