STATISTICAL ARBITRAGE IN CRYPTOCURRENCIES

Momentum & Reversal Strategies with Robust Backtesting

Abstract

This project develops and backtests four systematic trading strategies—two momentum (Channel Breakout, MA Crossover) and two reversal (Pairs Trading, Time Horizon) using Binance cryptocurrency data from 2021–2025. With transaction costs of 20 bps per trade, all strategies materially outperform Bitcoin buy-and-hold on the holdout set, achieving Sharpe ratios above 1.4, information ratios above 1.6, and delivering strong positive alpha. Beyond individual strategies, two diversified momentum portfolios are constructed by combining Breakout and Crossover signals using inverse-volatility weighting of sleeve-level portfolio returns. These combinations further enhance efficiency, producing Sharpe ratios up to 1.9, information ratios above 2.0, faster recovery from drawdowns, and near-zero beta to BTC. The results provide robust evidence of statistical arbitrage opportunities in digital assets and highlight the benefits of strategy diversification for improving stability and risk-adjusted returns in cryptocurrency markets.

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1. Introduction

Statistical arbitrage (stat-arb) is a class of systematic trading strategies designed to exploit predictable patterns in asset prices and volumes. In equities, stat-arb strategies have historically generated strong risk-adjusted returns by identifying momentum (trends that persist) and reversal (temporary mispricing that mean-revert).

Cryptocurrency markets are relatively young, less regulated, and often inefficient compared to traditional asset classes. This makes them fertile ground for discovering arbitrage opportunities. The goal of this research is to investigate whether well-established momentum and reversal strategies can be adapted to crypto and whether they can outperform a passive **Bitcoin buy-and-hold (HODL)** benchmark.

The project implements four systematic strategies:

- **Momentum – Moving Average Crossover**
- **Momentum – Channel Breakout**
- **Reversal – Pairs Trading (Cointegration)**
- **Reversal – Time Horizon**

In addition, the study examines **combined portfolios** that integrate these strategies to evaluate how diversification across momentum and reversal approaches impacts overall performance.

Each is tested on Binance OHLCV data (daily and intraday), with transaction costs modeled as 20 bps per trade - consisting of approximately **7 bps in commissions** and an assumed **13 bps in slippage** and turnover accounted for. Evaluation metrics include cumulative return, annualized return, volatility, Sharpe ratio, drawdowns, win rate, and regression-based alpha/beta against BTC/USDT.

2. Data and Methodology

2.1 Data Sources

The analysis uses historical OHLCV (Open, High, Low, Close, Volume) data from Binance covering January 2021 through August 2025. Two datasets are maintained:

- **Daily frequency**: used for the momentum strategies (Channel Breakout and Moving Average Crossover).
- **Hourly frequency**: aggregated to 4-hour bars for the time-horizon reversal strategy.

Data preprocessing steps:

1. **Cleaning:** duplicate rows were removed.
2. **Continuous index:** timestamps reindexed to continuous daily or 4-hour intervals. Missing observations forward filled.

3. **Liquidity filter:** assets with fewer than 90% valid entries were excluded to avoid illiquid or inactive coins.
4. **Top 100 market cap constraint:** for intraday strategies, only the top 100 cryptocurrencies by market capitalization were retained, ensuring liquidity and realistic execution.

2.2 Execution Costs and Turnover

Transaction costs are modeled as **20 bps per market order**, decomposed into 7 bps commission and 13 bps estimated slippage. For each rebalance, turnover is calculated as the difference between today's weights and yesterday's portfolio weights.

$$Turnover_t = \sum_{i=1}^{N} |w_{i,t} - w_{i,t-1}|$$

and costs are deducted from gross returns as:

$$net_r et = gross_r et - Turnover_t \times 20\ bps \times 10^{-4}$$

2.3 Performance Metrics

The success of any systematic strategy cannot be judged on returns alone; risk and efficiency of returns are equally important. In this project, we evaluate each strategy using the following performance metrics:

i) Cumulative Return - measures the total growth of a $1 investment over the backtest horizon. If ret_t is the portfolio return at time t, then cumulative performance is tracked as:

$$C_t = \prod_{k=1}^{t} (1 + ret_k)$$

This metric highlights how much wealth would have been generated by the strategy relative to a simple BTC buy-and-hold.

ii) Annualized Return - To compare strategies of different horizons and lengths, we convert mean returns into annualized figures:

$$\text{Ann. Return} = \overline{ret} \times A$$

where $\overline{ret}$ is the average per-period (daily/hourly) return and A is the number of periods in a year (A=365 for daily, A=365×6 for 4-hour data). This allows direct comparison across strategies, even when the trading frequency differs.

iii) Annualized Volatility - measures the standard deviation of returns, which is annualized for comparability:

$$Ann. Volatility = \sigma(ret) \times \sqrt{A}$$

High volatility implies greater uncertainty in outcomes, which may erode investor confidence even if returns are high.

iv) **Sharpe Ratio -** The Sharpe ratio standardizes returns by volatility, providing a risk-adjusted measure:

$$\text{Sharpe} = \frac{\overline{ret}}{\sigma(ret)} \times \sqrt{A} = \frac{\text{Ann. Return}}{Ann.Volatility}$$

A Sharpe above 1.0 is generally considered strong; values above 1.5 are excellent in the context of liquid markets.

v) **Maximum Drawdown (MDD)** Drawdown captures the largest observed peak-to-trough decline in the equity curve.

Drawdowns matter because investors often abandon strategies after large losses. For crypto, where volatility is extreme, strategies that limit drawdowns relative to BTC are highly desirable.

vi) **Drawdown Duration -** Equally important is how long it takes to recover from losses. Duration measures the time spent below the previous equity peak. Strategies with shorter drawdown durations allow faster recovery, which is crucial for capital allocation in live trading.

vii) **Win Rate -** The win rate is the percentage of trades that result in positive returns:

$$\text{Win Rate} = \frac{\#\{r_t > 0\}}{\#\{r_t \neq 0\}}$$

While useful, win rate can be misleading: a strategy may win less often but earn larger average profits per win, producing higher overall returns (as we observe in some reversal strategies).

viii) **Alpha and Beta vs BTC -** To measure independence from Bitcoin's market risk, we regress strategy returns on BTC returns:

$$ret_t^{\text{strategy}} = \alpha + \beta . ret_t^{BTC} + \epsilon_t$$

- **Alpha (α)**: the intercept, representing risk-adjusted return unexplained by BTC. Annualized alpha shows whether the strategy generates independent sources of return.
- **Beta (β)**: the slope, measuring sensitivity to BTC's moves. A beta near 1 means the strategy behaves like BTC; a beta near 0 or negative means it is market-neutral or hedging.

ix) **Information Ratio (IR) -** measures consistency of excess returns relative to BTC:

$$IR = \frac{\overline{ret^{\text{strategy}} - \beta . ret^{BTC}}}{\sigma(ret^{\text{strategy}} - \beta . ret^{BTC})} \sqrt{A}$$

A higher IR indicates steadier outperformance over the benchmark. Whereas the Sharpe ratio standardizes against absolute volatility, the IR focuses on *benchmark-relative efficiency*.

3. Momentum Strategies

3.1 Momentum Strategy 1 – Moving Average Crossover

3.1.1 Strategy Rationale

The Moving Average (MA) Crossover is a classical momentum strategy that captures medium-term price trends. The intuition is that when a short-term moving average rises above a long-term moving average, recent gains outweigh past performance, signaling upward momentum; conversely, when the short-term average falls below the long-term average, it signals downward momentum.

In cryptocurrency markets, where trends can persist due to retail herding and liquidity shocks, this crossover mechanism is effective for identifying when to ride medium-term moves while avoiding the noise of short-lived reversals.

3.1.2 Signal Construction

Let ret_t be the daily return of an asset at time t calculated using closing prices. Define a short-term moving average (window s) and a long-term moving average (window ℓ) as:

$$MA_t^{short} = \frac{1}{s}\sum_{k=0}^{s-1} ret_{t-k} \quad , MA_t^{long} = \frac{1}{\ell}\sum_{k=0}^{\ell-1} ret_{t-k}$$

The raw crossover signal is the relative difference:

$$Signal_t = \frac{MA_t^{short}}{MA_t^{long}} - 1$$

- Positive signal → bullish trend, go long.
- Negative signal → bearish trend, go short.

To ensure stability:

1. **Volatility Normalization:** dividing by rolling 63-day standard deviation of returns.

2. **Tanh Transformation:** compresses extreme signals to reduce over-leverage:

$$Signal_t = \tanh\left(\frac{Signal_t}{\sigma_{63}(ret)}\right)$$

3. **Gap Adjustment:** We also measure the gap between short- and long-term moving averages of **prices**:

$$Gap_t = Price_t^{short\ MA} - Price_t^{long\ MA}$$

   - If the gap is decreased when we are in long position, signals are reversed (go short) to avoid holding a losing trade too long.

- If the gap is decreased when we are in short position, signals are reversed (go long) to ride the upward trend. This ensures we don't enter late when the move is already reversed.
- Flipping signals to contrarian occurs when the gap shrinkage exceeds a volatility-scaled threshold.

3.1.3 Portfolio Construction

Signal intensity is rescaled by the square root of longer horizon volatility (window = 180). Finally, signals are converted into portfolio weights:

$$w_{i,t} = \frac{Signal_{i,t}}{\sum_j |Signal_{j,t}|}$$

ensuring the portfolio is fully invested.

3.1.4 Results and Interpretation

On daily Binance OHLCV data (2021–2025), the MA Crossover strategy produced strong and consistent risk-adjusted returns relative to BTC.

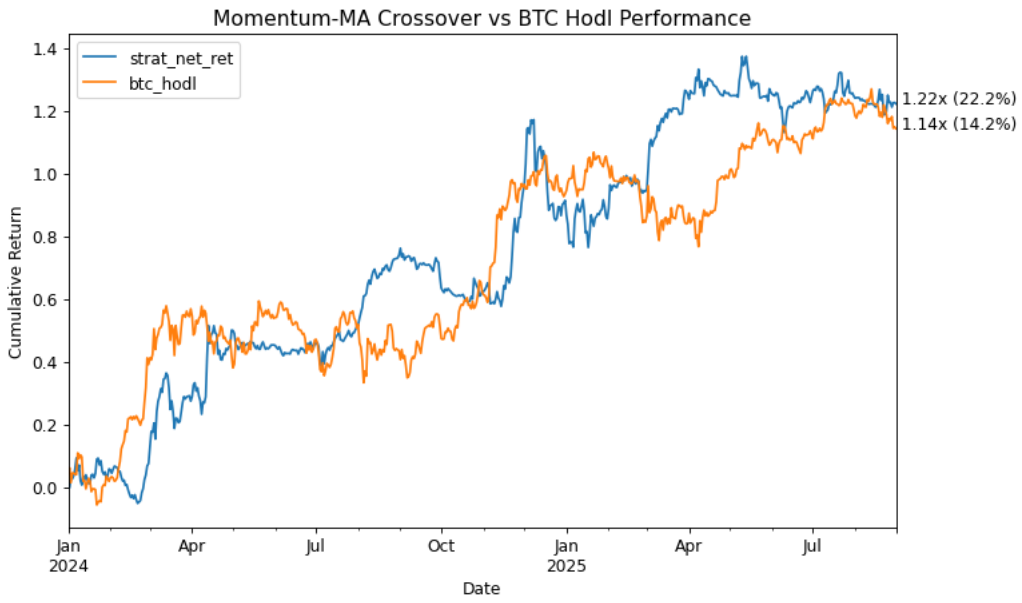

***Figure 1a**: The MA Crossover strategy (blue) shows a steadily rising cumulative return, ultimately outperforming BTC buy-and-hold (orange). By late 2025, the strategy's total accumulated return is 1.22x versus BTC's 1.14x, showing clear performance edge.*

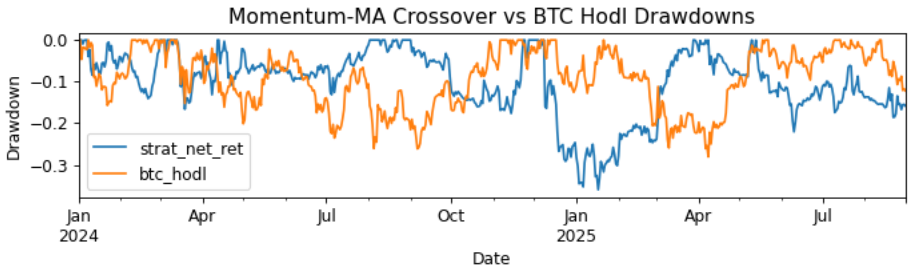

***Figure 1b**: Drawdowns show that the strategy occasionally dipped deeper than BTC, but it recovered faster, shortening underwater periods compared to the prolonged stagnation of BTC.*

Metric	Strategy (Net)	BTC HODL
Cumulative Return	182.79%	156.00%
Annualized Return	73.21%	68.47%
Annualized Volatility	46.65%	49.41%
Sharpe Ratio	1.57	1.39
Max Drawdown	-36.00%	-28.10%
Max Drawdown Duration	113 days	237 days
Win Rate	52.71%	51.72%
Info Ratio	1.73	-
Annualized Alpha	80.06%	-
Beta vs BTC	-0.1000	1.0
Holding Period	7.87 days	N/A

The **Moving Average Crossover strategy** delivered a **Sharpe ratio of 1.57**, higher than BTC's 1.39, while also operating with slightly **lower volatility (46.7% vs 49.4%)**. This indicates the strategy generated stronger risk-adjusted returns than simple buy-and-hold.
The strategy's **maximum drawdown was –36%**, deeper than BTC's –28.1%, but importantly, it **recovered much faster** with drawdowns lasting just **113 days** compared to BTC's **237 days**. This reflects the strategy's ability to rebound more quickly from adverse market conditions.

Regression analysis shows a **mildly negative beta (–0.10)**, suggesting that the strategy is largely uncorrelated with BTC and occasionally moves in the opposite direction. This independence is reinforced by its **annualized alpha of 80%**, highlighting that the returns came from the crossover logic itself rather than simple BTC exposure.

The **average holding period of ~8 days** positions the strategy in the intermediate-term space long enough to capture persistent trends but short enough to adapt when conditions change. With a **win rate of ~53%** and a strong **information ratio (1.73)**, the MA Crossover demonstrates that systematic momentum signals can consistently outperform passive BTC exposure on a risk-adjusted basis.

3.2 Momentum Strategy 2 — Channel Breakout

3.2.1 Strategy Rationale

The Channel Breakout strategy is a trading approach designed to capture strong directional moves in an asset's price. It is based on the principle that once prices break through important levels of support or resistance with momentum, they are likely to continue in that direction for some time. The intuition is straightforward: when an asset breaks above its recent highs, it often signals the beginning of a strong upward trend; conversely, a break below recent lows often precedes further declines. Crypto markets, with their high retail participation and herd-like behavior, are especially prone to sharp continuation moves following breakouts.

By systematically defining channel bounds and entering positions upon breakout confirmation, this strategy attempts to capture directional moves while cutting losses when breakouts fail.

3.2.2 Signal Construction

For each asset, define rolling higher and lower channels using the past long entry lookback (le_lookback) highs and short entry lookback (se_lookback) lows:

$$\text{Higher}_t = \max\left(\text{High}_{t-L_e+1:t}\right)$$
$$\text{Lower}_t = \min\left(\text{Low}_{t-S_e+1:t}\right)$$

- **Entry:**

$$\text{Long Entry}_t = 1_{\text{Close}_t > \text{Higher}_{t-1}}$$
$$\text{Short Entry}_t = 1_{\text{Close}_t < \text{Lower}_{t-1}}$$

- **Volume filter:** trade only if today's volume exceeds the rolling p-quantile of the last lookback window:

$$volume_t > Q_{lookback}(volume, p)\}$$

- **Exit rules:**
  - Price crosses opposite channel (stop-out).

$$\text{Long Exit}_t = 1_{\{\text{Close}_t < \text{Lower}_{t-1}\}}$$
$$\text{Short Exit}_t = 1_{\{\text{Close}_t > \text{Higher}_{t-1}\}}$$

  - Maximum holding period M reached.

$$Position_t = 0 \; if \; age > M$$

3.2.3 Portfolio Construction

After generating the raw positions, we construct the final tradable portfolio by risk-scaling, smoothing, and normalizing the positions.

- **Risk-Scaling by Volatility**
  Positions are scaled by recent asset volatility:

$$pos_t^i \leftarrow pos_t^i \times \sqrt{\sigma_t^i}$$

  where:

$$\sigma_t^i = \sigma\left(ret_{t-34:t}^i\right)$$

  Computes a **35-period rolling** standard deviation for each asset (i).

- **Normalization for Fully Invested Portfolio**
  Finally, positions are normalized to ensure total exposure sums to 1:

$$w_t^i = \frac{pos_t^i}{\sum_j |pos_t^j|}$$

  This creates a fully invested portfolio $\left(\sum_i |w_t^i| = 1\right)$.

3.2.4 Results and Interpretation

Using daily Binance data (2021–2025), the channel breakout strategy significantly outperformed BTC buy-and-hold.

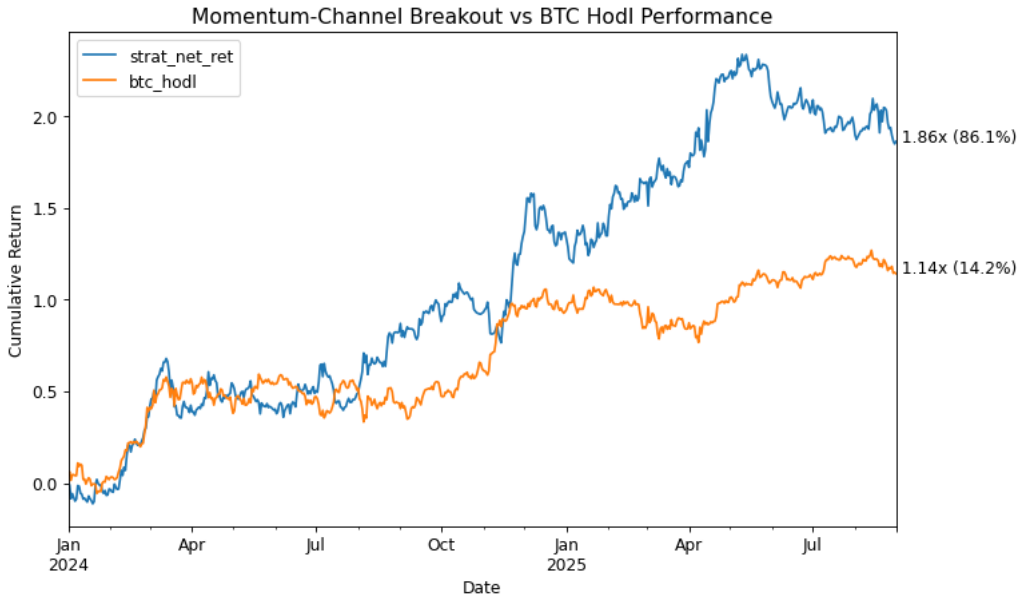

***Figure 2a**: The Channel Breakout strategy (blue) delivered a strong performance of 1.86x (86.1%), significantly ahead of BTC's 1.14x (14.2%). Breakouts during early 2025 drove sharp gains, though volatility was visibly higher.*

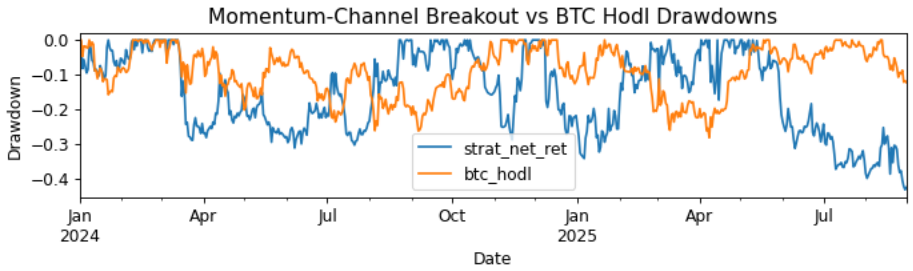

***Figure 2b**: Drawdowns highlight steeper equity declines than BTC, but with swift rebounds, consistent with the aggressive nature of breakout trading.*

Metric	Strategy (Net)	BTC HODL
Cumulative Return	287.34%	156.00%
Annualized Return	111.54%	68.47%
Annualized Volatility	77.98%	49.41%
Sharpe Ratio	1.43	1.39
Max Drawdown	-43.07%	-28.10%
Max Drawdown Duration	162 days	237 days
Win Rate	52.39%	51.72%
Info Ratio	1.71	-
Annualized Alpha	131.00%	-
Beta vs BTC	-0.2842	1.0
Holding Period	8.13 days	N/A

The Channel Breakout strategy delivered an **annualized return of 111.5%**, far exceeding BTC's **68.5%**, highlighting its ability to capitalize on strong directional moves. This came with elevated volatility of 78% versus BTC's 49%, reflecting the aggressiveness of breakout trades. Despite this higher risk, the **Sharpe ratio of 1.43** was still above BTC's 1.39, confirming that the strategy generated returns efficiently relative to the additional volatility. The **maximum drawdown of –43.1%** was steeper than BTC's –28.1%, but the **drawdown duration was shorter (162 vs 237 days)**, showing the strategy's ability to recover more quickly after losses.

The **information ratio of 1.71** and strong **annualized alpha (131%)** underscore that the majority of gains were independent of BTC's direction. This is supported by the **negative beta (–0.28)**, meaning the strategy often performed well when BTC struggled, providing diversification benefits. With an **average holding period of ~8 days** and a **win rate of 52%**, profits were driven by capturing large breakouts rather than frequent small wins. This reflects the strategy's design leveraging momentum bursts while maintaining manageable turnover.

Overall, the Channel Breakout strategy combines exceptional return potential with diversification benefits relative to BTC, making it a robust candidate for systematic trading in volatile crypto markets.

4. Reversal Strategies

4.1 Reversal Strategy 1 – Pairs Trading

4.1.1 Strategy Rationale

Pairs trading is a market-neutral reversal strategy that exploits temporary mispricing between two historically related assets. The intuition is that some crypto assets often within similar sectors or with strong correlation tend to move together in the long run. When their relative prices diverge significantly, the expectation is that the spread will eventually revert to equilibrium.

Unlike momentum approaches, which bet on trend continuation, pairs trading profits from mean reversion. Its key advantage is market neutrality: by going long one asset and short another, the portfolio's exposure to broad market swings is minimized. This makes it especially valuable in volatile markets like crypto, where overall direction can be difficult to forecast.

4.1.2 Signal Construction

1. **Pair Selection:**
   - Compute log-prices and log-returns, then define rebalance dates every 90 days window.
   - For each rebalance date, calculate a rolling correlation matrix of log returns over the past ~182 days(half year).
   - Selects candidate pairs with correlation above 0.82.
   - Test cointegration of each candidate pair; keep pairs with p-value < 0.1
   - Returns the top cointegrated pairs sorted by correlation for each rebalance date.

2. **Spread Formation:**
   For a given pair (x_t, y_t), estimate rolling (90 days) hedge ratio β:

$$logret_y = \alpha + \beta . logret_x + \epsilon_t$$
$$\beta_t = corr\left(logret_x, logret_y\right) \times \frac{\sigma_y}{\sigma_x}$$

   where the residual $logret_y - \beta . logret_y$ defines the **spread**.

3. **Z-score Standardization:**
   Standardize the spread over 90 days rolling window:

$$z_t = \frac{spread_t - \mu_{spread,t}}{\sigma_{spread,t}}$$

   Where $\mu_{spread,t}$ and $\sigma_{spread,t}$ are computed over the past 90 days.

4. **Entry and Exit Rules:**
   - Entry rules:

$$\begin{cases} z_t > z_{entry} \Longrightarrow short\ spread\colon\ y = -1, x = +\beta t \\ z_t < z_{entry} \Longrightarrow long\ spread\colon\ y = +1, x = -\beta t \end{cases}$$

   - Exit rules:

$$|z_t| < z_{\text{exit}} \Longrightarrow flat\ positions(0)$$

$$z_{entry} = \frac{1}{1 + e^{-entry * c}} + 1, where\ c = \frac{\sigma_{spread,t(rolling\ 90\ days)}}{\sigma_{spread,t(rolling\ 180\ days)}}$$

After optimization $entry = 0.5$ and $z_{\text{exit}} = 1.0$, z_{entry} ranges between [1,2].

4.1.3 Portfolio Construction

Tanh Transformation is performed to compress extreme signals to reduce over-leverage. Finally, positions are normalized to ensure total exposure sums to 1:

$$w_t^i = \frac{pos_t^i}{\sum_j |pos_t^j|}$$

This creates a fully invested portfolio $\left(\sum_i |w_t^i| = 1\right)$.

Turnover is controlled by the exit threshold and holding periods, which typically average several days.

4.1.4 Results and Interpretation

Across 2021–2025, the pairs trading strategy produced positive returns with lower volatility than BTC, consistent with its market-neutral design.

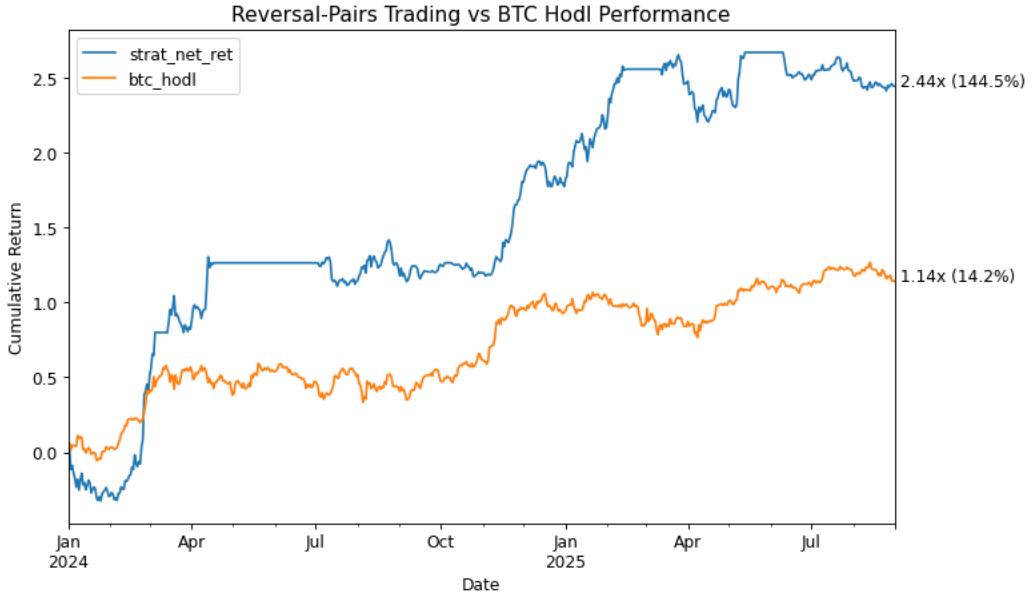

***Figure 3a**: The Pairs Trading reversal strategy (blue) was the top performer, compounding to 2.44x (144.5%) versus BTC's 1.14x (14.2%). The strategy captured strong mean-reversion opportunities, especially late-2024 and early 2025.*

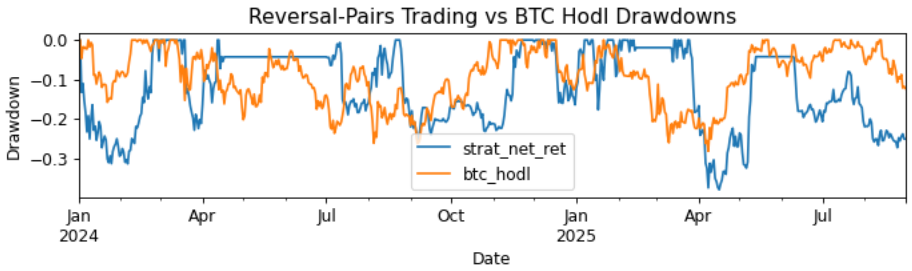

***Figure 3b**: Drawdowns show sharp but short-lived declines, followed by quick recoveries that propelled equity to new highs, while BTC's losses were shallower but longer lasting.*

Metric	Strategy (Net)	BTC HODL
Cumulative Return	674.75%	156.00%
Annualized Return	146.52%	68.47%
Annualized Volatility	69.81%	49.41%
Sharpe Ratio	2.10	1.39
Max Drawdown	-37.82%	-28.10%
Max Drawdown Duration	159 days	237 days
Win Rate	54.24%	51.72%
Info Ratio	1.92	-
Annualized Alpha	132.80%	-
Beta vs BTC	0.2002	1.0
Holding Period	12.98 days	N/A

The Pairs Trading strategy was the strongest performer, compounding an **annualized return of 146.5%**, more than double BTC's **68.5%**. Despite operating with slightly higher **volatility (69.8% vs 49.4%)**, the strategy achieved a **Sharpe ratio of 2.10**, far exceeding BTC's 1.39, confirming outstanding risk-adjusted performance. The strategy's **maximum drawdown of –37.8%** was deeper than BTC's –28.1%, but its **drawdown duration** was significantly shorter **(159 vs 237 days)**, highlighting its faster recovery from losses. A **win rate of 54%** indicates consistent trade success, with gains amplified by large reversals.

Factor analysis reveals a **beta of 0.20**, showing mild correlation with BTC, but an **annualized alpha of 132.8%**, demonstrating that most of the returns came from the mean-reversion logic rather than exposure to BTC's market direction. The **information ratio of 1.92** reinforces the efficiency and consistency of these returns. With an **average holding period of ~13 days**, the strategy reflects a medium-term horizon long enough to capture reversal cycles, yet short enough to reposition as market relationships shift.

Overall, the Pairs Trading approach combines exceptional returns, strong Sharpe performance, and rapid recovery from drawdowns, making it the most compelling strategy in the set for exploiting inefficiencies in crypto market co-movements.

4.2 Reversal Strategy 2 – Time Horizon (4H)

4.2.1 Strategy Rationale

The Time Horizon Reversal strategy exploits the well-documented tendency for short-term returns to mean-revert. In crypto markets, extreme price movements often arise from investor overreaction, liquidity shocks, or forced liquidations. While momentum may dominate at longer horizons, short-term moves tend to overshoot and then reverse.

Short-horizon crypto moves often mean-revert, but broad BTC trends can dominate cross-sectional returns. To isolate idiosyncratic action, we first hedge each asset's return against BTC using a rolling beta. We then trade reversals in the BTC-neutral residuals, only when dislocations are large enough to matter.

4.2.2 Signal Construction:

We first compute returns (ret) followed by rolling beta (β) to BTC (90-day lookback) and then compute the residuals $(resid)$.

$$ret_t^i = \frac{P_{i,t}}{P_{i,t-1}} - 1$$

$$\beta_{i,t} = corr\left(ret_t^{btc}, ret_t^i\right) \times \frac{\sigma_{90}^i(t)}{\sigma_{90}^{btc}(t)}$$

$$resid_{i,t} = ret_t^i - \beta_{i,t}.ret_t^{btc}$$

1. **Short-Term Reversal Signal**
   Using residual returns aggregated to 4-hour bars, define the raw reversal score as:

$$Signal_{i,t} = -\frac{1}{H}\sum_{k=0}^{H-1} resid_{i,t-k} \quad where\ H = 1$$

2. **Signal Dampening:** $Signal_{i,t} = 0 \ \ if \ \ \left|resid_{i,t}\right| < 0.11$

3. **Cross-Sectional Ranking**
   At each rebalance, rank signals across assets to ensure comparability and reduce the effect of outliers.

$$Signal_{i,t} = rank\left(Signal_{i,t}\ across\ all\ assets\ i\right)$$

4. **Dislocation filter**: $Signal_{i,t} = 0 \ \ if \ \ \left|resid_{i,t}\right| < 0.09$

   Also $Signal_{i,t} = 0 \ \ if \ \ resid_{i,t} < resid_{t,quantile(0.2,i)}$

The resulting signals are then used to construct the strategy portfolio.

4.2.3 Portfolio Construction

- **Universe:** The portfolio invests across the top 100 USDT pairs by market capitalization. Restricting to large-cap assets avoids illiquid names that could increase slippage and implementation risk
- **Rebalancing Frequency:** Positions are updated every 4 hours in line with the signal horizon.
- **Dollar Neutrality (Demeaning)**
  Cross-sectional means are subtracted to ensure that long and short exposures balance:

$$demeaned_{i,t} = Signal_{i,t} - \frac{1}{N}\sum_{j=1}^{N} Signal_{j,t}$$

- **Smoothing and Normalization**
  Demeaned signals are smoothed to reduce noise and turnover. The smoothed values are then normalized, ensuring the portfolio is both fully invested and comparable across time:

$$smoothed_{i,t} = EWMA(demeaned_{i,t}, span = 20)$$

$$weight_{i,t} = \frac{smoothed_{i,t}}{\sum_{j=1}^{N} |smoothed_{j,t}|}$$

The resulting portfolio is **dollar-neutral, fully invested, and risk-controlled**, with weights concentrated on assets showing the strongest residual signals.

4.2.4 Results and Interpretation

Using 4-hour Binance OHLCV data (2021–2025), the Time Horizon strategy strongly outperformed BTC with significantly higher risk-adjusted returns.

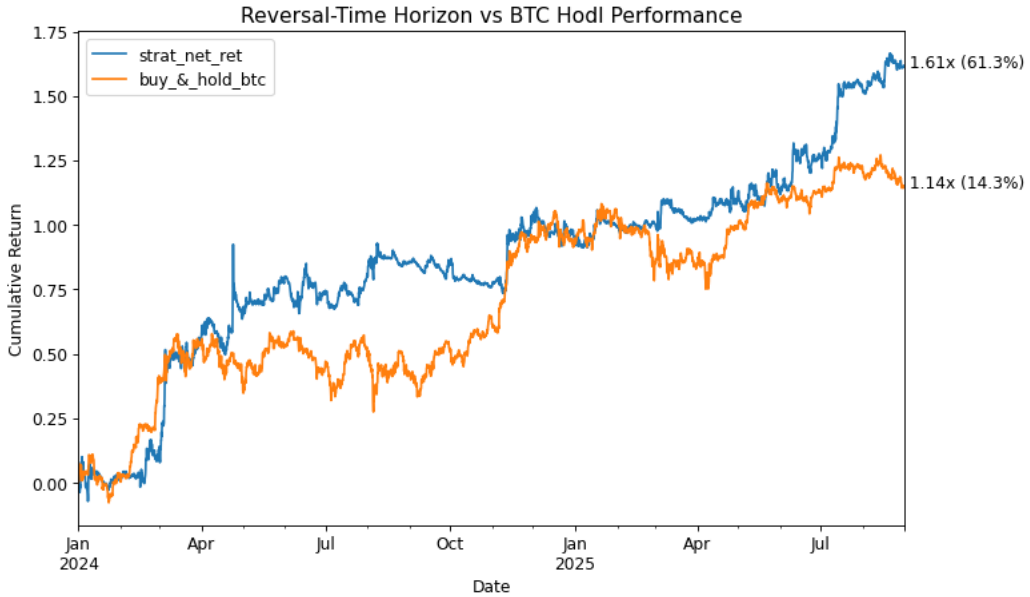

***Figure 4a**: The Time Horizon reversal strategy (blue) achieved 1.61x (61.3%), outperforming BTC at 1.14x (14.3%). Its path was smoother than pairs trading, reflecting tighter mean-reversion filters.*

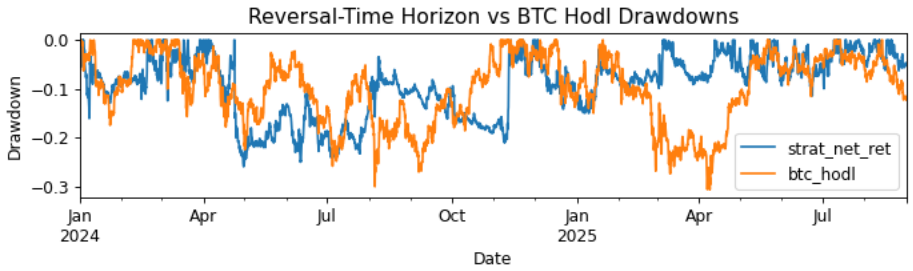

***Figure 4b**: Drawdown paths confirm that this strategy experienced shallower, shorter dips compared to BTC, offering steadier recovery across volatile phases.*

Metric	Strategy (Net)	BTC HODL
Cumulative Return	305.21%	156.00%
Annualized Return	96.65%	68.52%
Annualized Volatility	50.87%	49.35%
Sharpe Ratio	1.90	1.39
Max Drawdown	-25.94%	-30.64%
Max Drawdown Duration	203 days	237 days
Win Rate	46.66%	51.67%
Info Ratio	1.65	-
Annualized Alpha	81.92%	-
Beta vs BTC	0.2149	1.0
Holding Period	20.22 days	N/A

The Time Horizon reversal strategy generated an **annualized return of 96.7%**, clearly outperforming BTC's **68.5%**. This outperformance came with only slightly higher **volatility (50.9% vs 49.4%)**, producing a **Sharpe ratio of 1.90** compared to BTC's 1.39. The strong ratio shows that the strategy delivered superior returns relative to the level of risk taken.

Risk management was another key strength. The strategy's **maximum drawdown** was limited to **–25.9%**, notably better than BTC's –30.6%. In addition, drawdown **recovery time was shorter (203 vs 237 days)**, underscoring the model's resilience during adverse conditions. Although the **win rate** was lower **(46.7%)**, returns were driven by larger reversal trades rather than frequent small gains.

Factor analysis highlights a **mild BTC beta of 0.21** but a substantial **annualized alpha of 81.9%**, confirming that most of the gains came from the reversal mechanism itself. The **average holding period of ~20 days** reflects a longer-term stance compared to other strategies, helping capture extended cycles while keeping turnover manageable. Overall, the Time Horizon reversal approach combines superior downside protection with strong risk-adjusted returns, making it a reliable and steady performer.

5. Combined Strategies

5.1 Momentum Strategies Combo

To evaluate whether combining complementary momentum approaches improves performance, we construct a Momentum Combo Portfolio that blends the Channel Breakout and Moving Average Crossover strategies.

Methodology

We combine the Channel Breakout and Moving Average Crossover strategies using inverse-volatility weighting. At each date t, we compute each sleeve's realized portfolio return volatility over a rolling lookback window L = 30 days:

$$\sigma_t^{(k)} = StdDev\left(port\_ret_{t-L+1:t}^{(k)}\right)$$

Where $port\_ret_t^{(k)}$ is the portfolio return at time t of sleeve k,
And $\sigma_t^{(k)}$ is the rolling standard deviation of portfolio returns in sleeve k.

The allocation weight for sleeve k is normalized inverse of volatility:

$$weight_t^{(k)} = \frac{1/\sigma_t^{(k)}}{\sum_j 1/\sigma_t^{(j)}}$$

The combined portfolio is the weighted sum of the sleeves:

$$port_t^{combo} = \sum_{k \in \{MA, Breakout\}} weight_t^{(k)} * port_t^{(k)}$$

followed by normalization to enforce unit gross exposure:

$$port_t^{combo} = \frac{port_t^{combo}}{\sum_i |port_{i,t}^{combo}|}$$

This ensures overlapping exposures are netted out and the final portfolio is fully invested. Transaction costs (20 bps per turnover) are applied to the combined book.

Results and Interpretation

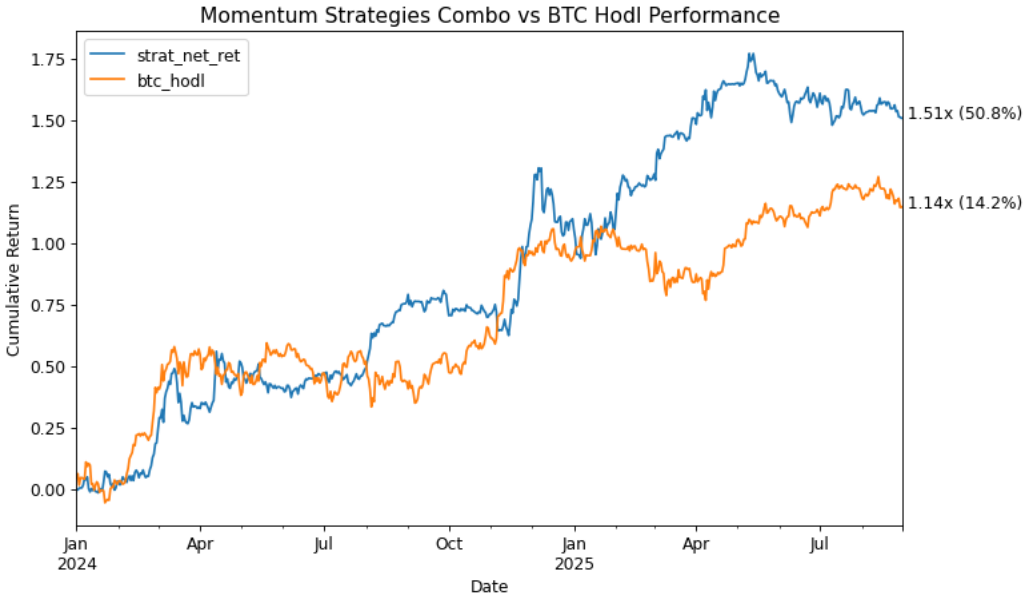

***Figure 5a**: The Momentum Combo (blue) reached 1.51x (50.8%), outpacing BTC at 1.14x (14.2%). By blending crossover and breakout signals, the combo achieved more balanced performance than either alone.*

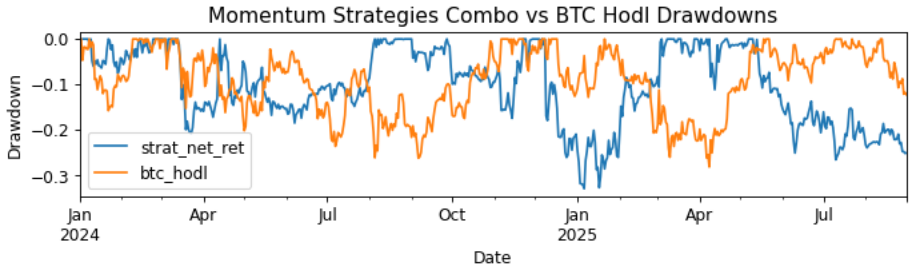

***Figure 5b**: Drawdowns were deeper at times than BTC, but recovery was quicker, showing diversification across momentum styles reduced stagnation.*

Metric	Strategy (Net)	BTC HODL
Cumulative Return	261.08%	156.00%
Annualized Return	90.36%	68.47%
Annualized Volatility	51.62%	49.41%
Sharpe Ratio	1.75	1.39
Max Drawdown	-32.87%	-28.10%
Max Drawdown Duration	113 days	237 days
Win Rate	53.87%	51.72%
Info Ratio	2.05	-
Annualized Alpha	103.96%	-
Beta vs BTC	-0.1986	1.0
Holding Period	6.87 days	N/A

The Momentum Combo strategy, which blends crossover and breakout signals, produced a 261% cumulative return and an **annualized return of 90.4%**, comfortably outperforming BTC's **68.5%**. With **volatility at 51.6% versus BTC's 49.4%**, the strategy maintained a **Sharpe ratio of 1.75**, significantly better than BTC's 1.39. These results show that diversifying momentum approaches improved the balance between return and risk.

Drawdown analysis reveals some trade-offs. The strategy's maximum drawdown reached **32.9%**, slightly worse than BTC's –28.1%. However, the **recovery time** was much shorter **(113 vs 237 days)**, showing the system's ability to bounce back quickly after losses. The **win rate of nearly 54%** also exceeded BTC's, suggesting that gains were both more frequent and better sustained.

Factor analysis highlights a **negative beta of –0.20**, indicating that performance was largely independent of BTC and occasionally moved in the opposite direction, providing diversification benefits. The strategy's **annualized alpha of 104%** and **information ratio of 2.05** confirm its efficiency in generating excess returns beyond the benchmark. With a short **holding period of ~7 days**, the combo is positioned as a fast-moving, tactical approach that captures medium-term momentum bursts without staying stuck in unproductive trades.

5.2 Momentum–Reversal Combo

We next investigate whether combining momentum and reversal approaches yields a more balanced portfolio. For this test, we exclude the high-frequency Time Horizon Reversal strategy to maintain consistency in frequency (daily), and blend:

- Channel Breakout (Momentum)
- Moving Average Crossover (Momentum)
- Pairs Trading (Reversal)

Methodology

We combine Channel Breakout, MA Crossover, and Pairs Trading using the same inverse-volatility weighting scheme:

$$port_t^{mom+rev} = \sum_{k \in \{MA, Breakout, Pairs\}} weight_t^{(k)} * port_t^{(k)}$$

Where $weight_t^{(k)}$ are computed as done previously in momentum strategies combo. This ensures sleeves contribute proportionally to risk, not capital.

Results and Interpretation

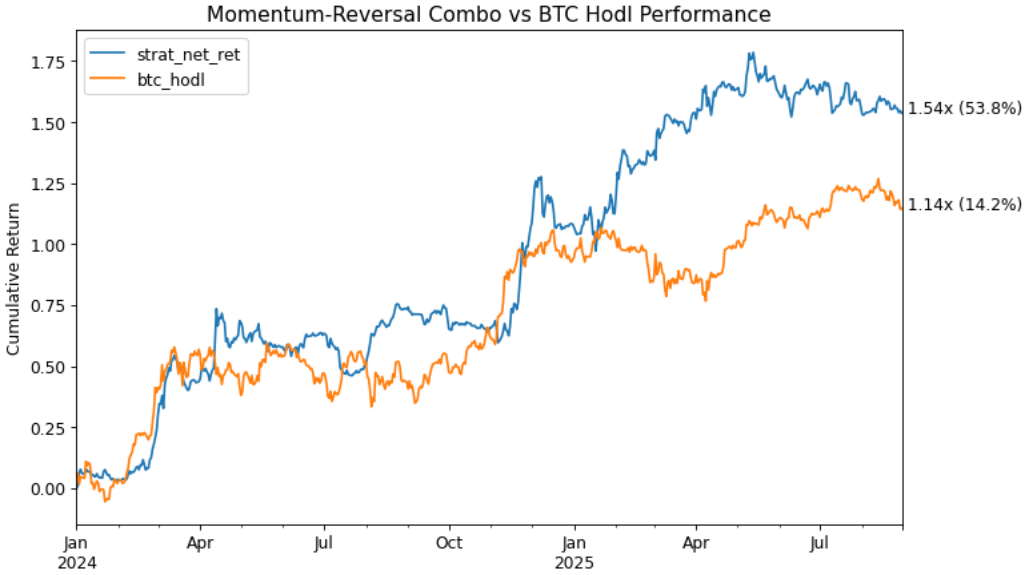

***Figure 6a**: The Momentum–Reversal Combo strategy (blue) compounded to 1.54x (53.8%), ahead of BTC's 1.14x (14.2%). The hybrid captured both medium-term trends and mean-reversion, producing stable performance.*

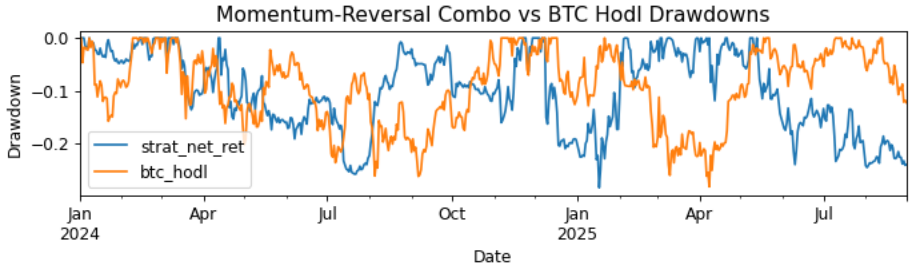

***Figure 6b**: Drawdowns were similar in depth to BTC, but the strategy rebounded faster, highlighting the complementarity of momentum and reversal signals.*

Metric	Strategy (Net)	BTC HODL
Cumulative Return	278.47%	156.00%
Annualized Return	92.17%	68.47%
Annualized Volatility	49.79%	49.41%
Sharpe Ratio	1.85	1.39
Max Drawdown	-28.29%	-28.10%
Max Drawdown Duration	222 days	237 days
Win Rate	52.06%	51.72%
Info Ratio	2.11	-
Annualized Alpha	103.59%	-
Beta vs BTC	-0.1668	1.0
Holding Period	7.34 days	N/A

The Momentum–Reversal Combo strategy achieved an **annualized return of 92.2%**, handily beating BTC's 68.5%. Importantly, this was done with nearly identical **volatility (49.8% vs 49.4%)**, leading to a strong **Sharpe ratio of 1.85** compared to BTC's 1.39. This balance shows that blending trend-following and mean-reversion provided both higher returns and improved efficiency.
In terms of risk, the strategy's **maximum drawdown of –28.3%** was almost the same as BTC's –28.1%. However, the **drawdown duration** was shorter **(222 vs 237 days)**, meaning the strategy recovered more quickly after losses. The **win rate of 52%** was only slightly higher than BTC's, indicating that performance was driven more by the quality of signals than by frequency of wins.

Factor analysis highlights a **negative beta of –0.17**, suggesting that the strategy often moved independently of BTC and sometimes in the opposite direction, adding diversification. The **annualized alpha of 104%** and **information ratio of 2.11** confirm that most of the excess performance came from the combo logic itself rather than market exposure. With an **average holding period of ~7 days**, the strategy maintained flexibility, rotating capital frequently enough to capture both trending and reversal opportunities.

6. Comparative Analysis

The six strategies span the spectrum from **pure momentum** (Channel Breakout, MA Crossover) to **pure reversal** (Pairs Trading, Time Horizon Reversal), to **multi-sleeve blends** (Momentum Combo, Momentum–Reversal Combo). Each offers distinct advantages and weaknesses, and together they demonstrate the value of diversification in a systematic framework.

6.1 Performance Overview

Strategy	Ann. Return	Ann. Volatility	Sharpe (SR)	Max DD	Info. (IR)	Ann. Alpha	Beta vs BTC
Momentum – MA Crossover	73.21%	46.65%	1.57	-36.00%	1.73	80.06%	-0.1000
Momentum – Channel Breakout	111.54%	77.98%	1.43	-44.07%	1.71	131.00%	-0.2842
Reversal – Pairs Trading	146.52%	69.81%	2.10	-37.82%	1.92	132.80%	0.2002
Reversal – Time Horizon (4h)	96.65%	50.87%	1.90	-25.94%	1.65	81.92%	0.2149
Momentum Strategies Combo	90.36%	51.62%	1.75	-32.87%	2.05	103.96%	-0.1986
Momentum-Reversal Combo	92.17%	49.79%	1.85	-28.29%	2.11	103.59%	-0.1668
BTC Buy & Hold (Benchmark)	68.47%	49.41%	1.39	-28.10%	-	-	1.0

6.2 Individual Strategies

1. **Momentum Strategies**
   - **Channel Breakout** delivered the highest raw return (111% annually) and the strongest alpha (131%). Its negative beta (−0.28) indicates some hedging benefit when BTC declines. However, this came with high volatility (78%) and the deepest drawdowns among all strategies (−44%), reflecting its aggressive nature.

   - **MA Crossover** provided steadier performance with lower volatility (46.7%) and a near-zero beta (−0.10). While its annualized return (73%) was smaller than Breakout, its smoother equity curve and faster recovery from drawdowns make it a valuable sleeve in range-bound or choppy markets.

2. **Reversal Strategies**
   - **Pairs Trading** was the strongest overall performer, achieving the highest annualized return (146%) and Sharpe ratio (2.10). With a mild positive beta (0.20), it maintained some correlation to BTC, but an exceptionally high alpha (133%) showed that most of its gains came from exploiting mean-reversion opportunities. Drawdowns (−38%) were steeper than BTC, but recovery was much faster.

   - **Time Horizon Reversal** delivered a balanced profile, with an annualized return of 96.7% and a Sharpe ratio of 1.90. It achieved the lowest maximum drawdown (−25.9%) among all strategies and recovered faster than BTC, underscoring its defensive strength. Combined with a solid annualized alpha of 82%, the strategy stands out as a dependable reversal approach that captures mean-reversion opportunities while maintaining strong downside protection.

6.3 Combined Strategies

1. **Momentum Combo** (Breakout + MA, inverse-vol weighting)
   - By blending two complementary momentum approaches, the strategy improved efficiency: Sharpe increased to **1.75** while drawdowns were contained (**−33%**) and recovery shortened (113 days). Annualized alpha remained strong (**104%**), and the negative beta (−0.20) preserved some diversification benefit

   - This confirms that diversification across momentum signals materially enhances stability without sacrificing returns.

2. **Momentum–Reversal Combo** (Breakout + MA + Pairs, inverse-vol weighting)
   - This three-sleeve portfolio achieved the **highest information ratio (2.11)** and a strong Sharpe ratio (**1.85**), with volatility held near 50% and drawdowns limited to −28%.

- Although its alpha (**104%**) was slightly below Pairs alone, the near-zero beta (−0.17) and consistent outperformance highlight its ability to remain neutral to BTC while delivering steady excess returns.

- This highlights the benefit of combining orthogonal styles: momentum captures trends, while reversal hedges noise and short-term dislocations.

6.3 Key Takeaways

- **Momentum dominates in trending markets**: Breakout and Crossover sleeves excel when crypto prices move directionally.

- **Reversal thrives in mean-reverting regimes**: Pairs and Time Horizon strategies exploit temporary inefficiencies, providing diversification and downside protection.

- **Combining sleeves enhances efficiency**: Both combos outperform their constituents in Information ratio, with the Momentum–Reversal Combo offering the most balanced, institutional-quality risk/return profile.

- **All strategies outperform BTC buy-and-hold**: Sharpe ratios consistently range from **1.43 to 2.10**, versus BTC's 1.39, while drawdowns are generally shorter in duration.

7. Conclusion

This project set out to evaluate whether systematic momentum and reversal strategies can outperform a passive Bitcoin buy-and-hold benchmark in cryptocurrency markets. Using Binance OHLCV data from 2021–2025, six strategies were implemented: two momentum-based (Channel Breakout, MA Crossover), two reversal-based (Pairs Trading, Time Horizon), and two diversified momentum portfolios constructed with inverse-volatility weighting.

The results were consistent across tests: all strategies outperformed BTC buy-and-hold on a risk-adjusted basis. Sharpe ratios ranged from 1.43 to 2.10, compared to BTC's 1.39, while drawdown durations were generally shorter, underscoring faster recoveries. Momentum strategies excelled during trending markets, reversal strategies thrived in mean-reverting phases, and diversified momentum blends provided the most balanced outcomes.

Among individual approaches, **Pairs Trading reversal** produced the highest annualized return (**146.5%**) and Sharpe ratio (**2.10**), confirming the strength of cross-asset mean reversion. **Time Horizon Reversal** offered the lowest maximum drawdown (**−25.9%**) and strong adaptability, making it the most defensive strategy. On the momentum side, **Channel Breakout** generated the highest alpha (**131%**) but with the steepest drawdowns (**−44%**), while **MA Crossover** delivered steadier performance and faster drawdown recovery, proving useful in sideways regimes.

The diversified portfolios reinforced the benefits of combining momentum styles. The **Momentum Combo** achieved a strong Sharpe ratio (**1.75**) and shortened recovery times, while the **Momentum–Reversal Combo** delivered the highest **information ratio (2.11)** and near-zero beta to BTC, confirming its consistency and independence from market direction.

In summary, this research confirms that systematic statistical arbitrage frameworks can materially enhance returns and reduce risk relative to passive BTC exposure. Momentum strategies harness directional persistence, reversal strategies exploit short-term inefficiencies, and their thoughtful combination produces institutional-quality risk/return profiles, marked by stability, diversification, and resilience across regimes.