Analysis of Stop Quarks with Small Stop-Neutralino Mass Difference at a Linear Collider

C. Milsténe - A. Freitas - M. Carena – Fermilab, U.S.A
A. Finch - A. Sopczak – Lancaster - UK
H. Nowak-DESY - Germany

March 20-2005 - Stanford - LCWS05

- Introduction
- A Case for the Linear Collider
- The Selection Cuts
  1-Pre-selection
  2-Selection
- Stop Discovery Reach
- Stop Parameters Determination
- Prediction for Dark Matter Density
- Conclusion

Introduction

• An Extension of scalar top studies for small visible energy in the detector.

•Theoretical motivation: The origin and stabilization of electroweak symmetry in particle physics and the nature of dark matter and baryogenesis in cosmology both suggest the existence of new symmetries within the reach of the next generation of colliders.

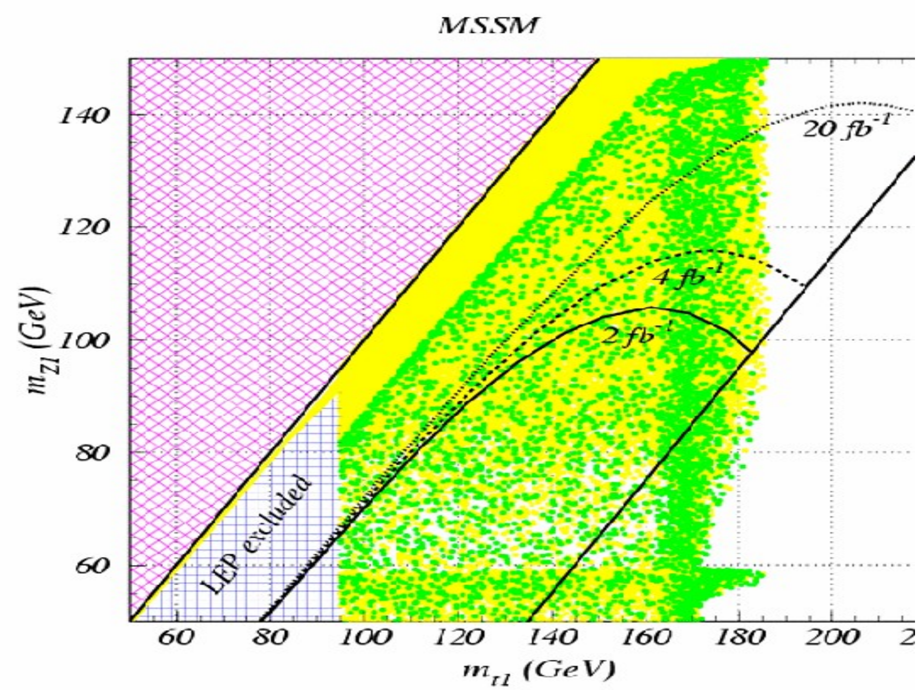
• Recently, the universe dark matter energy density has been precisely measured by the Wilkinson Microwave Anisotropy Probe (WMAP) to be $\Omega_{CDM}h^2$ =0.1126+0.0161/-0.0181.

•The super-symmetry with R parity conservation provides a stable neutral dark matter candidate, the Neutralino with mass and σ ~e.W energy scale.

The Neutralino-Stop co-annihilation region is characterized by a small mass difference M (stop-neutralino)= 20-30 GeV, with relic density compatible with the WMAP observation. The stop decays into neutralino and charm is the only decay channel allowed.

•Possible benchmark for vertex detectors and material budget.

Dark Matter: A Case For The ILC



On the figure* is represented a random scan of the parameter space projected on the plane, stop mass versus neutralino mass.

In green is the region with a relic density consistent with the WMAP observations over- layed the Tevatron light stop search sensitivity in the charm decay channel.

The co-annihilation region is out of reach due to background reduction limitations Inherent to hadron colliders.

This region is the region under study with the linear collider.

***C. Balazs,M. Carena,CEM Wagner-hep-ph/0403224-v2-aug 04**

Selection $e^+e^- \rightarrow \tilde{t}_1\overline{\tilde{t}}_1 \rightarrow c\tilde{\chi}_0^1\overline{c}\tilde{\chi}_0^1$

• Pythia with Simdet/Tesla was used for the simulations of both signal and background with CIRCE for the beamstrahlung.

•A short list of the sequential cuts applied as a preselection first, allowed larger samples to be produced and the cut refined at selection stage.

<u>Pre-selection</u>:

•4<Number of Charged tracks<50

•Pt> 5 GeV

•$\cos\theta_{Thrust}$ <0.8

•$|P_{l,tot}/P|$<0.9

•E_{vis}<380 GeV

•M(inv)<200 GeV

<u>Selection</u>:

•Njets =2

•Cos (A-coplanarity) <0.9

•$\cos\theta_{Thrust}$<0.7 , P_t >12 revisited.

•E_{vis}<200GeV

•2000 GeV^2 < $Minv^2_{jets}$ < 9000 GeV^2

Signal And Background Cross-Sections (pb)

Process $\tilde{t}\,\tilde{t}$	Beamst/ISR	FREITAS		
		unpol	L-pol	R-pol
M ($\tilde{t}$=120)	yes	0.2802		
M ($\tilde{t}$=140)	yes	0.21670	0.19635	0.23714
M ($\tilde{t}$=180)	Yes	0.10532	0.09532	0.11527
M ($\tilde{t}$=220)	yes	0.02487	0.02253	0.02720

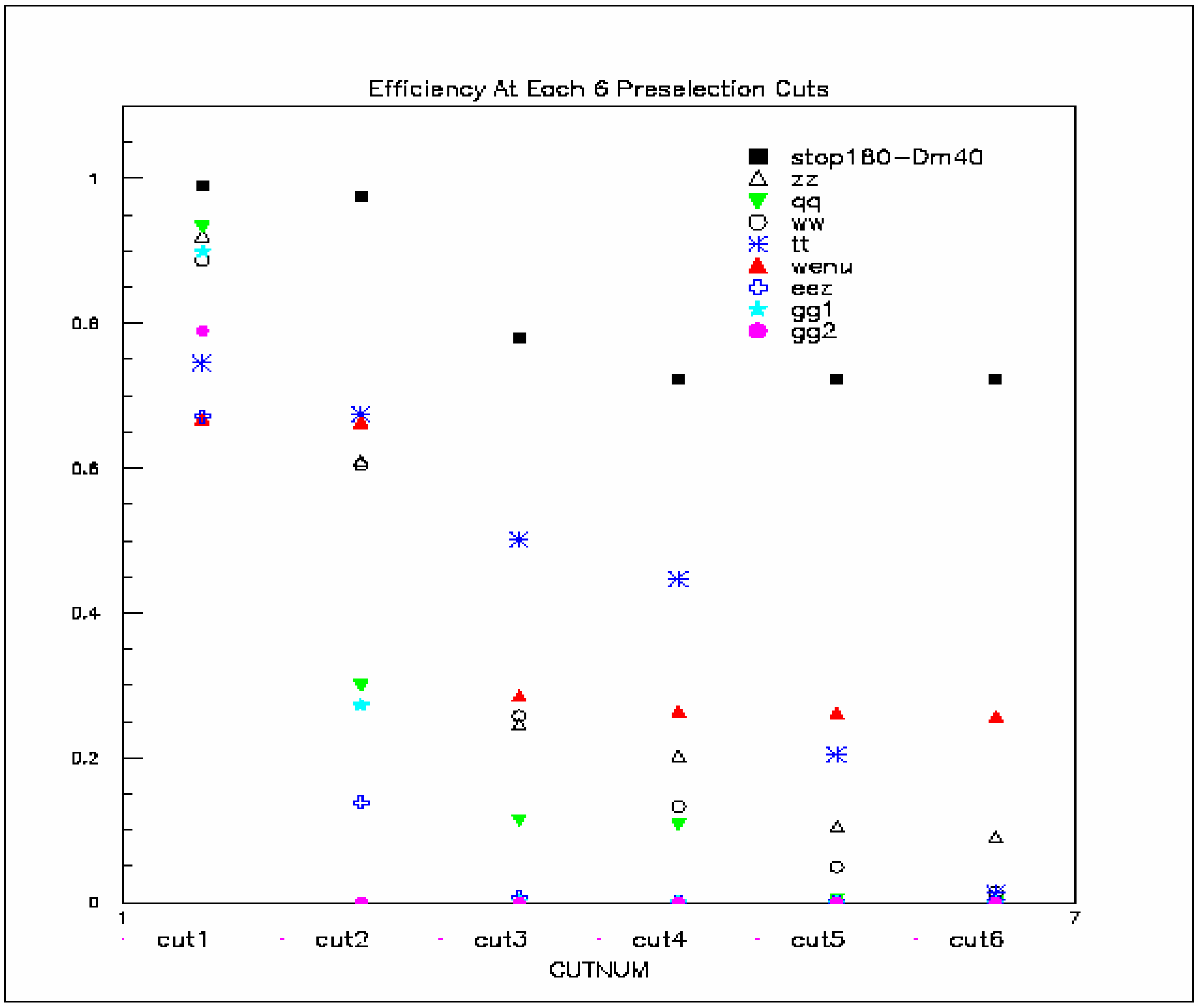
The Events have been produced with Beamstrahlung

σ normalizations without.

Process	Pythia	Beamst/ISR	GRACE		
			Unpol	L-pol	R-pol
ww	7.38	no	7.6141	15.172	0.05624
Wenu	5.30	no	6.142	9.268	3.016
ZZ	0.402	no	0.44000	0.6250	0.25501
eeZ	6.90	no	7.64	8.42	6.72
tt		no	0.56651	0.79536	0.33765
qq*		yes	13.974	18.345	10.941
γγ-Beamst.	782	yes			
2-photon	154	yes			

** A. Freitas 's program*

Pre-selection: Efficiency Each Cut

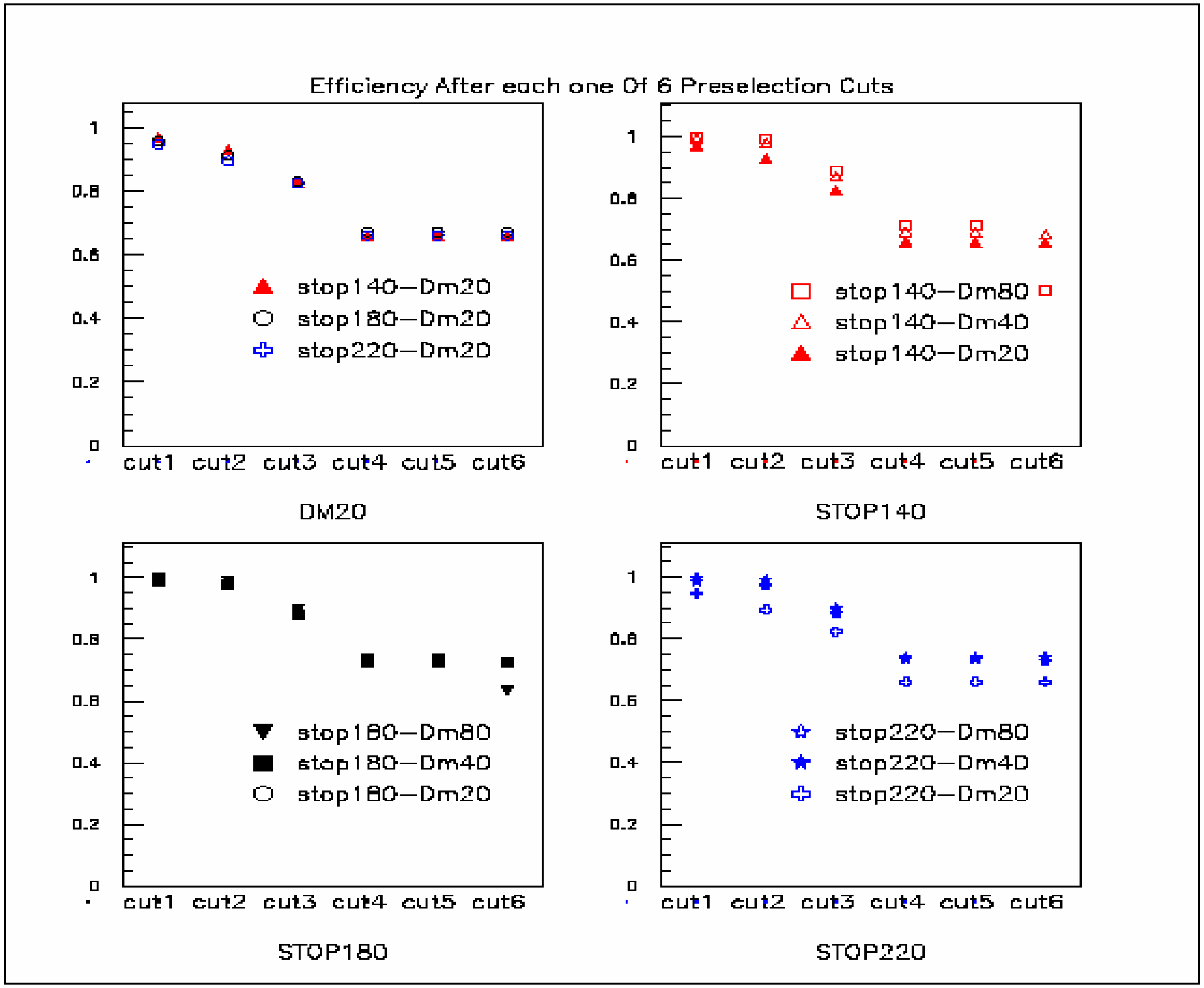


<u>Colour point</u>:
% of Background left after each cut
*The 2-photon is gg1 in the figure

<u>Black Points</u>:
% of signal left after each cut for

M(t̃=180GeV);
ΔM (t̃-X0)=40 GeV

Pre-selection Efficiency: Stop



Upper Left:
Δ M (t̃-X0)=20GeV
M (t̃=140GeV)
M (t̃=180GeV)
M (t̃=220GeV)

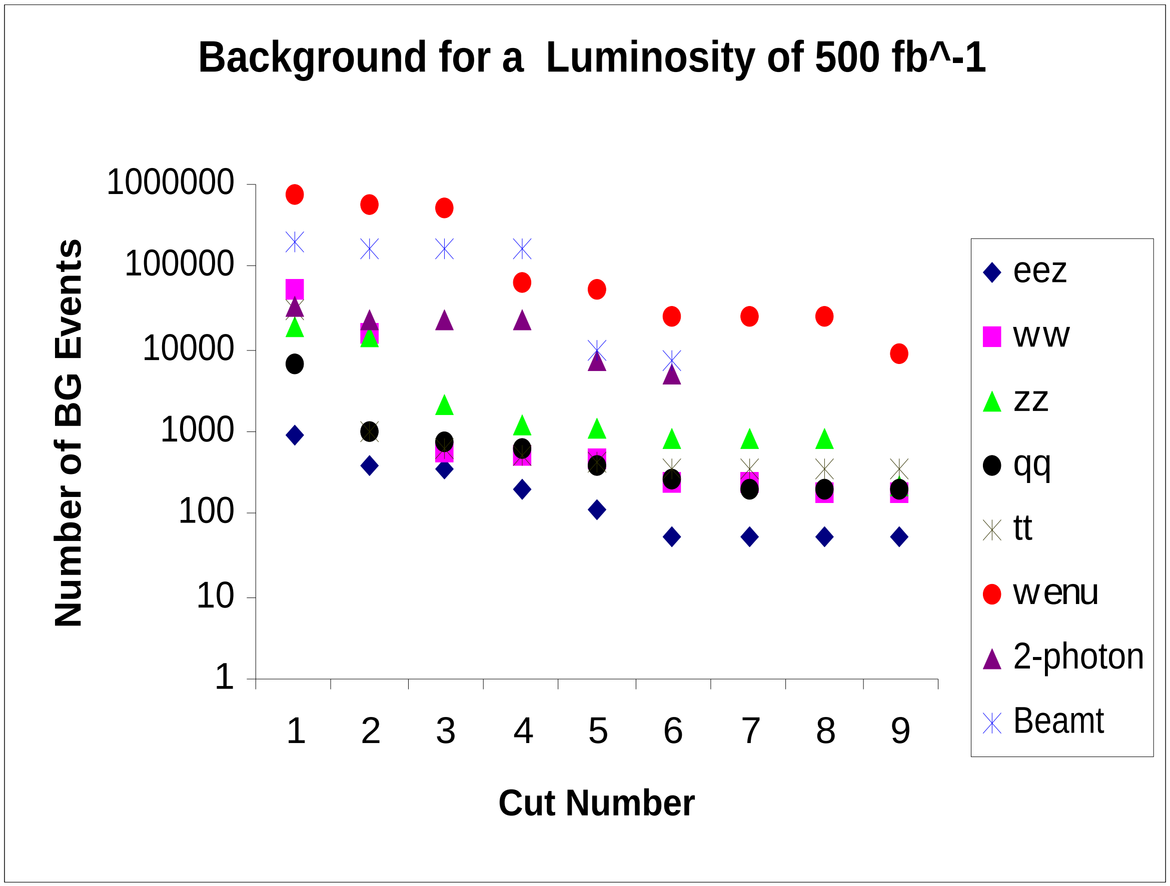
Others:
ΔM(t̃-X0)=
20,40, 80 GeV
Separatly for # M(t̃)

Selection: The Background Rejection

Background	% Left - End Presel	Number Gen. Selection	Num Left. End Sel. – For 500 fb^-1
γγ- Beamst.	0.06%	2.2 Millions	0. ~ 10.
2- photon	0.04%	1.0 M	0. ~ 1.
zz	9%	0.03 M	30. 220.
qq	0.09%	0.35 M	10. 200.
ww	1.45%	0.21 M	10. 181.
tt	1.36%	0.18 M	25. 400.
wenu	25.70%	0.21 M	624 9123.
eez	0.06%	0.21 M	3 55.

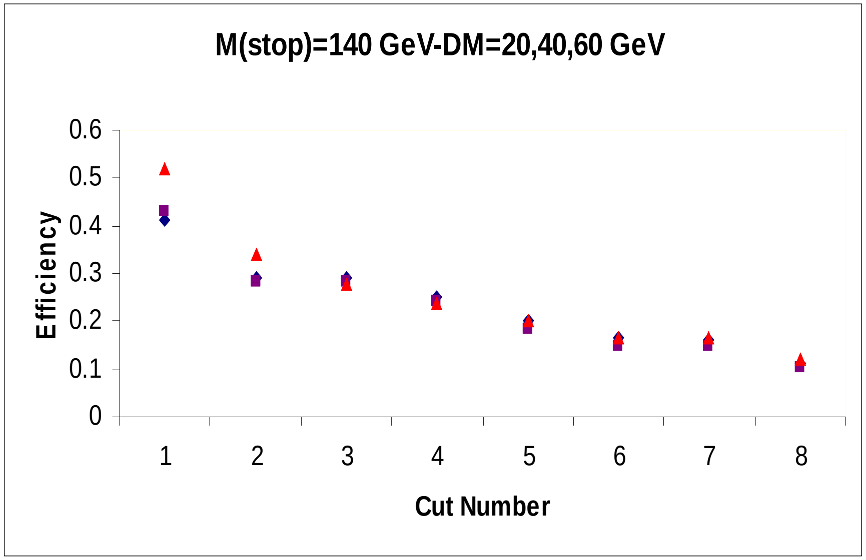
<u>The cut efficiency- </u>And the number of background particles left normalized to 500fb^-1 are shown in the next figure for each BG channel separately.

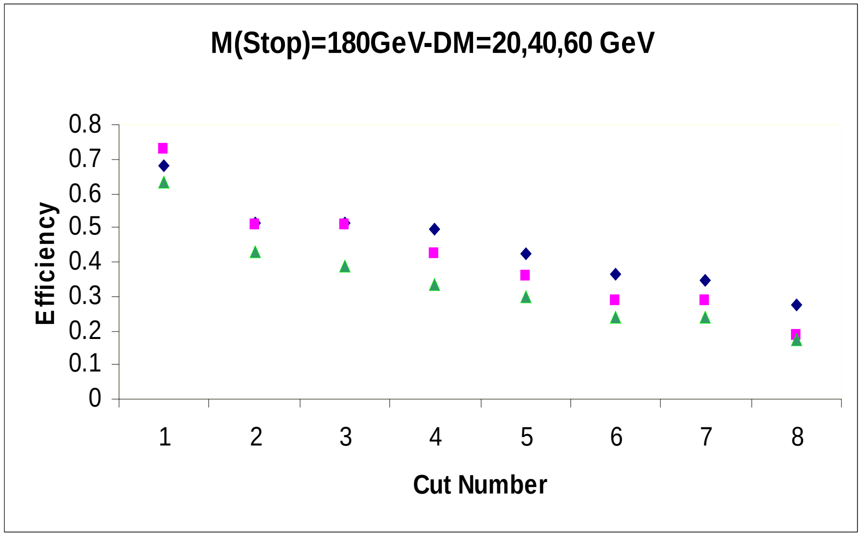
Selection: The Background



For a Luminosity of 500 fb^-1. the number of BG events left are reported after each of the 9 selection cuts

Selection: The Signal



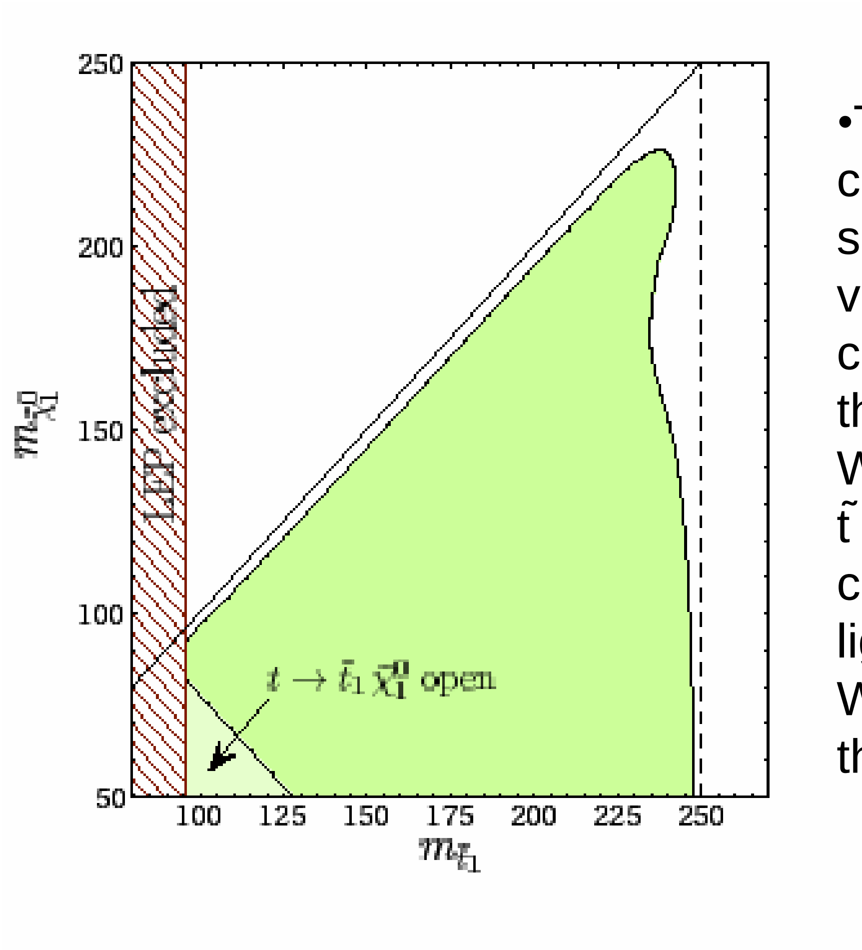


The efficiency of the selection cuts is shown for the 140 GeV stop, upper plot and the 180 GeV stop, lower plot.
In each cases it is represented for 3 neutralino masses, namely, M(t̃-X0)=20,40,60 GeV

Selection: The Signal

M ($\tilde{t}$)	% Signal End Preselection	Num. Gener. Selection	Num. Signal End Sel-For500fb^-1
140GeV			
Δm=20	65.8%	50 K	20080
Δm=40	68.2%	50 K	18440
Δm=80	50.1%	50 K	12920
180GeV			
Δm=20.	67.2%	25 K	14440
Δm=40	72.3%	25 K	9753
Δm=60	63.7%	25 K	9178
220 GeV			
Δm=20	66.1%	10K	4608
Δm=40	74.1%	10K	2578
Δm=60	72.8%	10k	2734

Stop Discovery reach



•The ratio signal to background has been calculated from the simulations, using signal efficiencies from the simulations for various M$\tilde{t}$ and MX0 and the theoretical cross-section. for a significance > 5 we get the green region in the plot M(X0)-M(Stop). We did not yet study the region where the $\tilde{t}$ and X0 masses are so light that they could come from the decay of the top (in light green-blue)

We can go to Δm,O(5GeV) and cover the whole co-annihilation region

Stop Parameters Determination

One particular parameter point

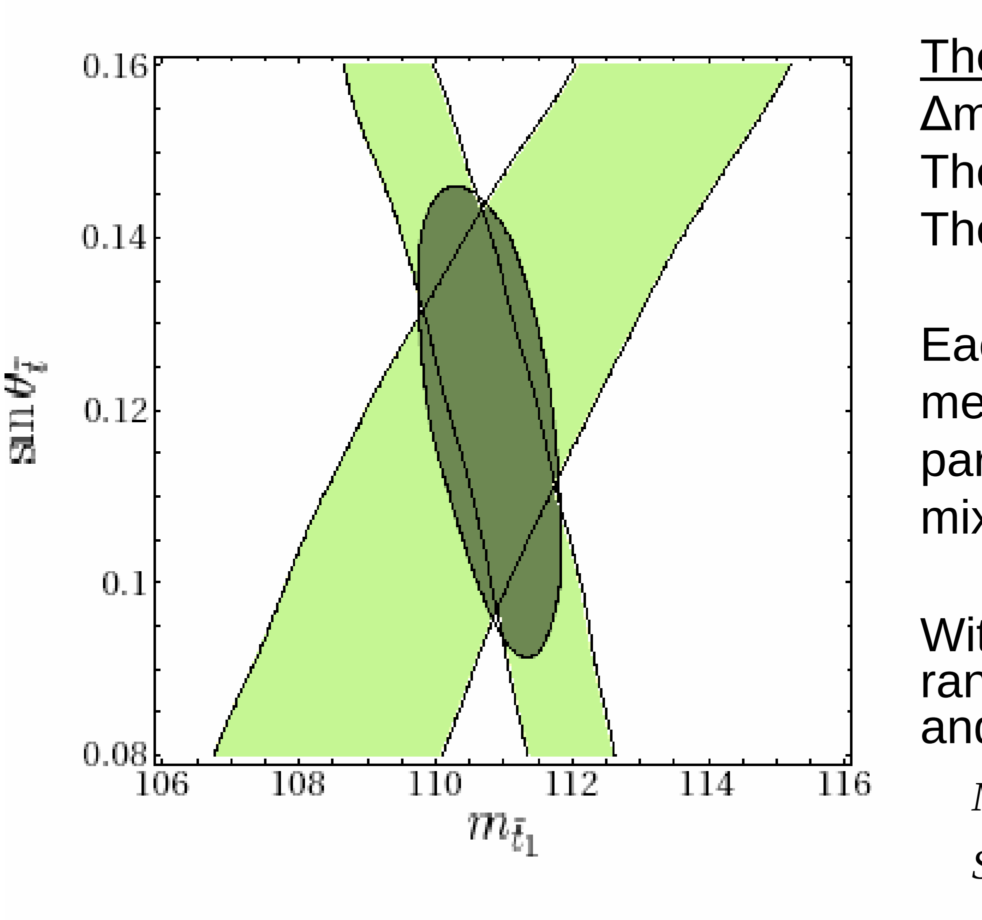
$MU3 = 0$
$MQ3 = 0.968$ TeV
$M1 = 99.13$ GeV
$M2 = 192.74$ GeV
$\mu = 352.39$ GeV
$\Phi\mu = \pi/4$ [CP-violating phase of μ]
$\tan(\beta) = 10$
$At = -675.1$ GeV

Which gives:

$\acute{\Omega}_{DM} h^2 = 0.115$
$\text{Cos}(\theta_{\tilde{t}}) = 0.985$ [stop Mixing angle]

In order to extract the stop parameters, we use the stop cross-section for 90% left and 90% right polarized e- beam, and 250fb-1 luminosity for each polarization.

Stop Parameters Determination



The errors :
Δm(x0)=0.05; Beam Polar. Δp/p =0.5%
Theoretical (Bg simul)=Δ(BG)/BG=0.3%
The Statistical Errors

Each of the two cross-section, with 2σ measurements, results in a band in the parameter plane of the stop mass and mixing angle

With these errors and the statistics we ran, the resulting 1σ bounds for the mass and mixing angle are

$$M(stop) = 110.8 \pm 0.7 GeV$$

$$Sin(\theta stop) = 0.12^{+0.025}_{-0.020}$$

Stop Parameters Determination-(Errors)

- Error on the mneu(1) mass: d(mneu(1)) = 0.05 GeV

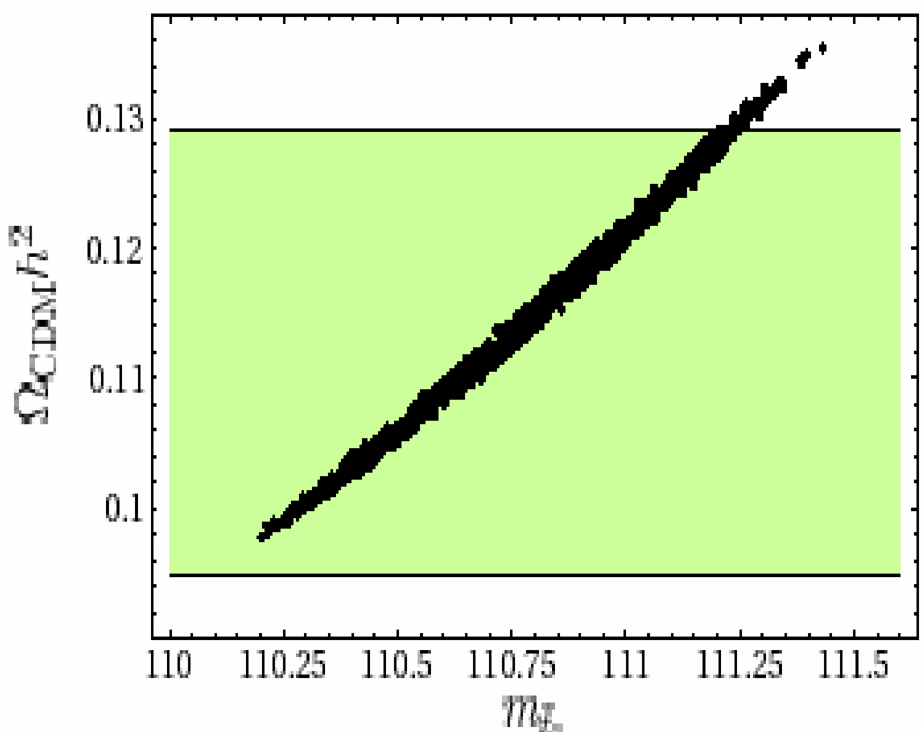
  LHC/ILC Study Group Working Report, eds. G.Weiglein {``Physics interplay of the LHC and the ILC,'' hep-ph/0410364.
- Error on the beam polarization: d P / P = 0.5%

  G.~Moortgat-Pick , Beam Polarization at a future Linear Collider}, working group report in preparation.
- Background simulation (theoretical predictions): d(BG) / BG = 0.3%

  This estimate is based on the (W e nu) process as the largest background. While a complete NLO is still missing a recent result for the related process of W pair production is used.

- Luminosity: d(L) / L = 2 *10^{-4} from Technical Design Report, Part IV, eds. T.~Behnke,S.~Bertolucci, R.D.~Heuer and R.~Settles, DESY-2001-011D.

Predictions For Dark Matter Density



Using the stop parameters detailed above and combining estimated errors for Chargino and Neutralino, the collider measurements of the stop and Chargino/Neutralino parameters constrain the relic density at the1-σ level (dark points) to:

$0.098 < \acute{\Omega}_{DM}h^2<0.135$
WMAP measurements (in green)
$0.095 < \acute{\Omega}_{DM}h^2<0.129$

So the overall precision is comparable to the direct WMAP determination. The uncertainty in the theoretical determination is dominated by the uncertainty in the stop mass, while the precision on the determination of the Neutralino, and Φμ and θstop are also important.

Conclusion

We have shown that with the linear collider we can cover the region of co-annihilation down to mass differences ~O(5GeV).

We can determine the parameters accurately enough to reach comparable precisions for the dark matter predictions than the direct WMAP measurements

Next to be done

a) Further refinement of the analysis.

b) Vary the parameters to analyze more dark matter cases.

c) c-tagging (LCFI Vertex Detector)

d) Scalar tops: possible benchmark reaction for vertex detector projects (e.g. Sopczak LCWS'04).

Starting International Collaboration involving Fermilab (USA), Lancaster (UK) within the LCFI (Linear Collider Flavor Identification) Collaboration and DESY (Germany).

Backup

Discovery Reach

Δm	Eff. Mstop = 120GeV	Eff. Mstop= 140GeV	Eff. Mstop= 180GeV	Eff. Mstop= 220GeV
5 GeV	2.54%	1.07%	0.26%	0.11%
10 GeV	19.0%	21.1%	20.0%	18.3%
20 GeV	14.9%	18.5%	27.4%	37.1%
40 GeV		10.2%	18.5%	20.7%
80 GeV		11.9%	18.3%	22.0%

Efficiencies used in The Discovery reach Are reported in the table with 90% Left polarized e^- beam and 90% right polarized e^- beam

Stop Parameters Determination

The calculations using a point giving a viable dark matter and close to SPS1a its leads to

mneu(1) = 96.18

mneu(4) = 377.9

mcha(1) = 177.35

mstop(1) = 110.80

cos(th_stop) = 0.985 [stop mixing angle]

Xt = 700 GeV [off-diag. entry in stop mass matrix]

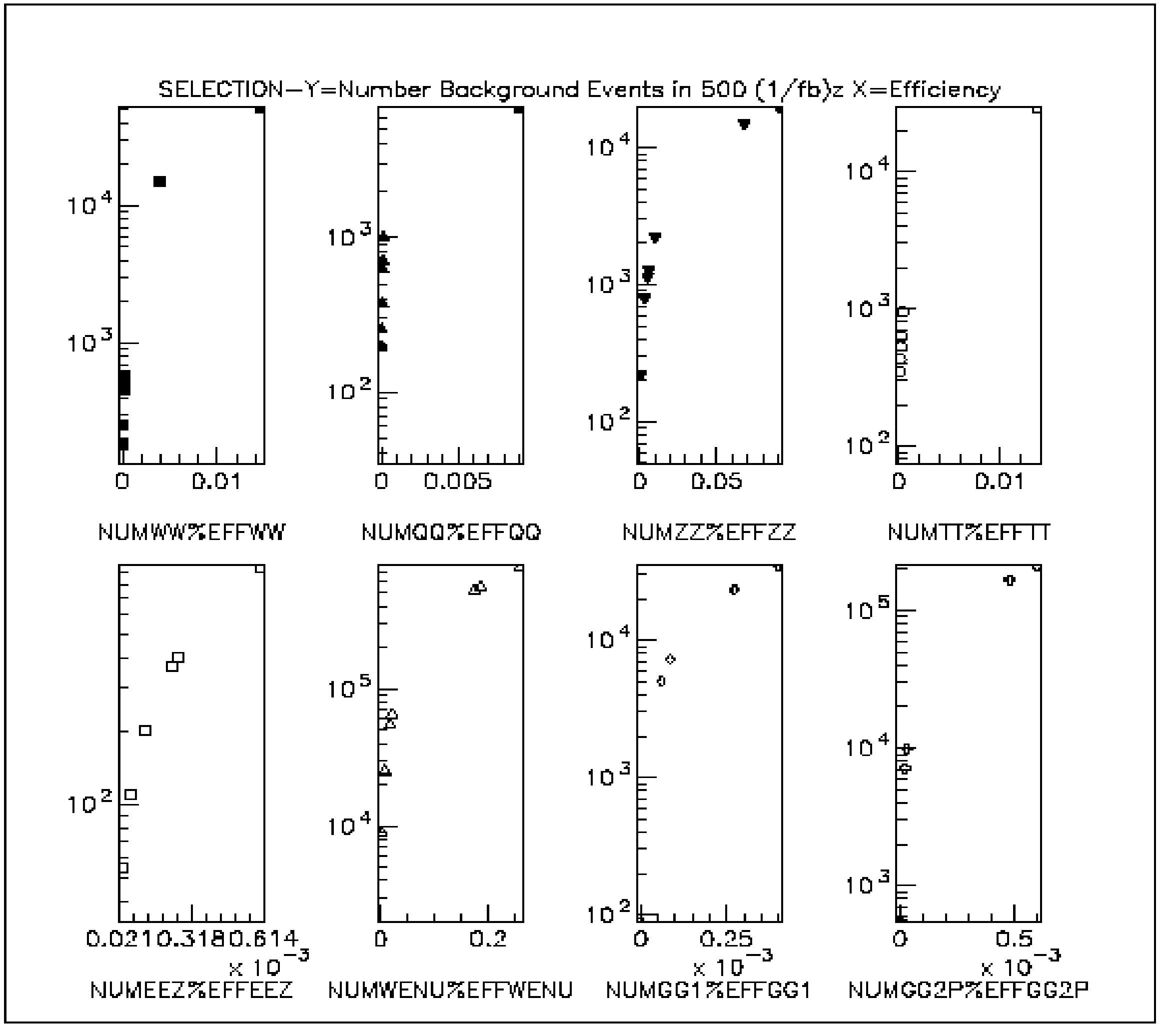
•Omega_dm = 0.115

In order to extract the stop parameters, the measurement of the stop

cross-section for different polarization of the incoming e- beam is utilised, as proposed in

A.~Bartl, H.~Eberl, S.~Kraml, W.~Majerotto, W.~Porod and A.~Sopczak- ``Search of stop, sbottom, tau-sneutrino, and stau at an e+ e- linear -collider with s**(1/2) = 0.5-TeV to 2-TeV,''Z.\ Phys.\ C, 549 (1997)[hep-ph/9701336] - HEP-PH 9701336.

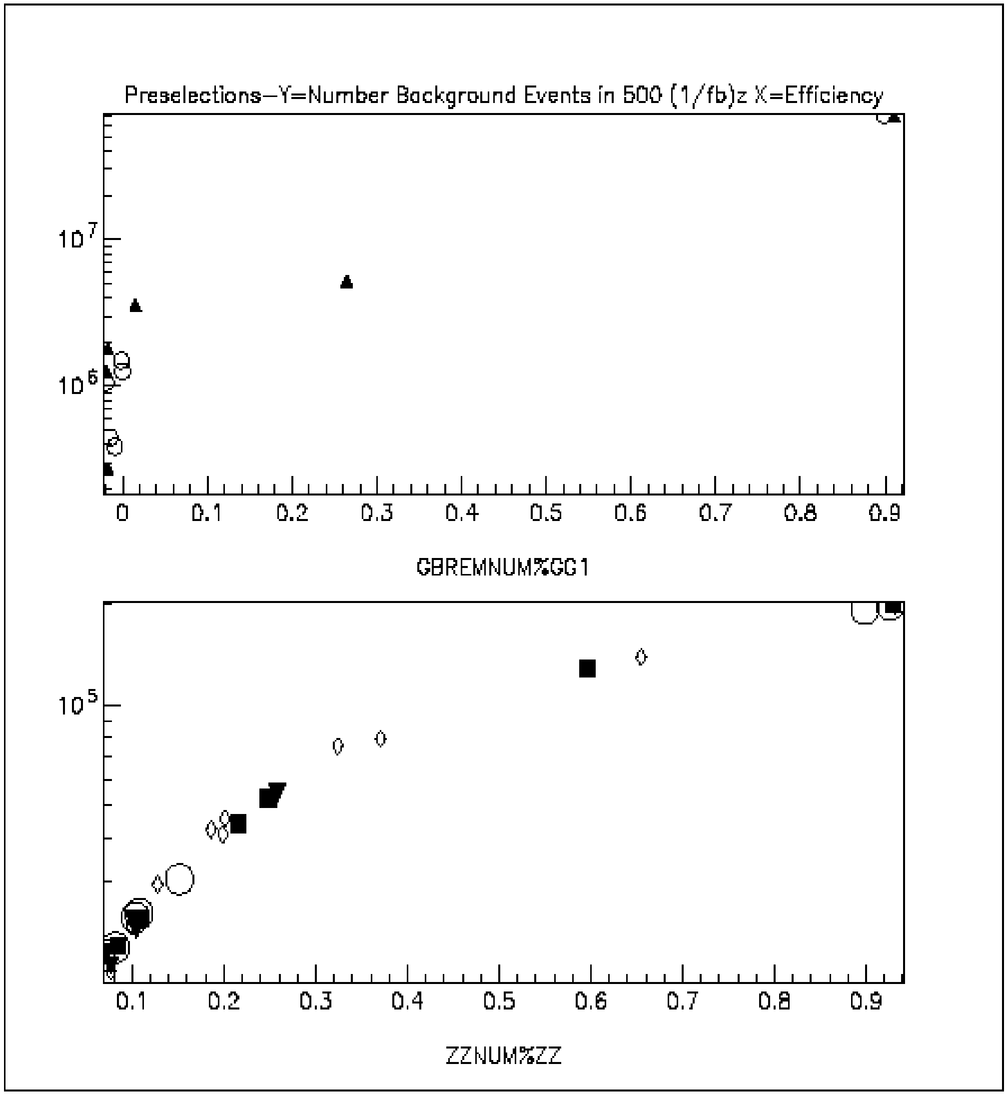
Selection: Efficiency of The Background Reduction at Each Cut



<u>The Number of Background Events,</u>normalized to 500 Fb^-1 luminosity, Are shown on y on logarithmic scale versus the Efficiency of the cuts on x, at Selection.

It is shown for each One of the backgrounds the cuts are powerful enough to span few orders of magnitudes.

#BG Events at preselection



Number of BG events in y
Efficiency in x at preselection cuts
Upper: Gamma-gamma
Lower: Other BG