Single Production of a Vector-Like Top Partner via the Recoil-Mass Technique

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Overview

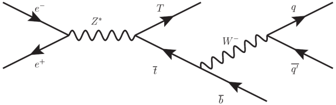
- Motivation for vector-like top partners and the recoil-mass strategy
- Benchmark model, simulated samples, and analysis workflow
- Event-selection highlights and baseline performance
- Impact of ISR and beam polarization on sensitivity
- Discovery reach in the (m_T, κ) plane and outlook

Motivation

- Vector-like quarks help stabilize the Higgs potential and appear in composite/little Higgs scenarios.
- A clean e^+e^- environment allows precise studies of single-production channels.
- Recoil-mass techniques provide mass-agnostic and decay-mode-agnostic searches that remain sensitive across wide m_T ranges.
- Objective: quantify discovery potential for single-T production at $\sqrt{s} = 3\,\text{TeV}$ with $5\,\text{ab}^{-1}$.

Model and Benchmarks

- Signal: $e^+e^- \to T\,\bar{t}$ with effective coupling κ at the T–top–gauge vertex.
- Benchmark masses: $m_T = \{1.2, 1.6, 2.0, 2.4\}$ TeV with widths from dedicated simulations.
- Reference coupling: $\kappa = 0.20 \Rightarrow \Gamma_T \approx 22.3$ GeV for $m_T = 1.2$ TeV.
- Additional samples scan $\kappa \in \{0.10, \ldots, 0.60\}$ to map the discovery reach.



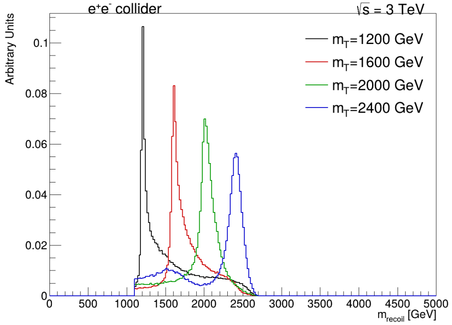
Event Samples and Reconstruction

$$\mathcal{L}_{\text{eff}} \supset \kappa_T \left\{ \sqrt{\frac{\zeta^W_{Tq}}{\Gamma_W}} \frac{g}{\sqrt{2}} \left[\bar{T}_{L/R} W^+_\mu \gamma^\mu d_{L/R} \right] + \sqrt{\frac{\zeta^Z_{Tt}}{\Gamma_Z}} \frac{g}{2c_W} \left[\bar{T}_{L/R} Z_\mu \gamma^\mu u_{L/R} \right] - \sqrt{\frac{\zeta^H_{Tt}}{\Gamma_H}} \frac{M}{v} \left[\bar{T}_{R/L} H u_{L/R} \right] \right\} + \text{h.c.}$$

- Model: Mathieu Buchkremer et al. "Model-independent framework for searches of top partners"(Nuclear Physics B 876.2 (2013), págs. 376-417.).
- Generation: MadGraph5_aMC@NLO + MadSpin with Pythia 8 showering.
- Backgrounds: $t\bar{t}$, $t\bar{t}Z$, $t\bar{t}h$, W^+W^-Z, normalized to $5\,\text{ab}^{-1}$.
- Two configurations: baseline (no ISR, unpolarized) and ISR + $P_{e^-} = +80\%$.

Selection Strategy

- Identify a high-p_T Cambridge–Aachen $R = 1.0$ fat jet tagged with the Johns Hopkins top-tagger.
- Require at least one b-tagged subjet/small-R jet to suppress light-flavor backgrounds.
- Constrain event kinematics: $E_{\text{miss}} < 1$ TeV and $m_{\text{recoil}} > 1.1$ TeV.

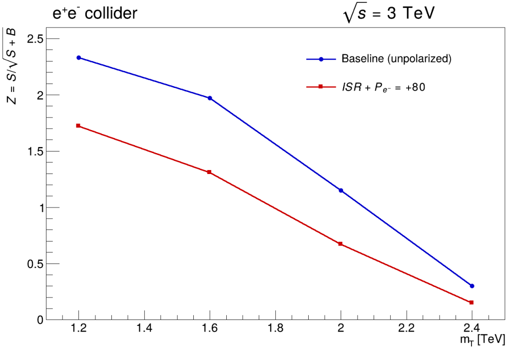


Baseline Performance

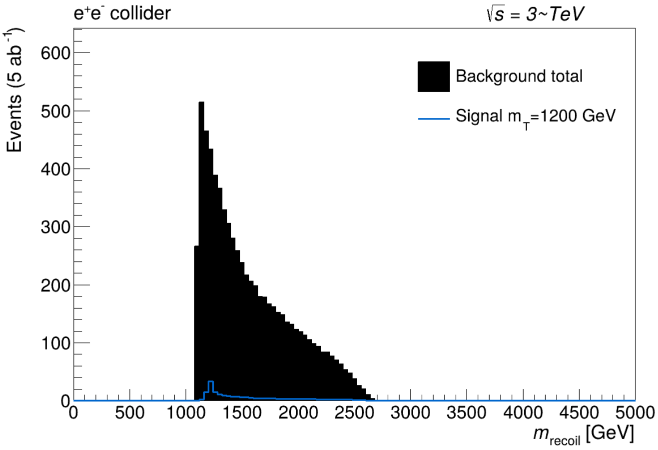
- $t\bar{t}$ reduced from $\mathcal{O}(10^5)$ to 2.3×10^3 events after the full selection.
- Signal efficiency for $m_T = 1.2\,\text{TeV}$ retains $\sim 16\%$ of events ($\approx$199 / 1232) at $L = 5\,\text{ab}^{-1}$.
- Total background after full selection: $B \approx 6940$ events for $L = 5\,\text{ab}^{-1}$.
- Counting significance for $\kappa = 0.20$: $Z = 2.35$ at $m_T = 1.2\,\text{TeV}$ for $L = 5\,\text{ab}^{-1}$.

Significance Summary

m_T [TeV]	Z_{base}	$Z_{\text{ISR+pol}}$
1.2	2.35	1.72
1.6	1.97	1.31
2.0	1.15	0.67
2.4	0.30	0.15

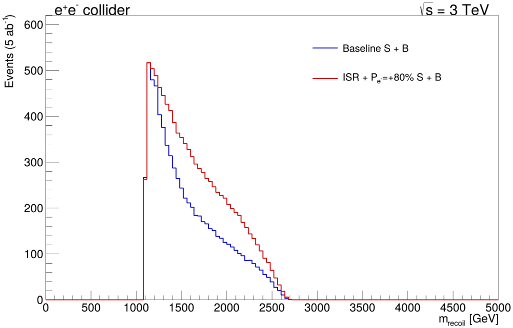


Recoil-Mass Spectrum



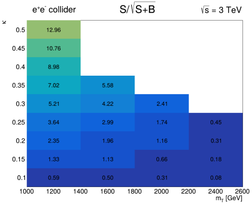
Impact of ISR and Polarization

- ISR increases background acceptance to $B = 9789$.
- Signal yield drops from 199 to 172 events at $m_T = 1.2\,\text{TeV}$.
- Net effect: $\sim 25\%$ loss in counting significance.

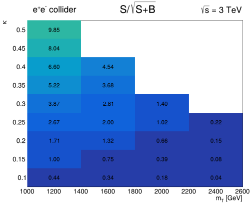


Coupling Scan

- Dedicated samples map $Z = S/\sqrt{S+B}$ versus (m_T, κ).
- Baseline (no ISR) reaches $Z \approx 5$ at (1.2 TeV, $\kappa = 0.30$).
- ISR + $P_{e^-} = +80\%$ shifts the reach to $Z \approx 3.7$ at the same point.
- Sensitivity falls below $Z = 1$ near $m_T \gtrsim 2$ TeV unless $\kappa \gtrsim 0.4$.



Baseline



ISR + $P_{e^-} = +80\%$

Summary and Outlook

Summary

Baseline selection reaches about 2.35 sigma at 1.2 TeV with kappa 0.20, retaining roughly 16 percent of the signal while remaining mass and decay-mode agnostic across the scanned benchmarks.
ISR with plus-eighty-percent electron polarisation reduces the yield but the recoil observable keeps broad sensitivity over the mass versus kappa plane.

Next Steps

Optimise the selection separately for low and high masses, extend the dedicated studies to additional kappa benchmarks, and incorporate ISR-aware observables to recover significance.

Backup: Baseline Cutflow

Selection step	Signal	$t\bar{t}$
All events	1232.3	95 706.0
Fat-jet preselection	1232.0	95 335.1
Top tagged	401.4	41 535.0
Substructure tag	348.6	37 869.4
Isolation veto	215.1	31 975.5
$m_{\text{recoil}} > 1.1$ TeV	206.1	5897.1
$E_{\text{miss}} < 1$ TeV	198.6	5654.6
$\text{BDT}_{t\bar{t}}$	189.2	4244.3
BDT_{1200}	187.3	4122.1
Final (BDT_{2400})	110.0	2322.6