Scalar Top Study: Detector Optimization

André Sopczak (Lancaster University)

Caroline Milsténe (Fermilab)

Many thanks: Alex Finch, LCFI Colleagues

Outline

- Introduction
- Vertex Detector c-Tagging
- Small Stop-Neutralino Mass Differences
- Variation of Vertex Detector Design:
  - Effect on c-Tagging Performance
  - Effect on Background Expectation
- Comparison with Large Stop-Neutralino Mass Differences
- Conclusions

Introduction

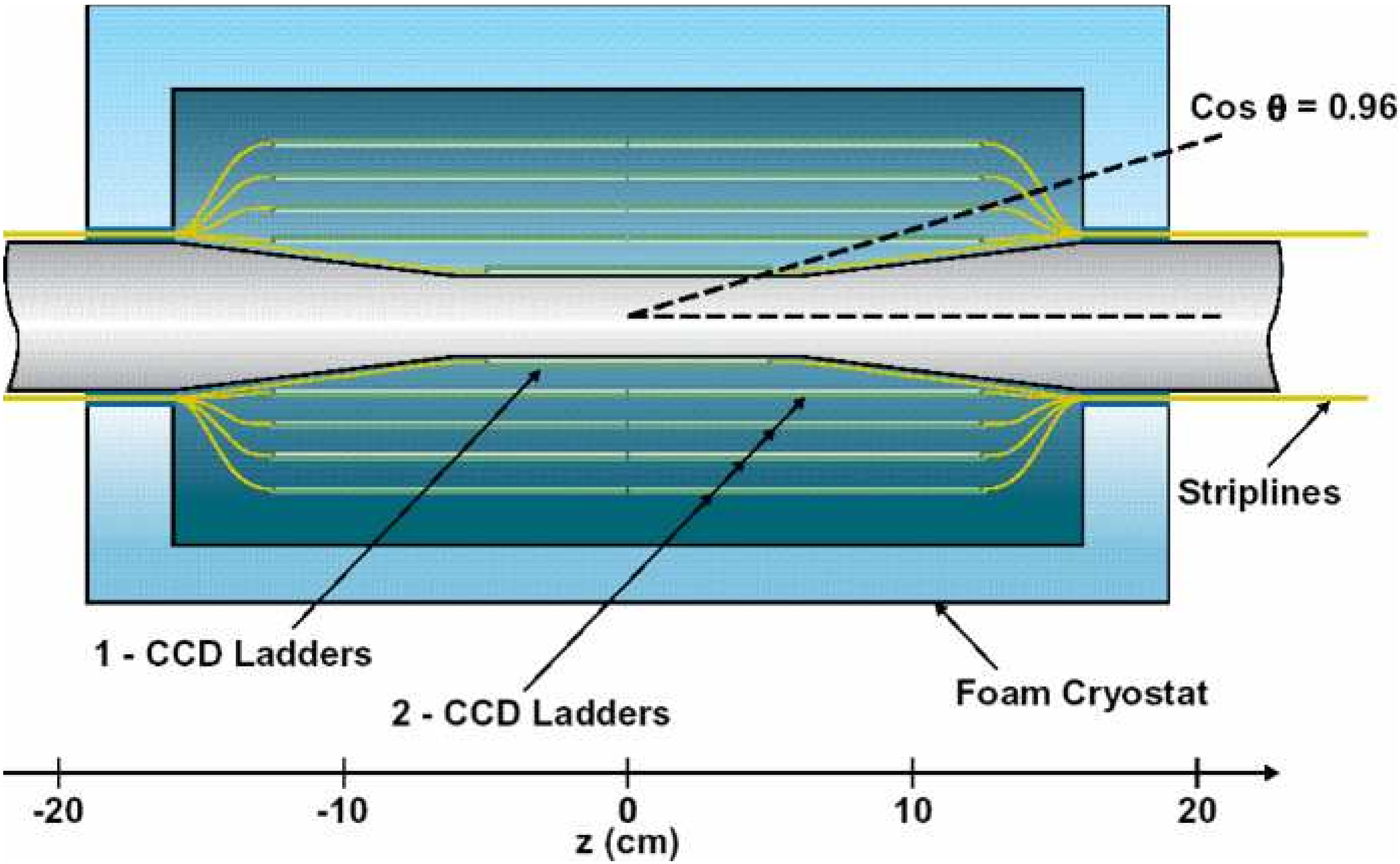
Large challenge to develop a vertex detector for heavy quark flavour identification at a future LC.

Key aspects:

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

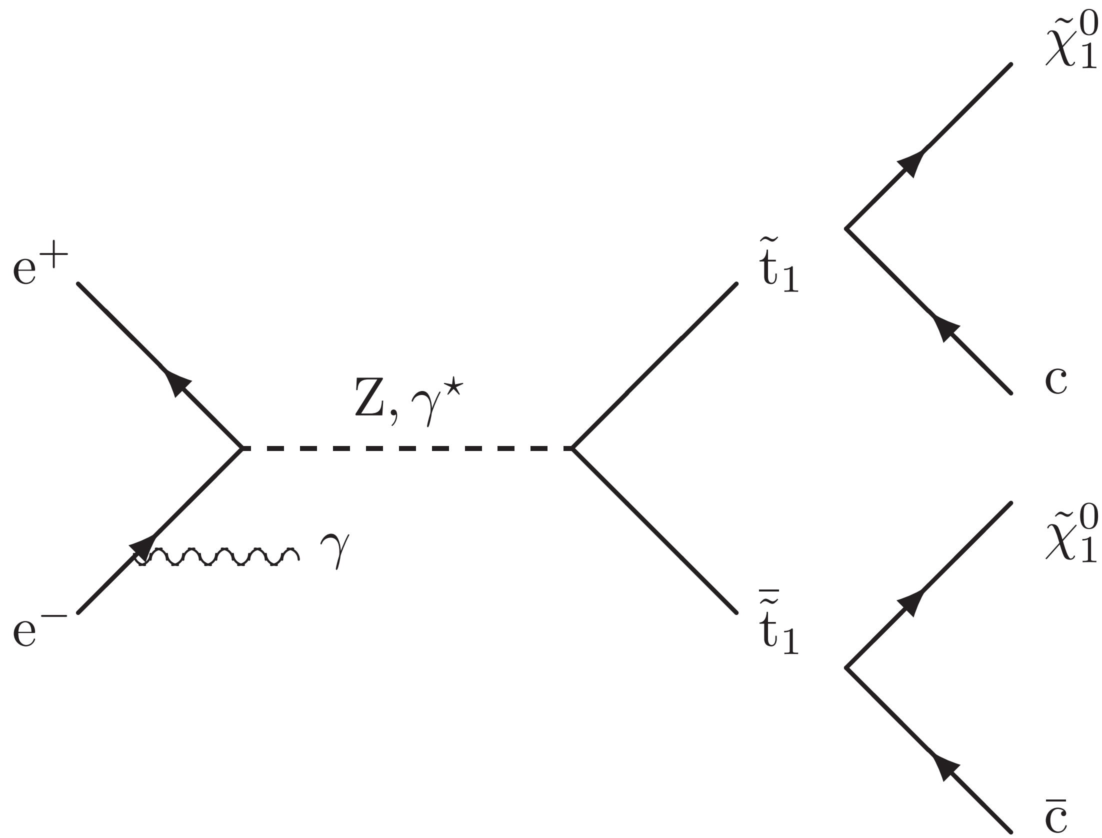
CCD Vertex Detector

Five layer CCD detector is implemented in c-tagging simulations.



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

c-Quark Tagging: a Benchmark Reaction



Signal: Two soft charm jets and missing energy.

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

Small Stop-Neutralino Mass Difference Studies

Motivations:

- Challenge for heavy quark flavour identification with a Vertex Detector.
- Dark Matter (Carena, Balázs, Wagner, PRD70:015007,2004):
  $\tilde{\chi}^0_1$ is Cold Dark Matter (CDM) candidate in the MSSM.
  Correct CDM rate for small $\tilde{t}_1 - \tilde{\chi}^0_1$ mass difference (co-annihilation).
- Dark Matter Determination at LC possible
  (Carena, Finch, Freitas, Milsténe, Nowak, Sopczak, PRD72:115008,2005).
- Optimization of the radius of the innermost layer is important for the design of a vertex detector.
- Co-annihilation for small $\Delta m = m_{\mathrm{stop}} - m_{\mathrm{neutralino}_1}$
- Difficult for searches at the Tevatron and LHC

Reduction of Background

1. Exactly 2 jets. Durham algorithm with jet resolution parameter $y_{\rm cut} = 0.003 \times \sqrt{s}/E_{\rm vis}$, tuned to most effectively reject four-jet $\rm W^+W^-$.

2. $E_{\rm vis} < 0.4\sqrt{s}$ to reduce $\rm W^+W^-$, ZZ and di-quark events. In addition, 70 GeV $< m_{\rm jet,inv} <$ 90 GeV reduces large Weν background.

3. $\cos\phi_{\rm acol} > -0.9$ reduces $\rm e^+e^- \rightarrow q\bar{q}$ and $\gamma\gamma \rightarrow \rm q\bar{q}$ processes with back-to-back topology.

4. $|\cos\theta_{\rm thrust}| < 0.7$ reduces events with W bosons further.

5. Remaining two-photon background is almost completely removed by $p_{\rm t} > 12$ GeV.

6. c-quark tagging improves the signal-to-background ratio further. Neural network optimized for small Δm. And, excluded invariant jet mass window increased to 60 GeV $< m_{\rm jet,inv} <$ 90 GeV.

Small Δm Study: Remaining Background Events

Recall: PRD72:115008,2005: $\sqrt{s} = 500$ GeV.

Process	Total	After presel.	cut 1	cut 2	cut 3	cut 4	cut 5	cut 6	Scaled to 500 fb^{-1}
W^+W^-	210,000	2814	827	28	25	14	14	8	145
ZZ	30,000	2681	1987	170	154	108	108	35	257
$We\nu$	210,000	53314	38616	4548	3787	1763	1743	345	5044
eeZ	210,000	51	24	20	11	6	3	2	36
$q\bar{q}$, $q \neq t$	350,000	341	51	32	19	13	10	8	160
$t\bar{t}$	180,000	2163	72	40	32	26	26	25	38
2-photon	8×10^6	4061	3125	3096	533	402	0	0	$<$164

cut1-cut6 are sequential cuts. $We\nu$ is the dominant background.

120 GeV stop mass (Δm=10 GeV): 20.46% efficiency and 11765 events/500 fb^{-1}.

Varying Vertex Detector Design

- Study is based on 50,000 120 GeV ($\Delta m = 10$ GeV) signal events and 210,000 $We\nu$ background events for each detector design.

Four detector designs are compared:

VX12 the TESLA TDR design with 5 layers and single (0.064% X_0 radiation length per layer).

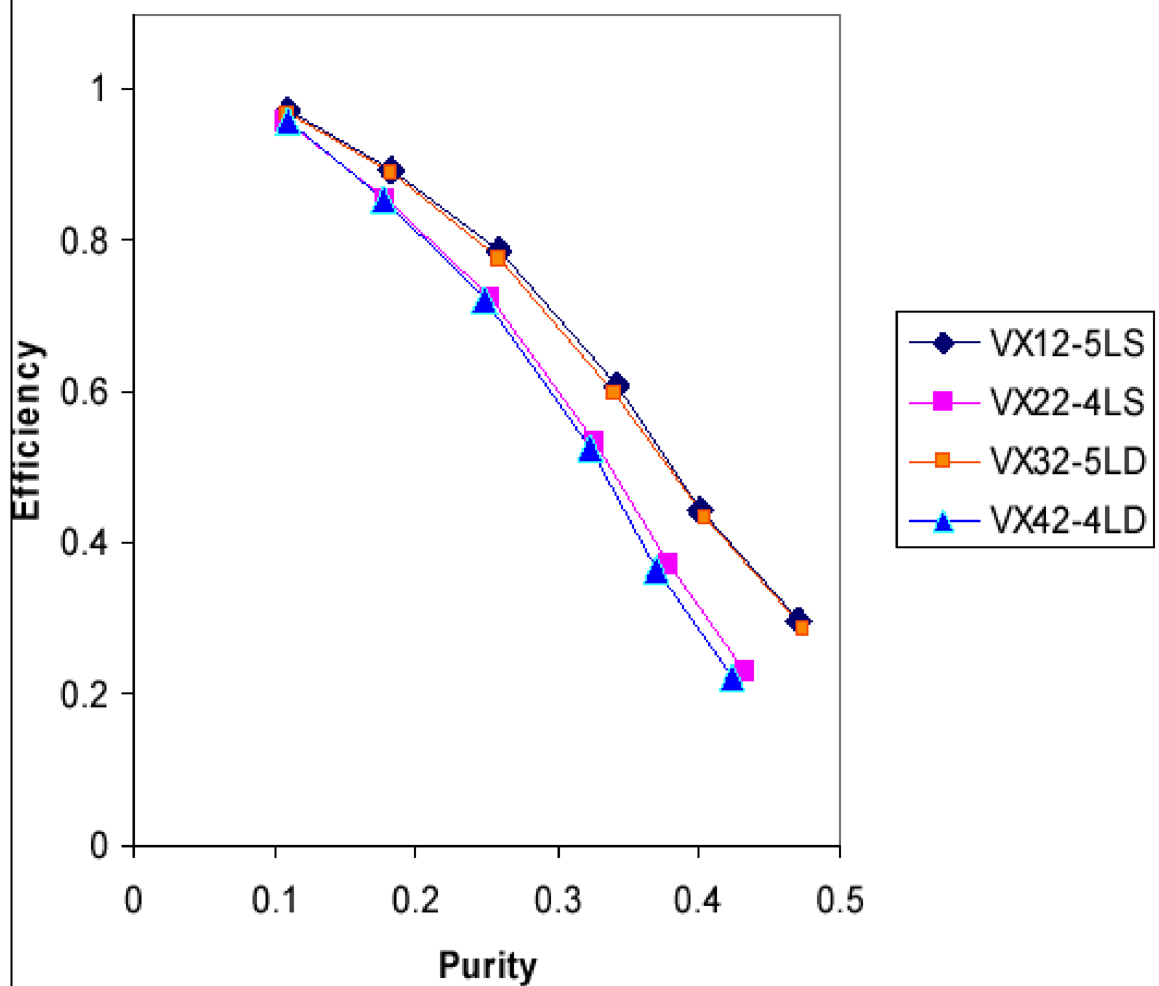
VX22 4 layers (the innermost layer removed). This scenario could for example occur if the vertex detector is exposed to a large dose of machine background from the accelerator.

VX32 5 layers and double material thickness (0.128% X_0 radiation length per layer).

VX42 4 layers (the innermost layer removed) and double thickness (0.128% X_0 radiation length per layer).

c-Tagging: Varying Vertex Detector Design

Effect of detector design variation increases with increasing purity (harder c-tagging Neural Network cut).
Radius of innermost layer has large effect on c-tagging performance.
Doubling radiation length has no significant effect. (0.128% X_0 radiation length per layer).
Increase of multiple scattering between single and double thickness is not significant compared to flight distance of charm mesons.



Effect on Sig. and Bkg: Varying Vtx Detector Design

- Same c-tagging working point as in the previous analysis (PRD72:115008,2005) with c-tagging efficiencies near 90% and 18% purity was chosen. This corresponds to the second set of points in c-tagging performance plot.

- The analysis is repeated four times for the different detector designs based on four independent sets of simulated signal and background events.

- The result is expressed as signal efficiency and number of Weν background events, and their statistical uncertainties:

Thickness	layers	signal eff. (in %)	Weν/210k	Weν/500 fb^{-1}
Single	5 (4)	20.46 (19.67)$\pm$0.18	364 (369)$\pm$19	5322 (5396)$\pm$280
Double	5 (4)	20.32 (19.52)$\pm$0.18	366 (385)$\pm$19	5352 (5630)$\pm$280

Only a small variation of the signal efficiency and background rate is observed for the selection described in PRD72:115008,2005. The detector design will have a larger effect on the performance for a harder c-tagging neural network cut.

Comparison: SPS-5 Varying Vtx Detector Design

For SPS-5 parameters: stop mass 220.7 GeV ($\Delta m = 100.7$ GeV) [Finch, Nowak, Sopczak, DESY LC-DET-2004-035]:

Same result observed as for this stop mass 120 GeV ($\Delta m = 10$ GeV) study.

(1) Vertex detector radiation length:

Normal thickness (TESLA TDR) versus double thickness.

(2) Number of vertex detector layers:

5 layers - innermost layer at 15 mm (like TDR) versus

4 layers - innermost layer at 26 mm (layer 1 removed)

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

Large effect of innermost radius and no significant effect of radiation length.

Conclusions

- Effect of vertex detector design on c-quark tagging performance and scalar top analysis studied.
- Small stop-neutralino mass difference study motivated by cosmology, vertex detector development and difficult reach at Tevatron and LHC.
- SIMDET detector simulation: LCFI CCD vertex detector.
- Four detector configurations simulated: dominant background $We\nu$.
- Same observation from small and large Δm studies: radius of the innermost layer of the vertex detector has a large effect on the c-quark tagging performance. No significant effect on the c-quark tagging performance from doubling the material budget.
- For the complete stop analysis: small variation of the selection performance, however, effect of detector design variation increases with increasing purity (harder c-tagging neural network cut).
- Plan: update analysis with new C++ LCFI vertexing and flavour tagging tools, which are under development.