Using a Simulator to Develop Execution Algorithms

Robert Almgren

quantitativebrokers

University of Edmonton
July 7, 2016

Outline

1. Rates trading is becoming electronic
   futures first, then cash
2. Business of algo execution
   new in futures and fixed income
3. How to get good results
   understanding of market microstructure
4. How do we improve toward that result?
   use a market simulator
5. How do we build and use a simulator?

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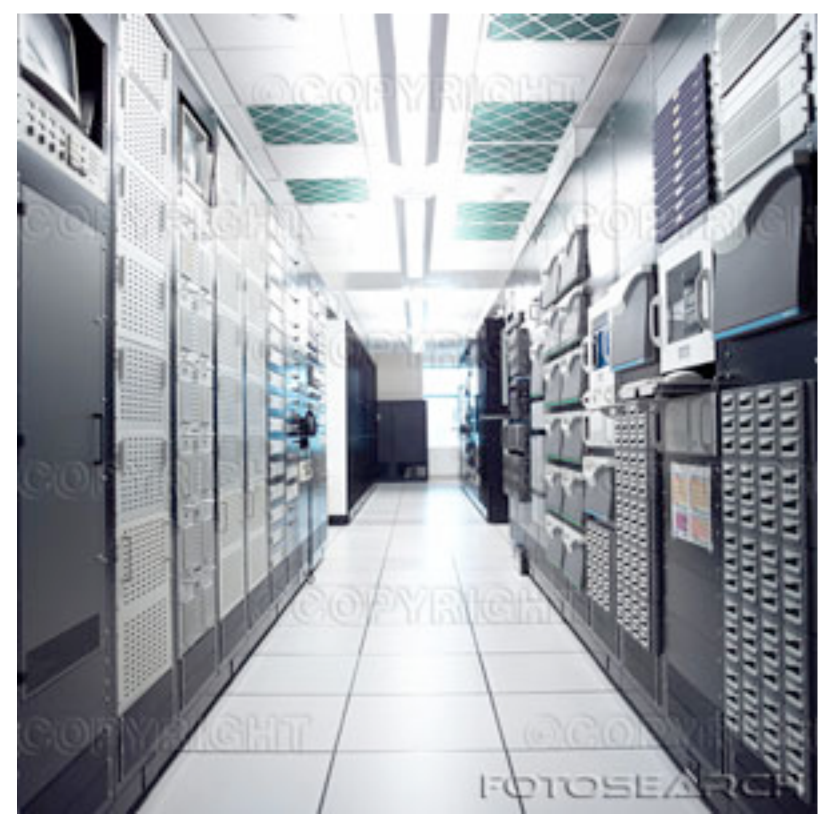
Pit trading → electronic

Pit		Electronic
position traders	⟶	HFT & Market Makers
floor brokers	⟶	algorithmic brokers (QB)



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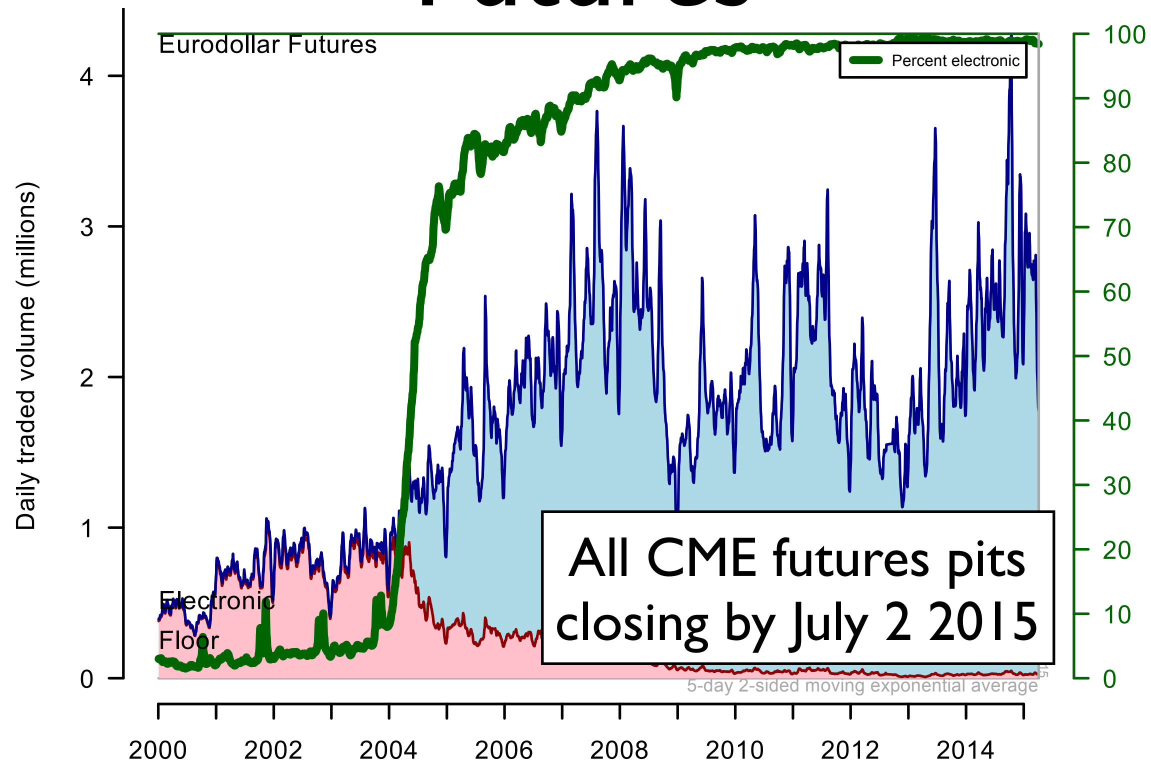
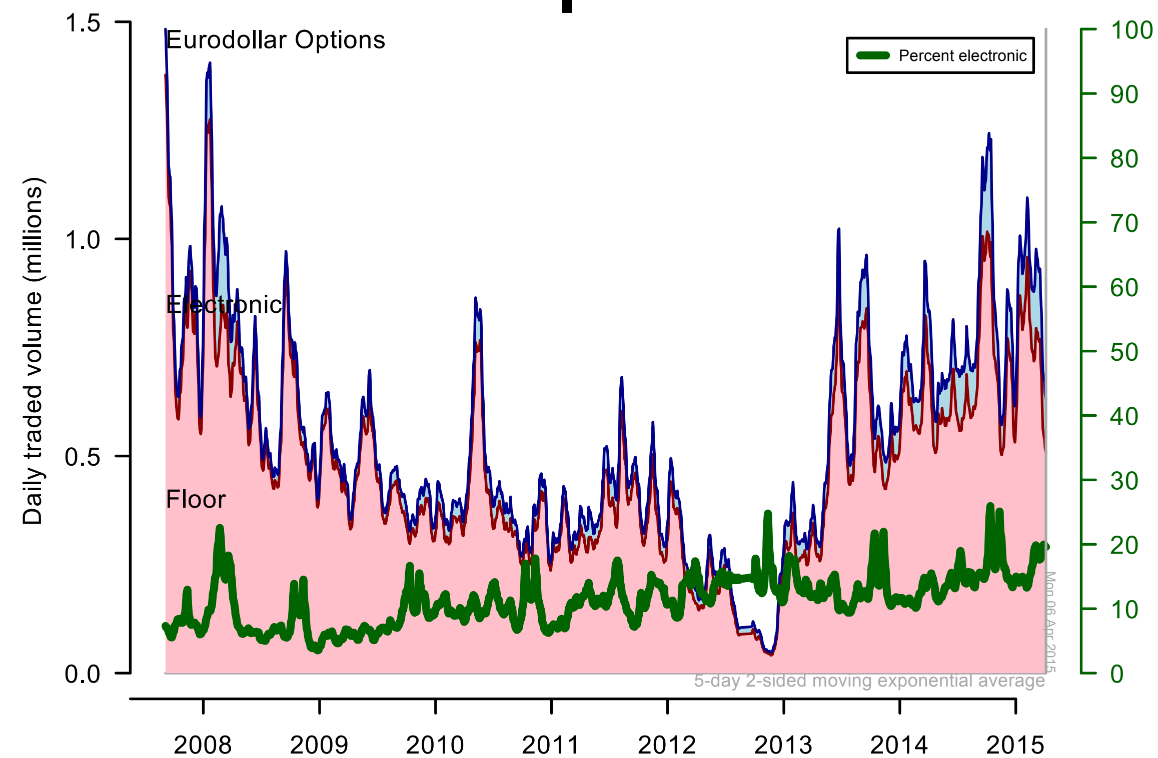
CME rates futures shift to electronic

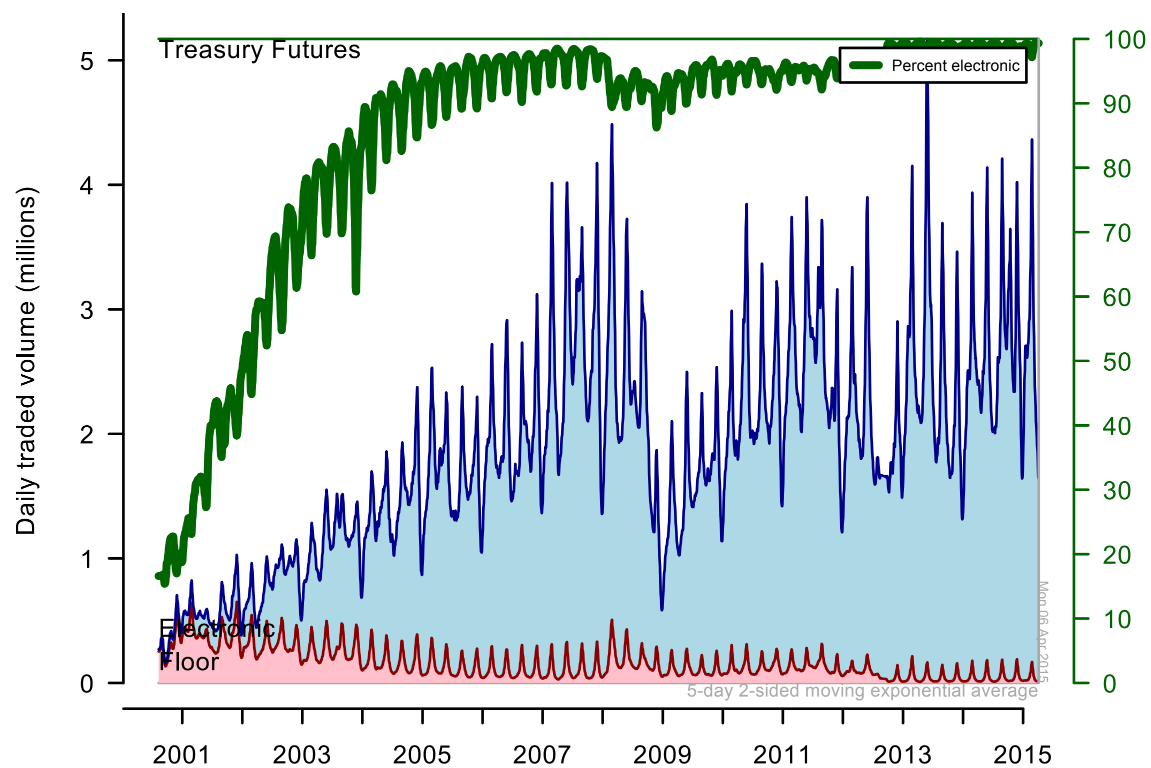
Futures | Options

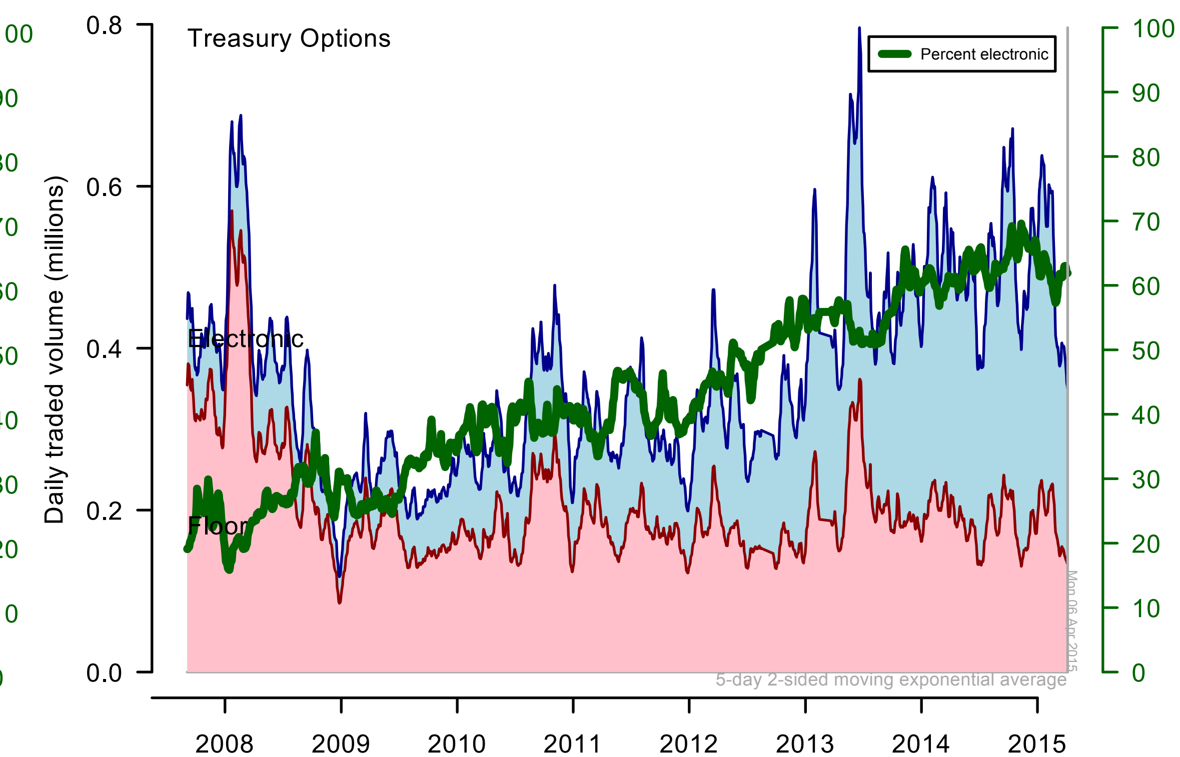
Eurodollar





Treasury





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Produced by QB from CME data

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- Algorithmic execution and cost measurement
  - No prop trading or market making
- Interest rate products, starting with futures
  - Equities, FX already well served
  - Futures on CME, Eurex, LIFFE, Montréal, ICE
  - cash Treasuries live May 2015
  - basis trading futures vs cash
- Good execution depends on microstructure expertise

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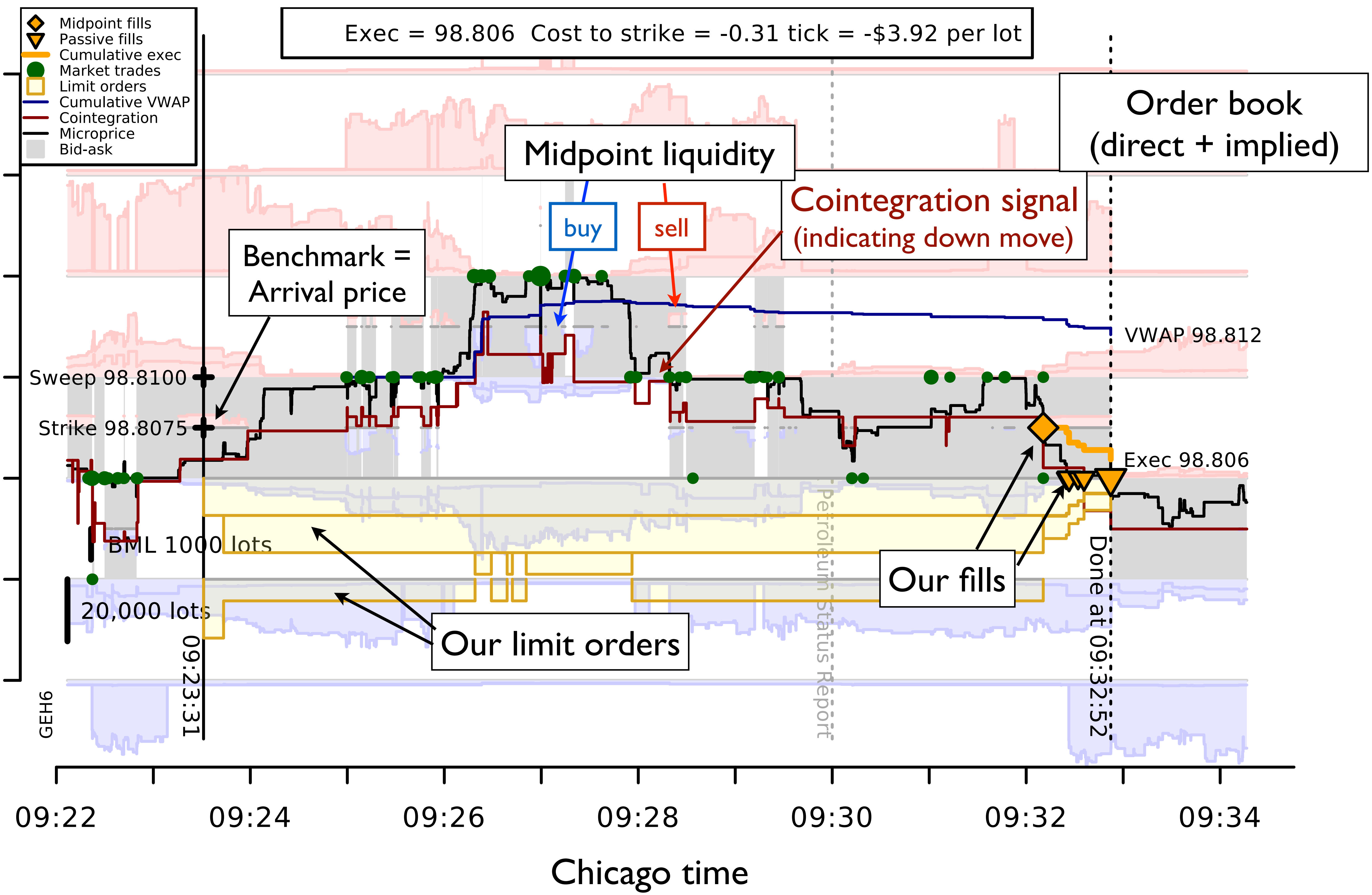
BUY 129 GEH6 BOLT



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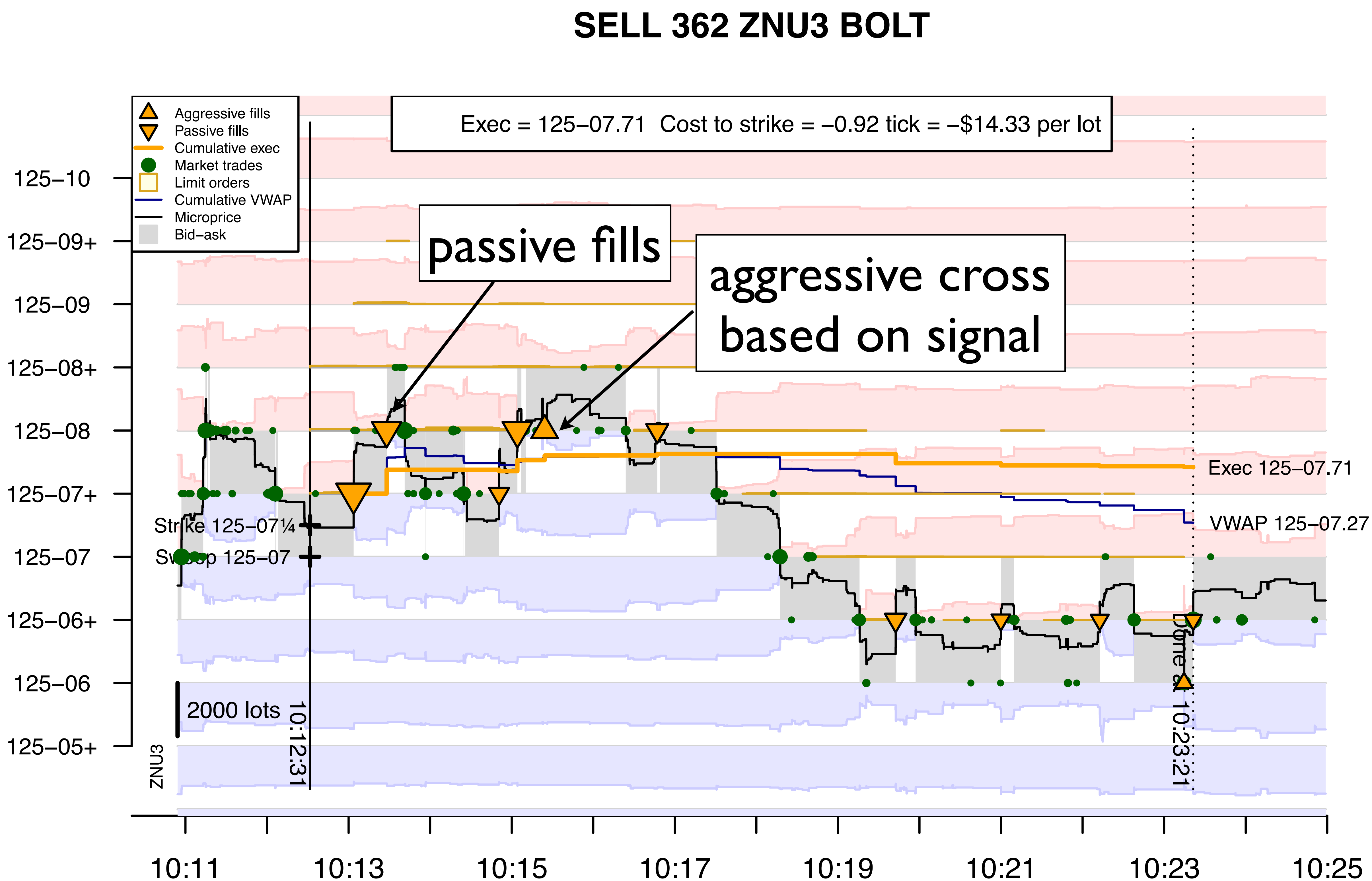

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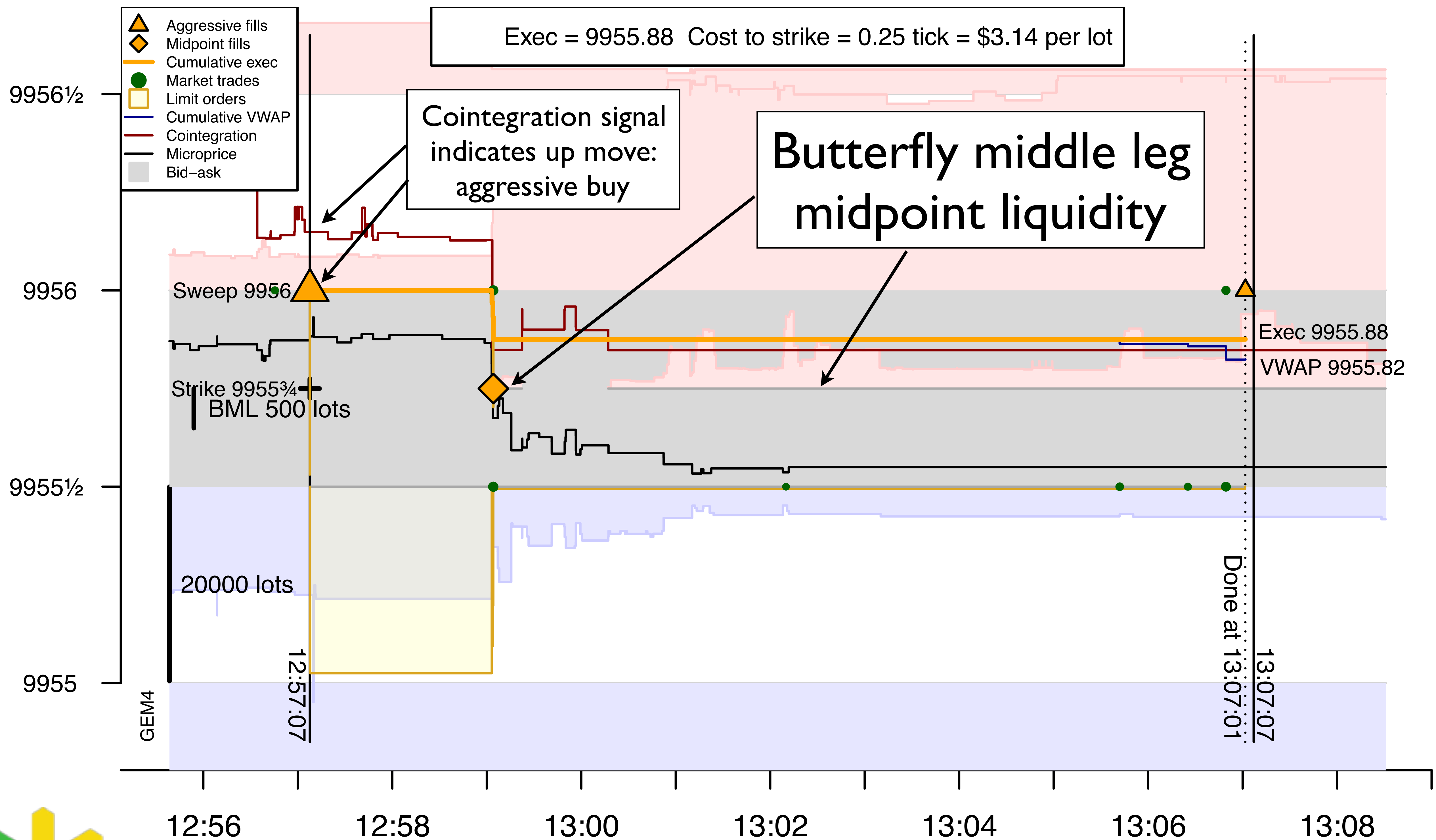
BUY 165 GEM4 BOLT



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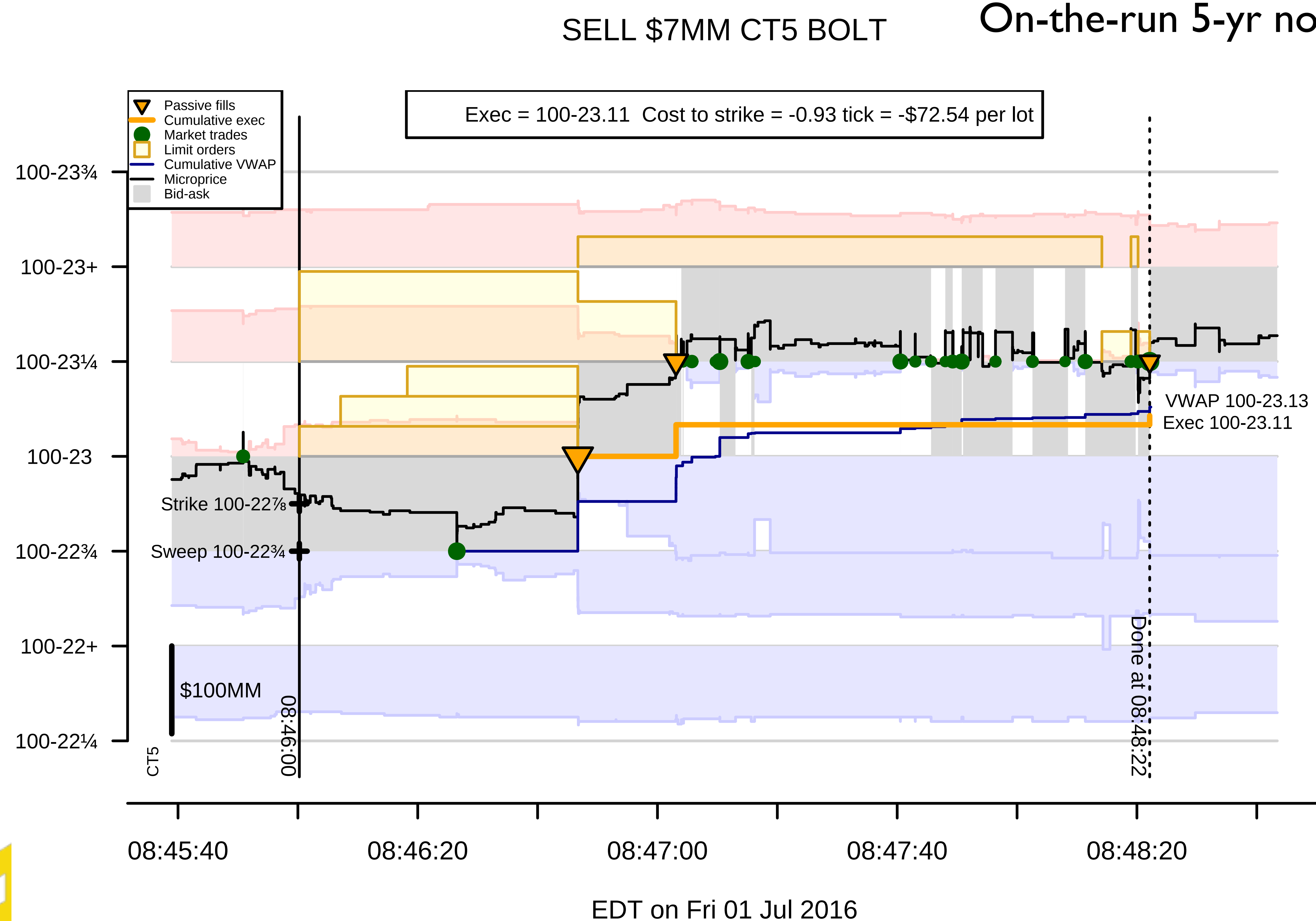
Produced by QB from CME and internal data

Example bond execution

On-the-run 5-yr note



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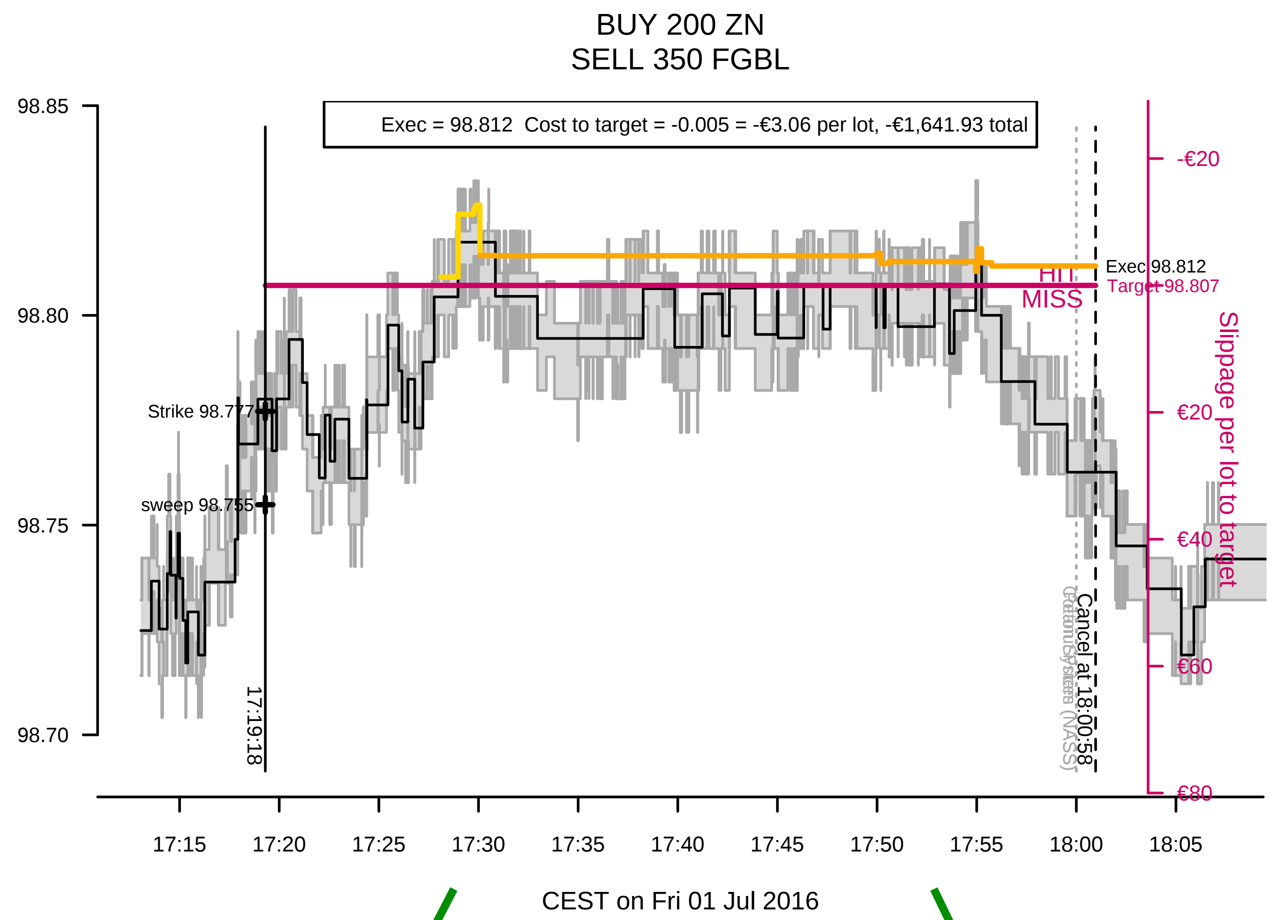
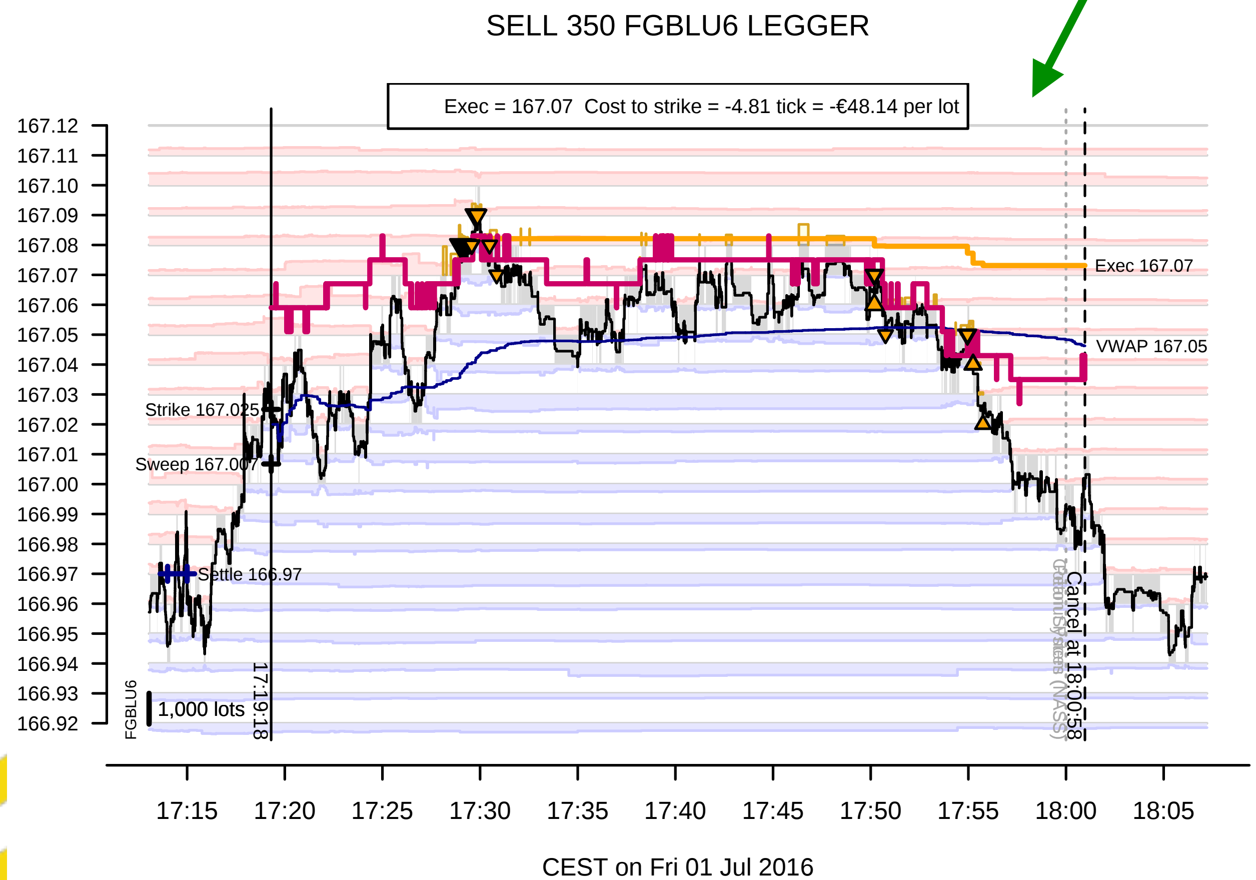
Produced by QB from internal and external data

Multi-asset

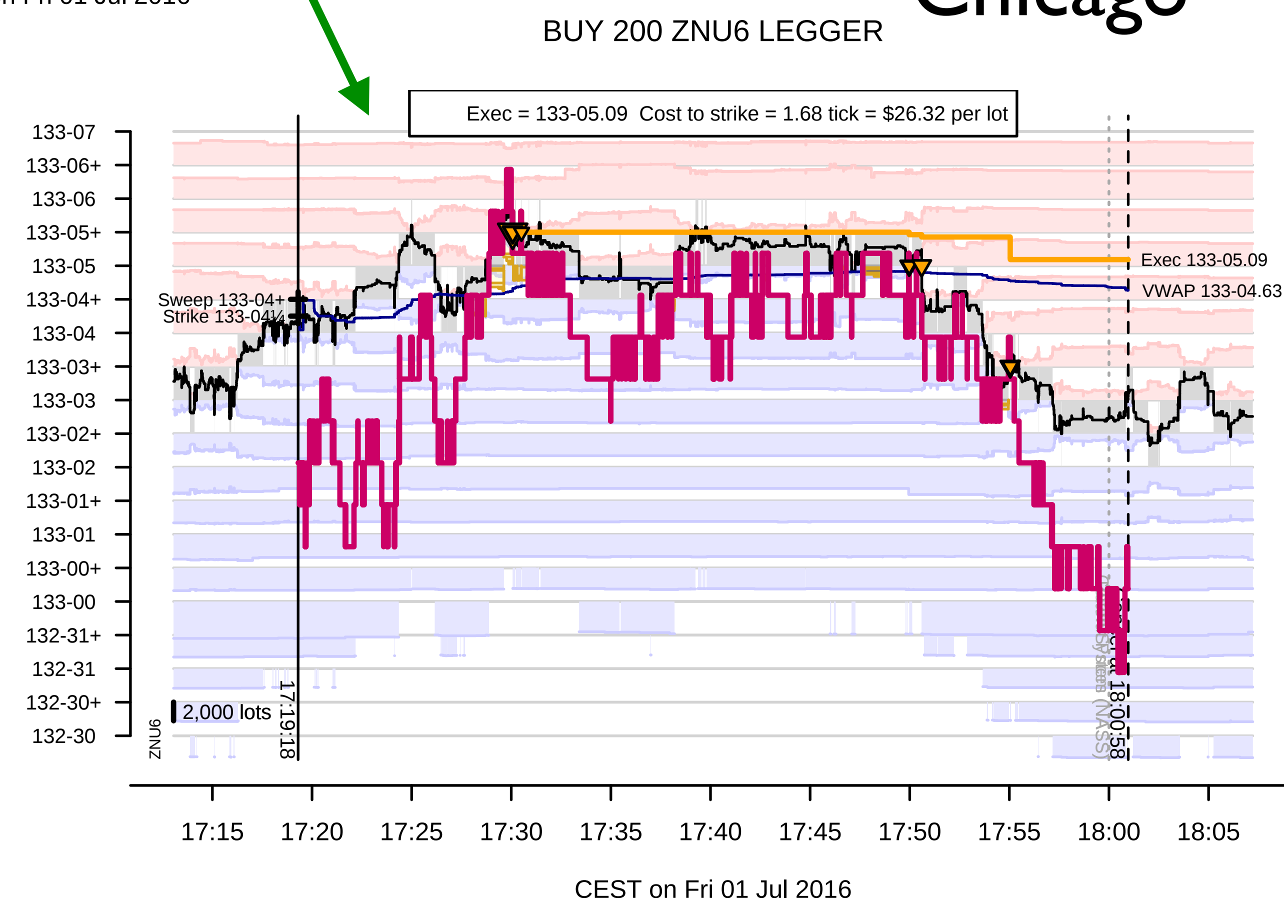
Buy spread in this region



Frankfurt



Chicago



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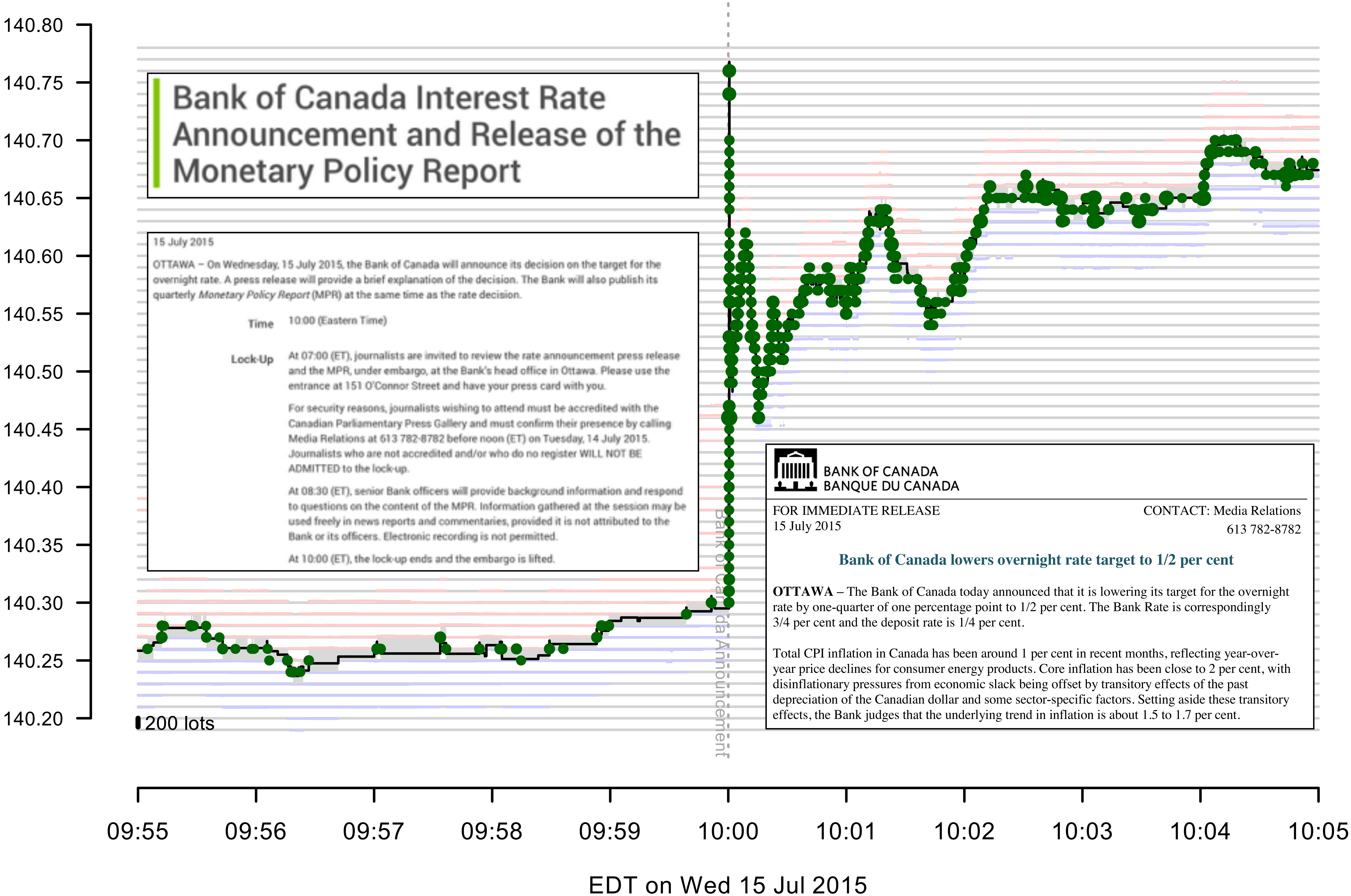
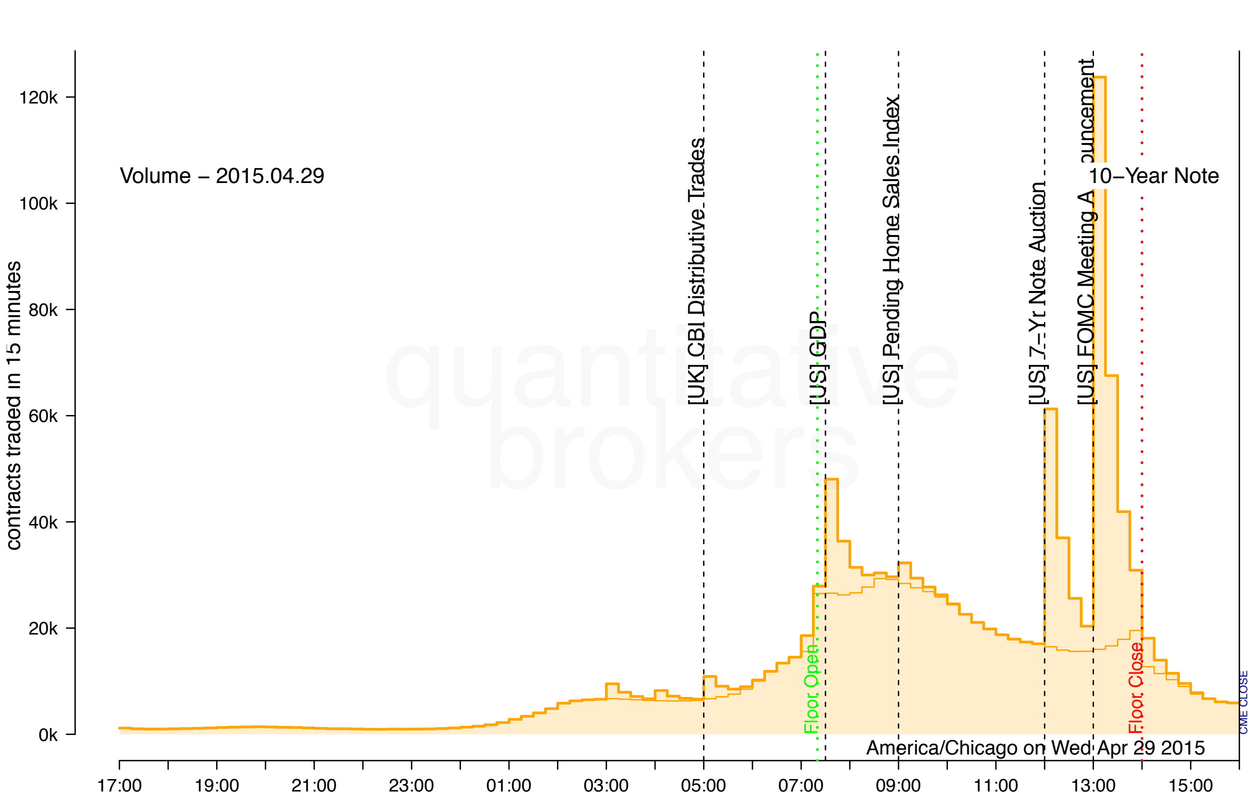
Differences between rates futures and equities

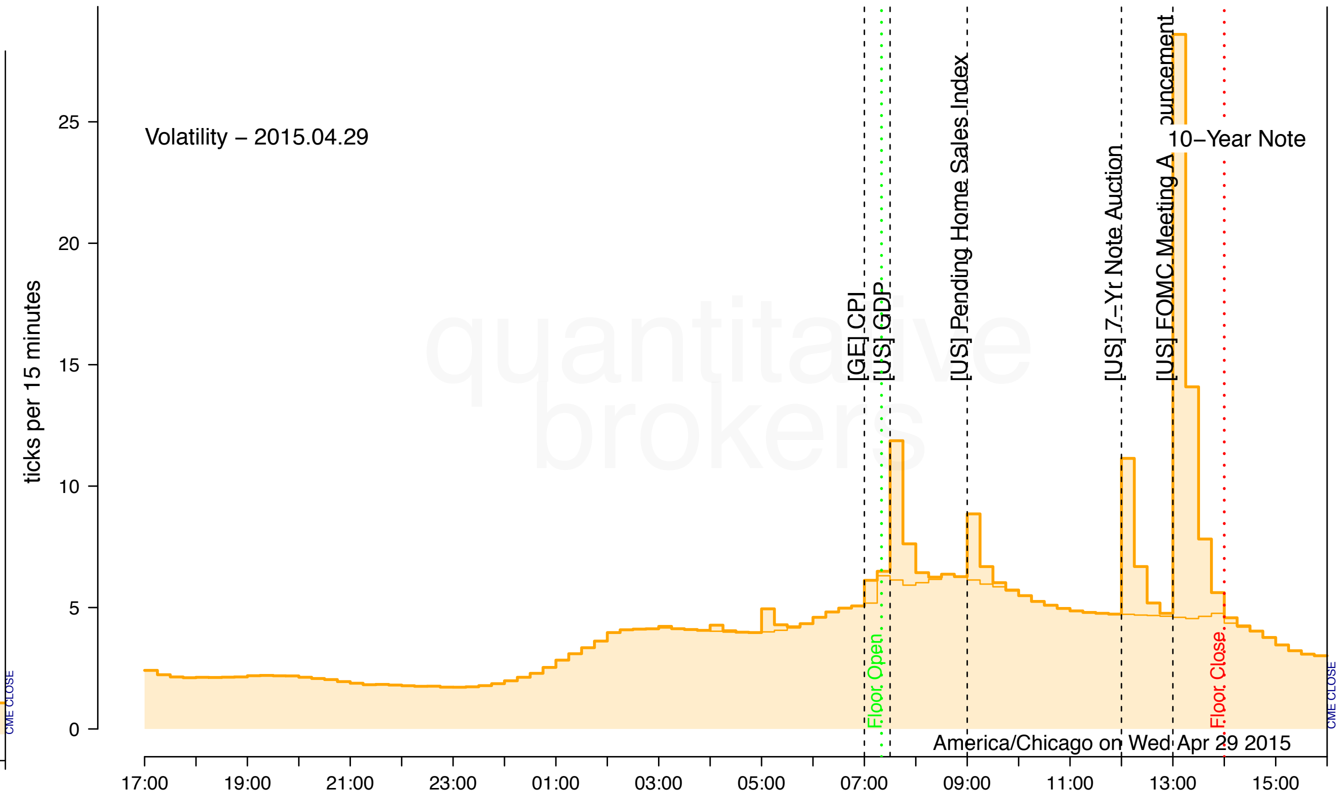
- No market fragmentation (futures)
    - simple routing, good market data
- Trading rules more complicated
    - match algorithms
    - implied quoting
- Large tick size (bid-ask spread)
- High degree of interrelation
    - cointegration
    - multidimensional algorithms
        - basis trading, substitutions, etc
- Round the clock trading
    - Information events

CGBU5: 10-year Canadian note futures



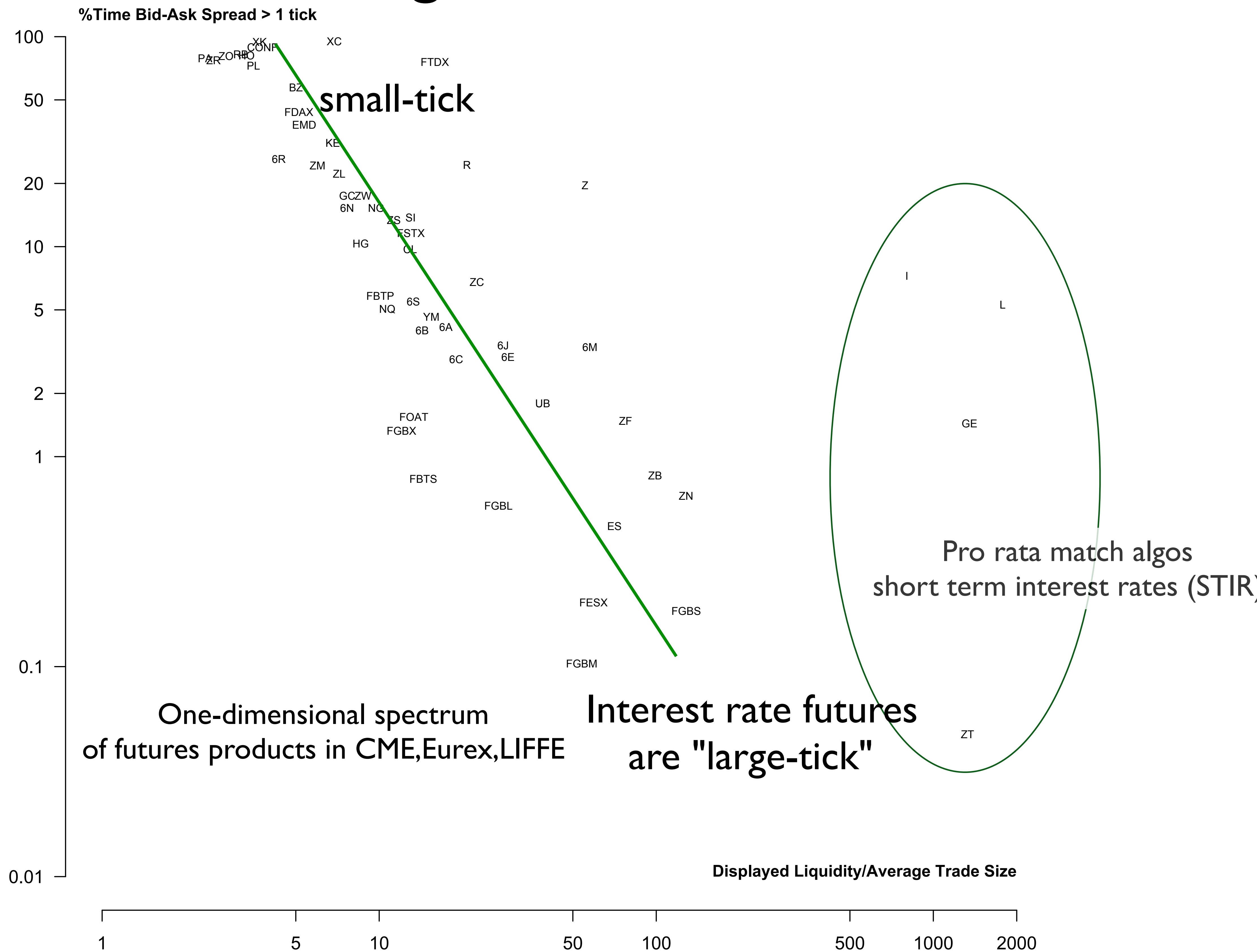
Intraday forecast curves





time	date	NYtime	UKtime	GEtime	src	region	event
2015.04.29T06:00:00.000	2015.04.29	02:00	07:00	08:00	econ	UK	Nationwide HPI
2015.04.29T08:00:00.000	2015.04.29	04:00	09:00	10:00	econ	EC	M3 Money Supply
2015.04.29T09:00:00.000	2015.04.29	05:00	10:00	11:00	econ	EC	EC Economic Sentiment
2015.04.29T09:30:00.000	2015.04.29	05:30	10:30	11:30	auct	GE	Bobl
2015.04.29T10:00:00.000	2015.04.29	06:00	11:00	12:00	econ	UK	CBI Distributive Trades
2015.04.29T11:00:00.000	2015.04.29	07:00	12:00	13:00	econ	US	MBA Mortgage Applications
2015.04.29T12:00:00.000	2015.04.29	08:00	13:00	14:00	econ	GE	CPI
2015.04.29T12:30:00.000	2015.04.29	08:30	13:30	14:30	econ	US	GDP
2015.04.29T14:00:00.000	2015.04.29	10:00	15:00	16:00	econ	US	Pending Home Sales Index
2015.04.29T14:30:00.000	2015.04.29	10:30	15:30	16:30	energy	US	EIA Petroleum Status Report
2015.04.29T17:00:00.000	2015.04.29	13:00	18:00	19:00	auct	US	7-Yr Note Auction
2015.04.29T18:00:00.000	2015.04.29	14:00	19:00	20:00	econ	US	FOMC Meeting Announcement

Large tick markets



Slippage measurement

Live or die by transaction costs
Look at main determinants of good slippage

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BEST EXECUTION FOR FIXED INCOME AND FUTURES

February 12, 2016

Algorithm Performance Comparison

April 2013 through Feb 2016

	28,512 orders 60.5 lots avg 1,724,316 lots	27,249 orders 58.4 lots avg 1,591,694 lots	$/lot

Market	Bid/Ask	Bulge Bracket Banks AP	Bulge Bracket Banks I-VWAP	Quantitative Brokers AP	Quantitative Brokers I-VWAP	QB Improvement AP	QB Improvement I-VWAP
US 5-yr Note	7.81	3.14	2.22	1.53	−0.76	−1.61	−2.98
US 10-yr Note	15.63	6.84	4.81	2.44	−0.94	−4.40	−5.75
US 30-yr Bond	31.25	13.6	9.16	4.18	−1.59	−9.42	−10.75
Eurex Bobl	11.39	3.65	1.61	2.05	−0.59	−1.60	−2.20
Eurex Bund	11.39	5.89	1.51	4.2	−1.17	−1.69	−2.68
LIFFE Long Gilt	14.1	6.69	1.46	6.25	−2.14	−0.44	−3.60
E-mini S&P	12.5	5.8	3.54	3.56	−1.49	−2.24	−5.03
E-mini NASDAQ	5	4.2	1.45	2.82	−1.11	−1.38	−2.56
NYMEX Heating Oil	4.2	13.95	4.12	9.66	−2.49	−4.29	−6.61
NYMEX Crude Oil	10	13.7	2.55	9.32	−3.52	−4.38	−6.07
NYMEX Nat. Gas	10	12.76	3.15	10.64	−3.44	−2.12	−6.59
Weighted Average:		6.94	3.17	4.06	−1.44	−2.88	−4.61

$9.5MM in 34 months: 77 bp annual improvement in return

http://quantitativebrokers.com/wp-content/uploads/2016/05/QB-Algorithmic-Performance-2016.pdf

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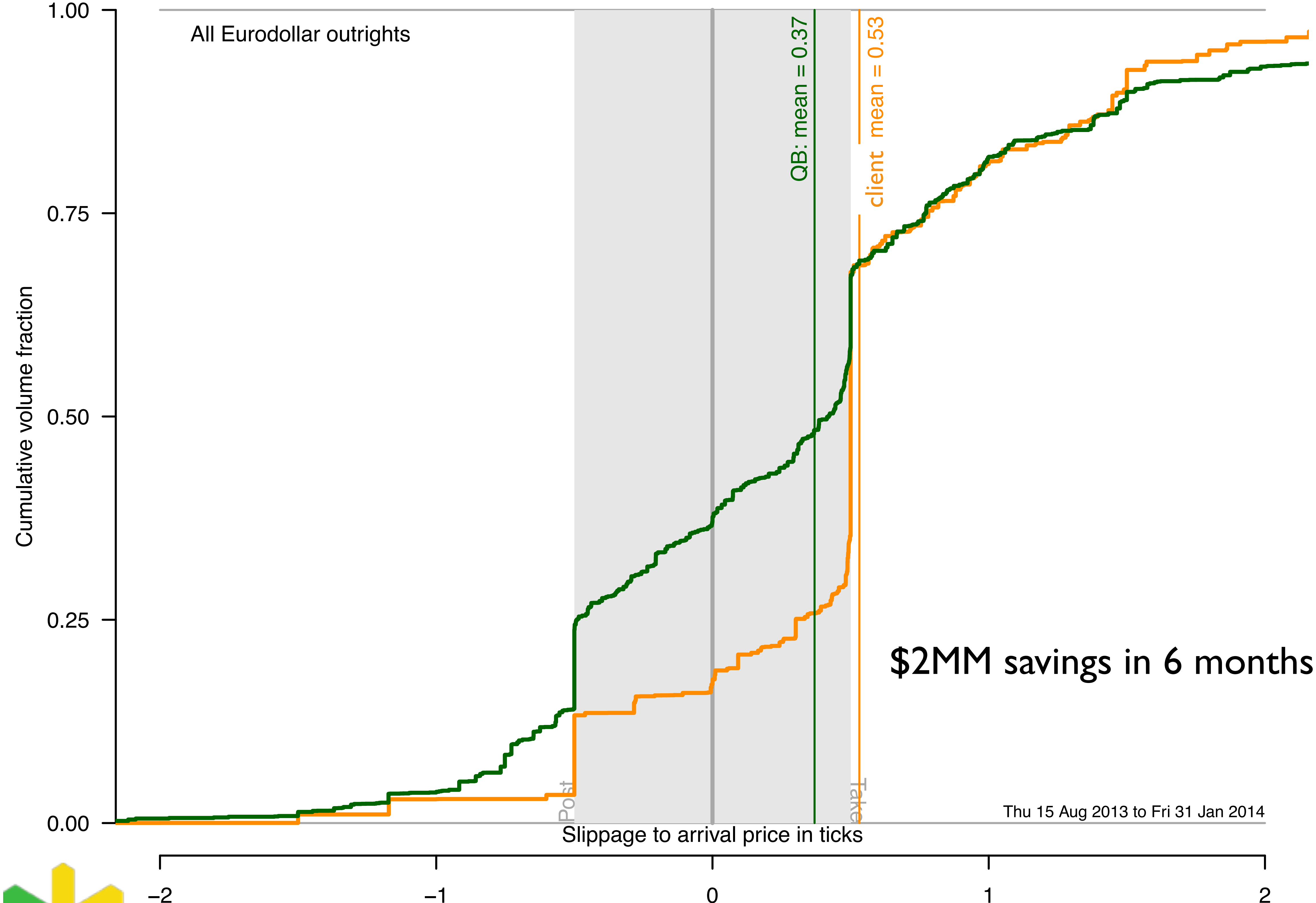
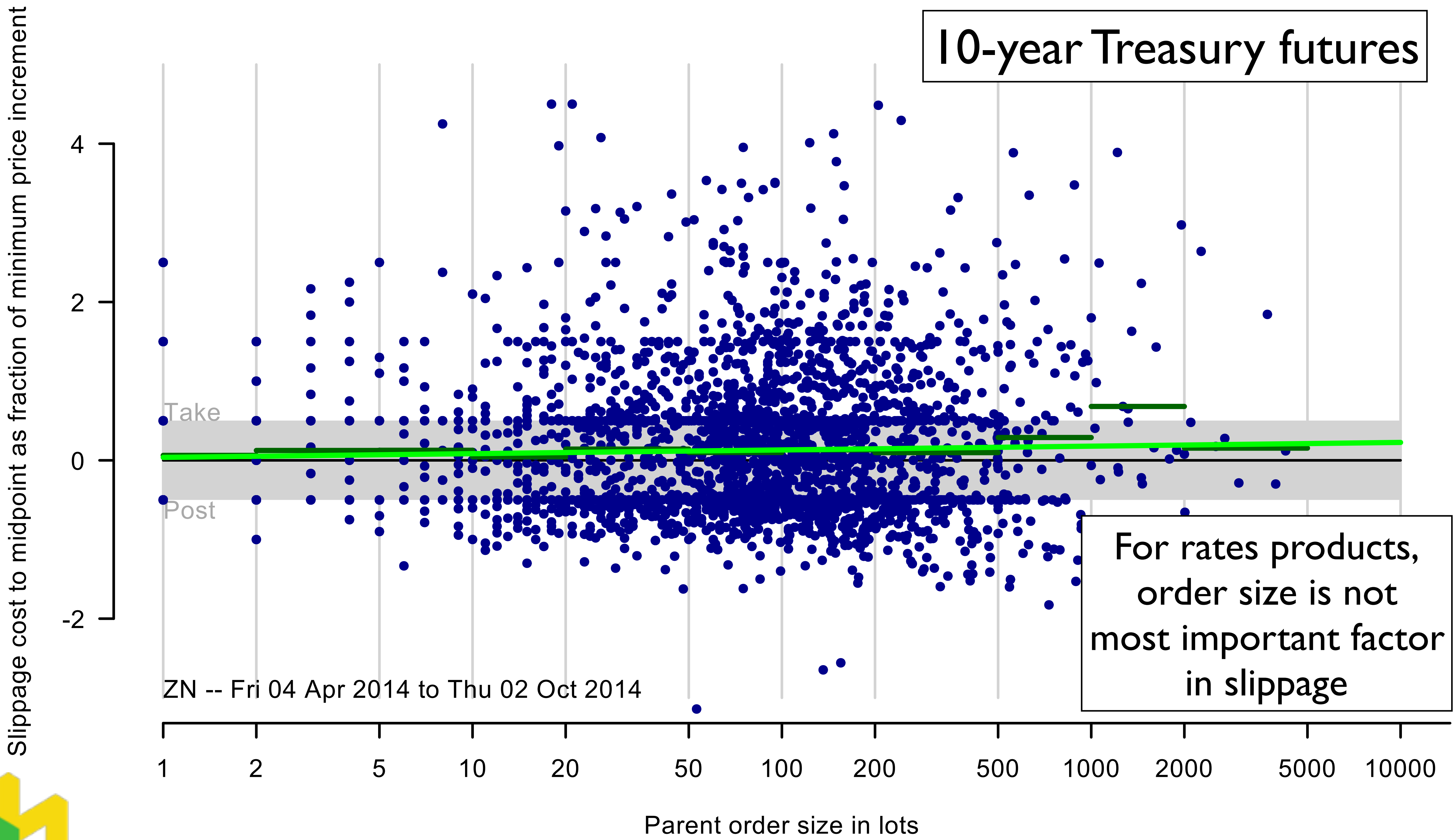

All Eurodollar outrights
Cumulative volume fraction
1.00
0.75
0.50
0.25
0.00
QB: mean = 0.37
client mean = 0.53
Post
Take
$2MM savings in 6 months
Thu 15 Aug 2013 to Fri 31 Jan 2014
Slippage to arrival price in ticks
−2
−1
0
1
2

Size is not most important variable for rates



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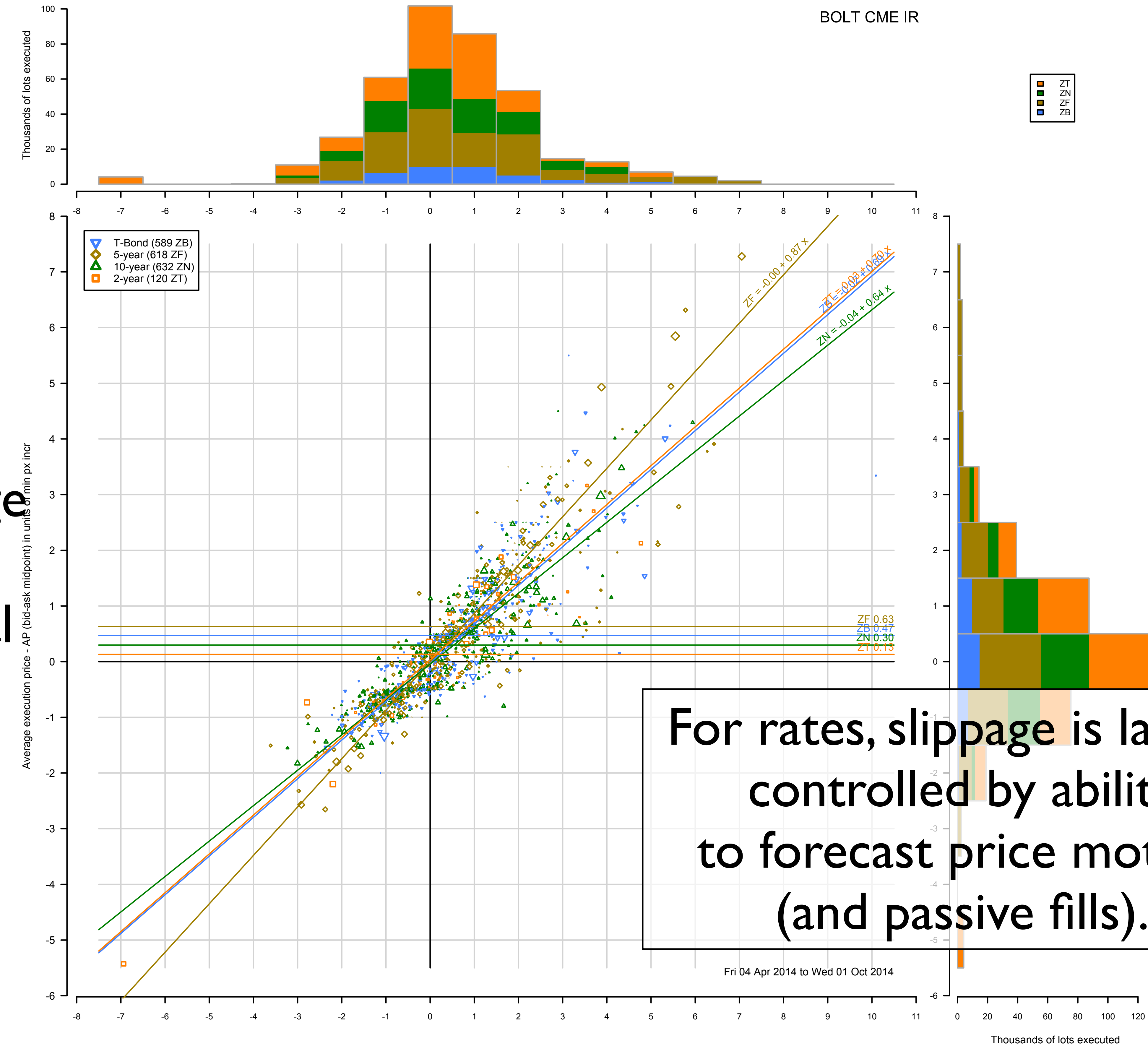
Slippage to Arrival Price



For rates, slippage is largely controlled by ability to forecast price motion (and passive fills).

Price change during execution

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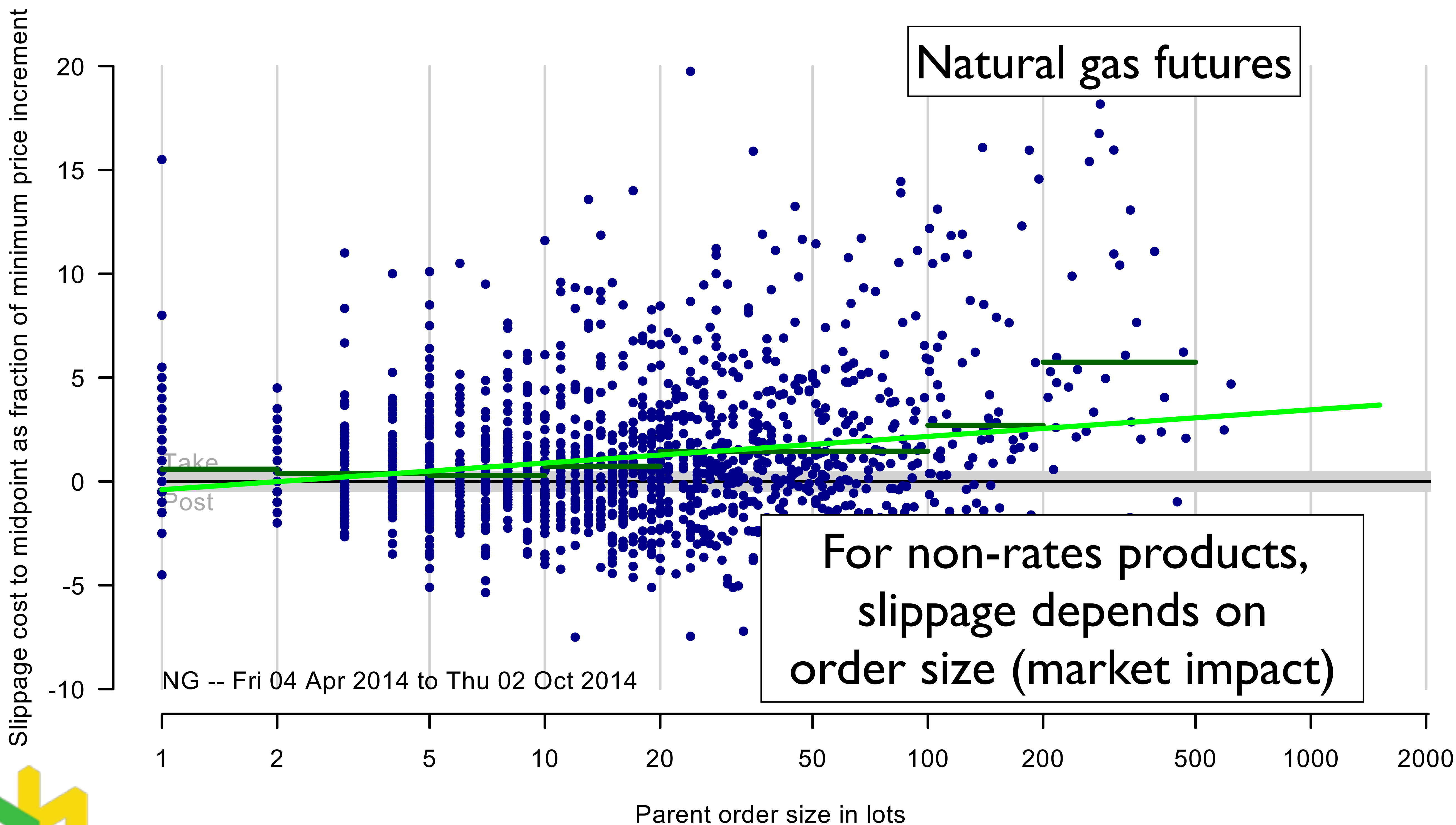
Produced by QB from CME and internal data

Size matters more for non-rates



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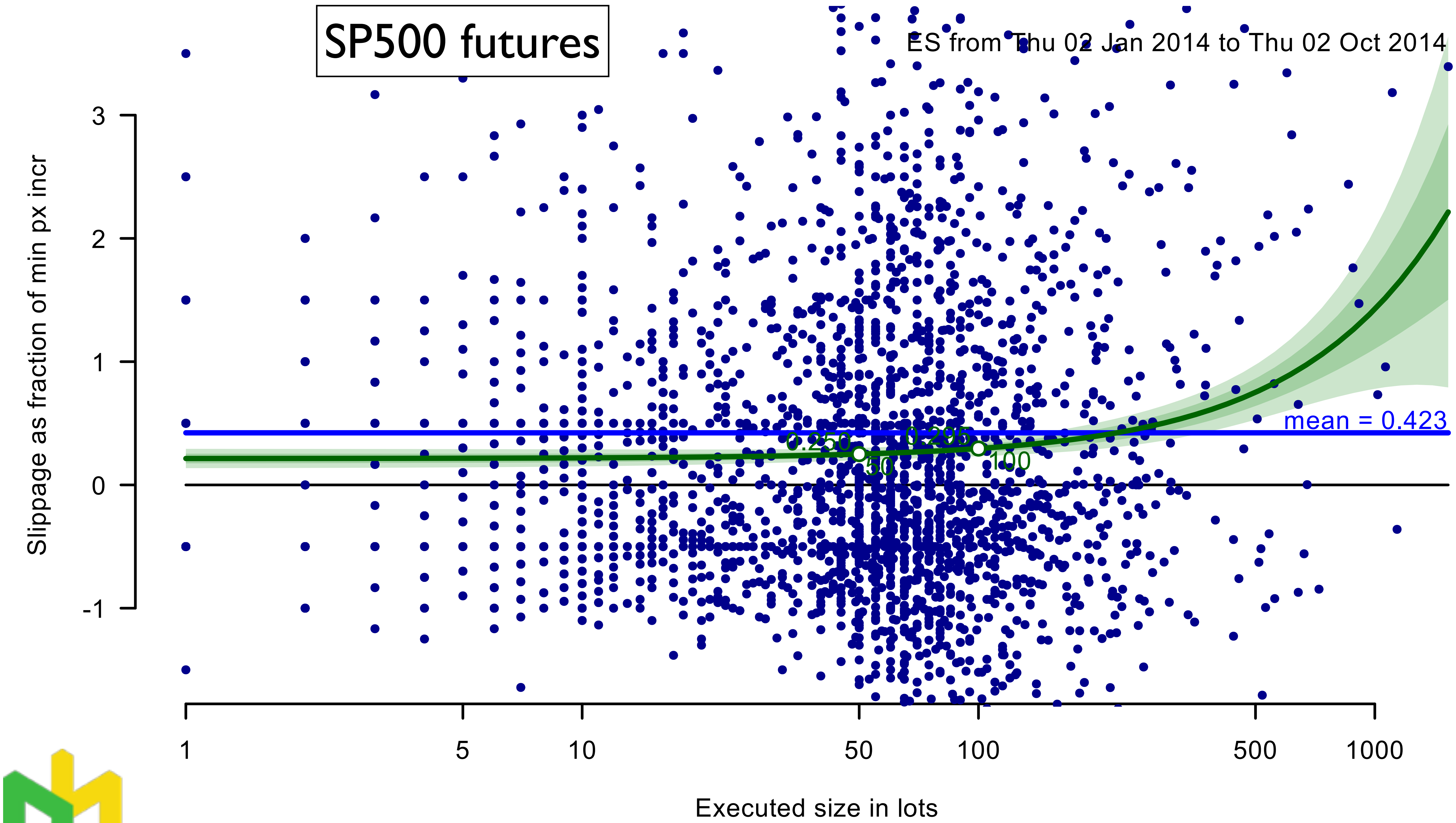
Impact cost model



Produced by QB from CME and internal data

What does performance depend on?

Passive fills
Short term price signals
Reliable performance in different mkt conds

How to develop and improve algos?

1. Pure theory and quant modeling
2. Experiment with real client orders
3. Simulator

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waters
trading technologies for financial-market professionals

Managed Futures' ALGO CHASE

A potent mixture of in-house, futures commission merchant, and boutique brokerage-provided algorithms now play a part in commodity trading advisors' and managed futures funds' trading activities. Tim Bourgaize Murray examines why a new cadre of simulation tools is helping to organize—and perhaps re-mold—these buy-side specialists' order flow.

"Skate to where the puck is going to be, not where it has been," Wayne Gretzky once told an interviewer. As the Great One described it, what cuts certain players a level above isn't native instinct alone, so much as endless practice seeing the ice and, frankly, the hard work of getting to where a scoring opportunity will be, before it reveals itself.

Gretzky's advice is one of Robert Almgren's favorite lines—but not because the co-founder of Quantitative Brokers (QB) is a hockey fan. Instead, he says a similar idea applies to the business of algorithmic futures execution: the more you see, the more you

much of the value, they say, derives from what comes before any trades are even made.

> "We do perform reviews on all algos internally using our own simulator, and are always keen to compare these results with those of the provider. If they cannot provide a simulator, it takes a lot longer to see if we believe their story." Murray Steel, AHL

SALIENT POINTS

- Managed futures specialists are increasingly taking advantage of boutique agency brokers' algorithms, citing their ability to be opportunistic and adjust to markets' behavior, as well as faster speed to implementation and greater alpha realized through price slippage.
- Rates futures, particularly, are ripe for these applications given their correlation and the characteristics of the complexes within which they're traded, and are well-serviced by Quantitative Brokers (QB), among other independent shops. Hedge fund AHL and CTA Revolution Capital Management are among QB's users for rates.
- Another value-added feature at smaller shops like QB is their simulation environments, which mimic the matching engine logic of relevant futures exchange venues and can test new adjustments to algorithms with real-time market data before putting the algos into production.
- Sources expect a greater variety of such brokers to crop up in coming years, while sell-side futures commission merchants (FCMs), sensing greater competition, are also expected to mature their offerings and continue bundling futures algos with other execution and clearing services.

Waters Technology
Tim Murray
April 2014

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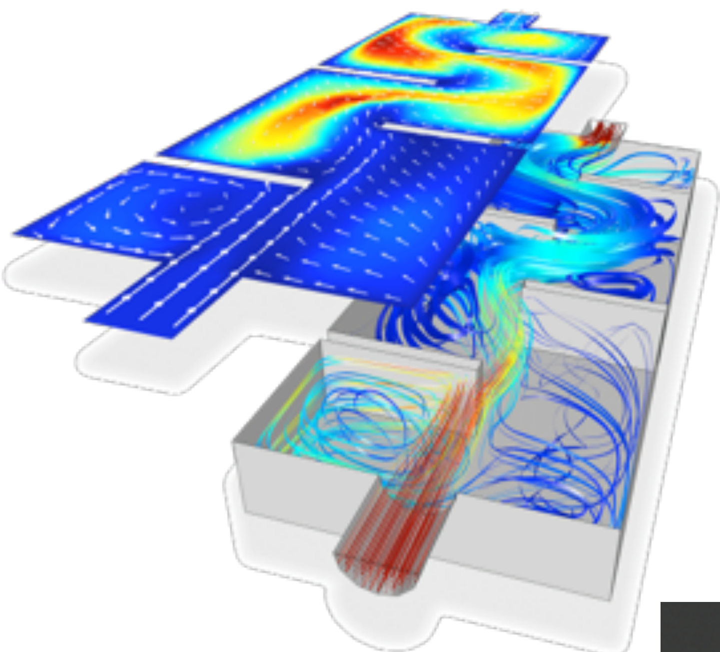
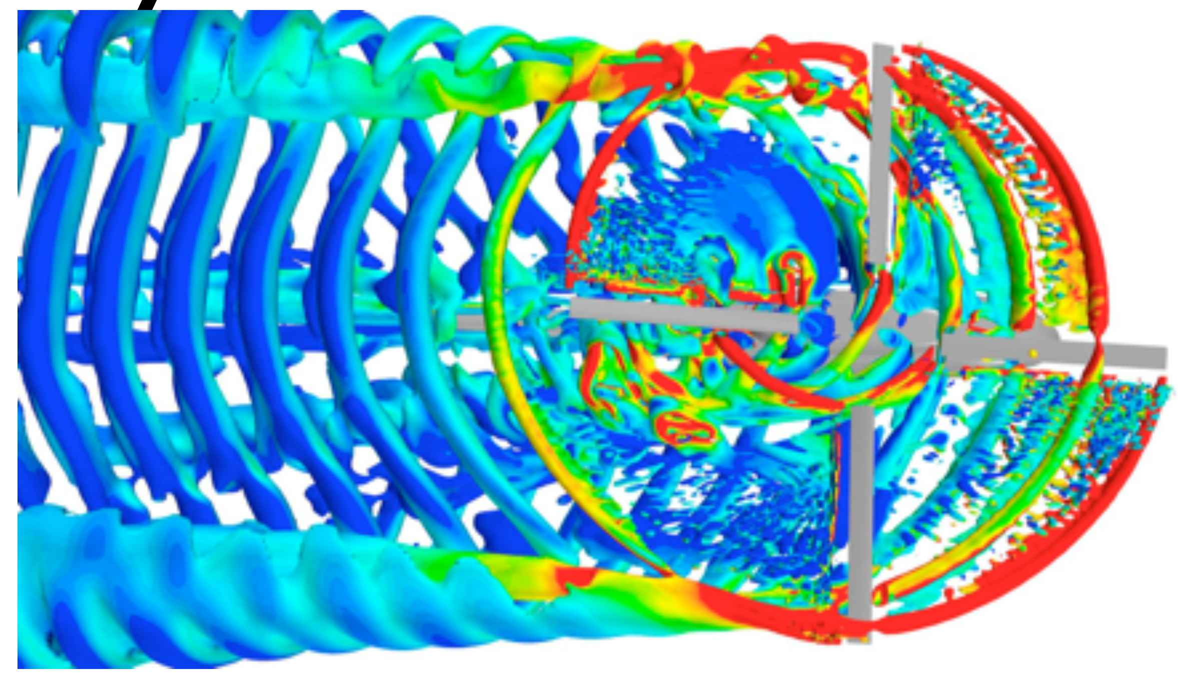
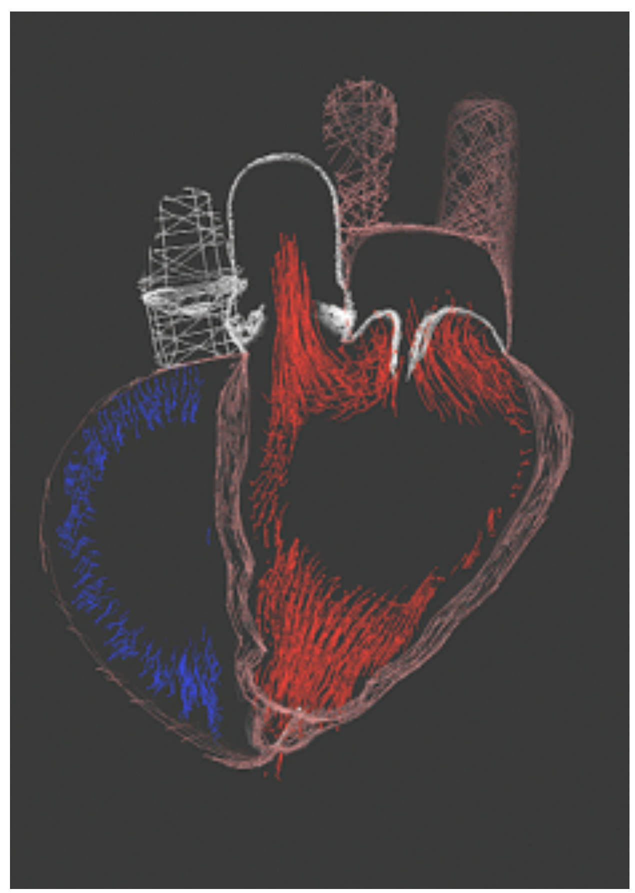
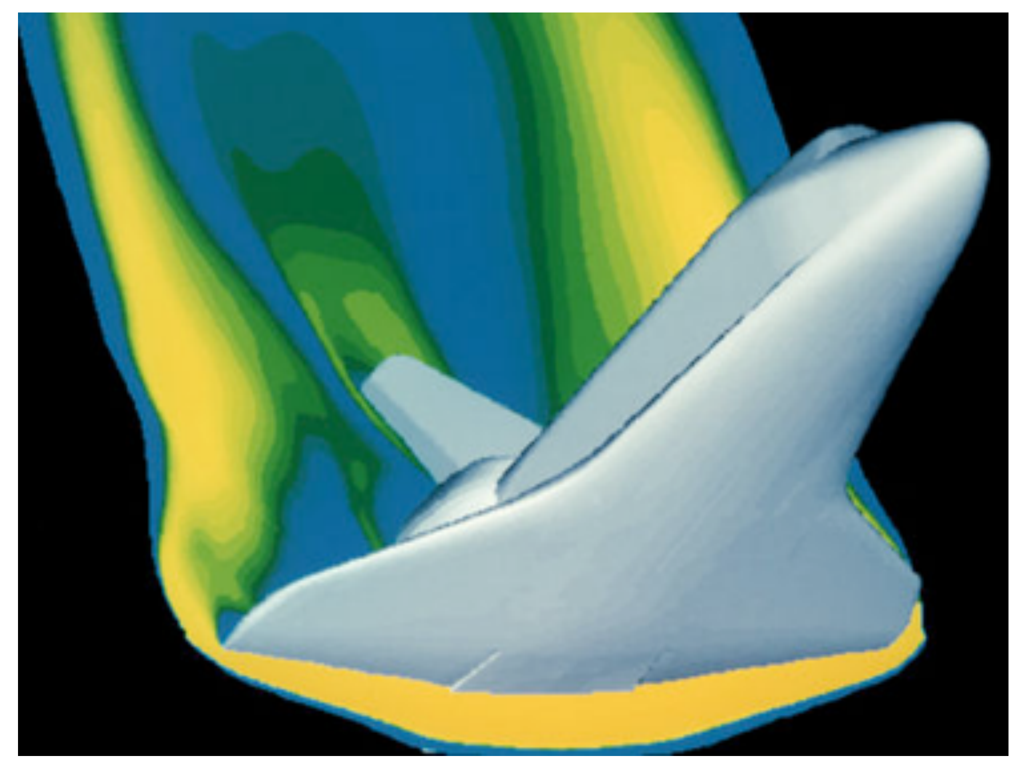
Computational fluid dynamics









Computational fluid dynamics

Complete simulation is impossible
Discretize to capture key features:

- Conservation of mass, momentum, etc
- Positivity of density, etc
- Vortex dynamics
- Chemical reactions
- 2-D, 3-D, axisymmetric, etc
- Nonlocal effects (incompressible flow)

Computational market simulation

Complete simulation is impossible
(Human reaction is very complicated)

Key features to include:

- queue position and match algorithms
- price movement

Features to neglect for simplicity:

- market impact

(Literature on agent-based markets)

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‘They were obliged to have him with them,’ the Mock Turtle said: ‘no wise fish would go anywhere without a porpoise.’

‘Wouldn’t it really?’ said Alice in a tone of great surprise.

‘Of course not,’ said the Mock Turtle: ‘why, if a fish came to me, and told me he was going a journey, I should say “With what porpoise?”’

‘Don’t you mean “purpose”?’ said Alice.

‘I mean what I say,’ the Mock Turtle replied in an offended tone.

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Market simulator

Tool for developing and testing execution algorithms for interest rate products.

Capture essential features of main markets:

- matching algorithms and passive fill probabilities
- short term pricing signals

Will have limitations -- useful anyway

Does not embody model of market impact

The one most natural way to build a simulator

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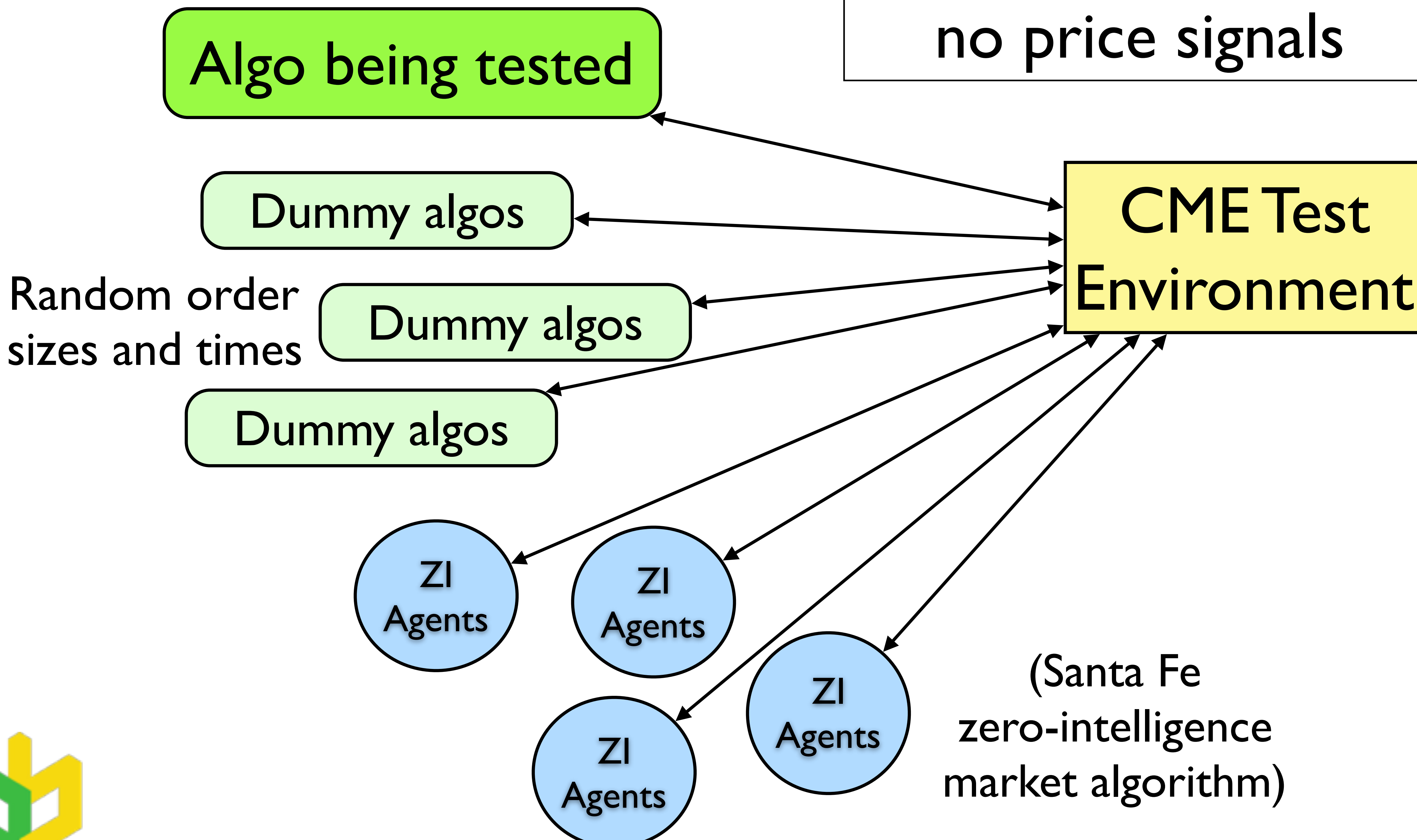
What did not work

No real market data: no price signals



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Simulating and analyzing order book data: The queue-reactive model

Weibing Huang[1,2], Charles-Albert Lehalle[3] and Mathieu Rosenbaum[1]

Through the analysis of a dataset of ultra high frequency order book updates, we introduce a model which accommodates the empirical properties of the full order book together with the stylized facts of lower frequency financial data. To do so, we split the time interval of interest into periods in which a well chosen reference price, typically the midprice, remains constant. Within these periods, we view the limit order book as a Markov queuing system. Indeed, we assume that the intensities of the order flows only depend on the current state of the order book. We establish the limiting behavior of this model and estimate its parameters from market data. Then, in order to design a relevant model for the whole period of interest, we use a stochastic mechanism that allows to switch from one period of constant reference price to another. Beyond enabling to reproduce accurately the behavior of market data, we show that our framework can be very useful for practitioners, notably as a market simulator or as a tool for the transaction cost analysis of complex trading algorithms.

4 Conclusion and perspectives

In this work, we have modeled market participants intelligence through their average behaviors towards various states of the LOB. This enabled us to analyze the different order flows and to design a suitable market simulator for practitioners, allowing notably to investigate the transaction costs of complex trading strategies. To our knowledge, our model is the first one where such pre-trade cost analysis is possible in a simple and efficient way.

Another important public information, the historical order flow, is not considered in this approach. Market order flows have been shown to be autocorrelated in several empirical studies, see for example Toth, Palit, Lillo, and Farmer (2011b). Thus, adding such feature in our framework would probably be relevant. Another possible direction for future research would be to explain the shape of the estimated intensity functions in a more sophisticated way. For example, it would be interesting to design some agent based model where these repetitive patterns of the LOB dynamics would be reproduced, providing an even better understanding of the nature of these intensity curves.

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Simulating and Analyzing Order Book Data: The Queue-Reactive Model

Weibing HUANG, Charles-Albert LEHALLE, and Mathieu ROSENBAUM

Journal of the American Statistical Association
March 2015, Vol. 110, No. 509, Applications and Case Studies

Through the analysis of a dataset of ultra high frequency order book updates, we introduce a model which accommodates the empirical properties of the full order book together with the stylized facts of lower frequency financial data. To do so, we split the time interval of interest into periods in which a well chosen reference price, typically the midprice, remains constant. Within these periods, we view the limit order book as a Markov queuing system. Indeed, we assume that the intensities of the order flows only depend on the current state of the order book. We establish the limiting behavior of this model and estimate its parameters from market data. Then, to design a relevant model for the whole period of interest, we use a stochastic mechanism that allows to switch from one period of constant reference price to another. Beyond enabling to reproduce accurately the behavior of market data, we show that our framework can be very useful for practitioners, notably as a market simulator or as a tool for the transaction cost analysis of complex trading algorithms.

KEY WORDS: Ergodic properties; Execution probability; High frequency data; Jump Markov process; Limit order book; Mechanical volatility; Market impact; Market microstructure; Market simulator; Queuing model; Transaction costs analysis; Volatility.

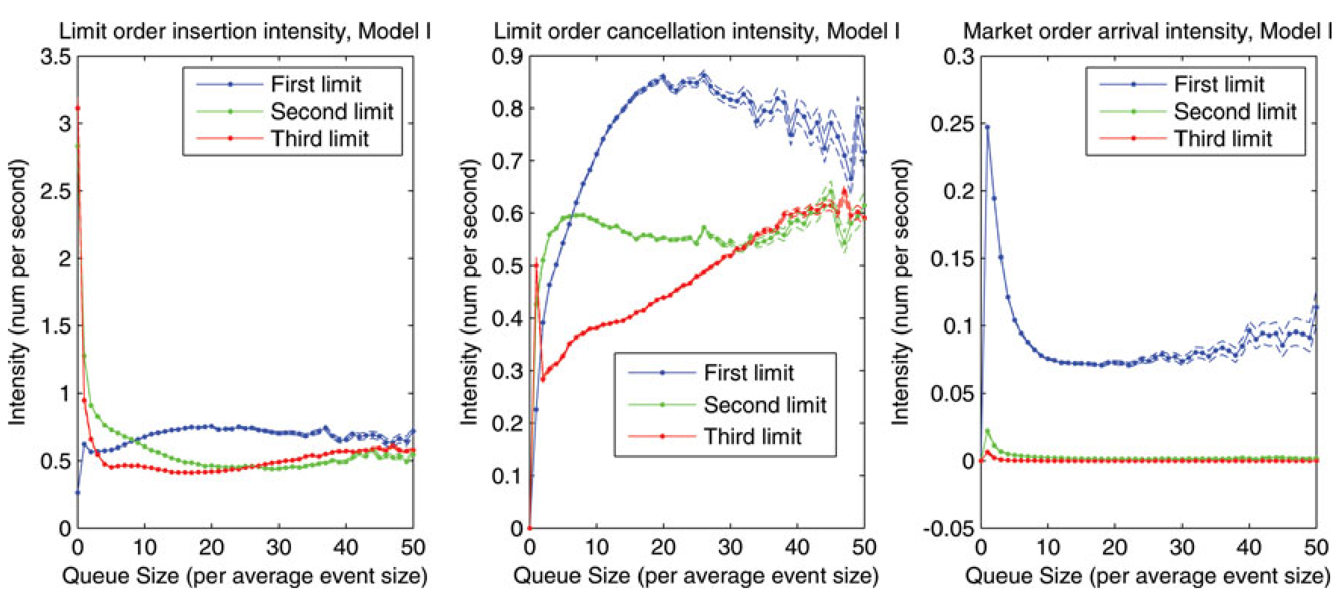

Figure 2. Intensities at $Q_{\pm i}, i = 1, 2, 3$, France Telecom.

4. CONCLUSION AND PERSPECTIVES

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Other simulators

The PLAT Project has developed a trading simulation that merges automated clients with real-time, real-world stock market data. This simulation has been used for three competitions.

The Penn-Lehman Automated Trading Project

Michael Kearns and Luis Ortiz, *University of Pennsylvania*

The Penn-Lehman Automated Trading Project is a broad investigation of algorithms and strategies for automated trading in financial markets. The PLAT Project's centerpiece is the Penn Exchange Simulator (PXS), a software simulator for automated stock trading that merges automated client orders for shares with real-world, real-time order data. PXS automatically computes client profits and losses, volumes traded, simulator and external prices, and other quantities of interest. To test the effectiveness of PXS and of various trading strategies, we've held three formal competitions between automated clients.

We also actively use PXS as a platform for developing novel, principled automated trading strategies (clients). The real-data, real-time nature of PXS lets us examine computationally intensive, high-frequency, high-volume trading strategies (although this last property always presents the challenges of estimating the *market impact*—the effect on prices). We're particularly interested in developing clients that make predictive use of limit order book data, including those using statistical modeling and machine learning. We hope that, over time, the project will generate a library of clients with varying features (trading strategy, volume, frequency, and so on) that can serve to create realistic simulations with known properties.

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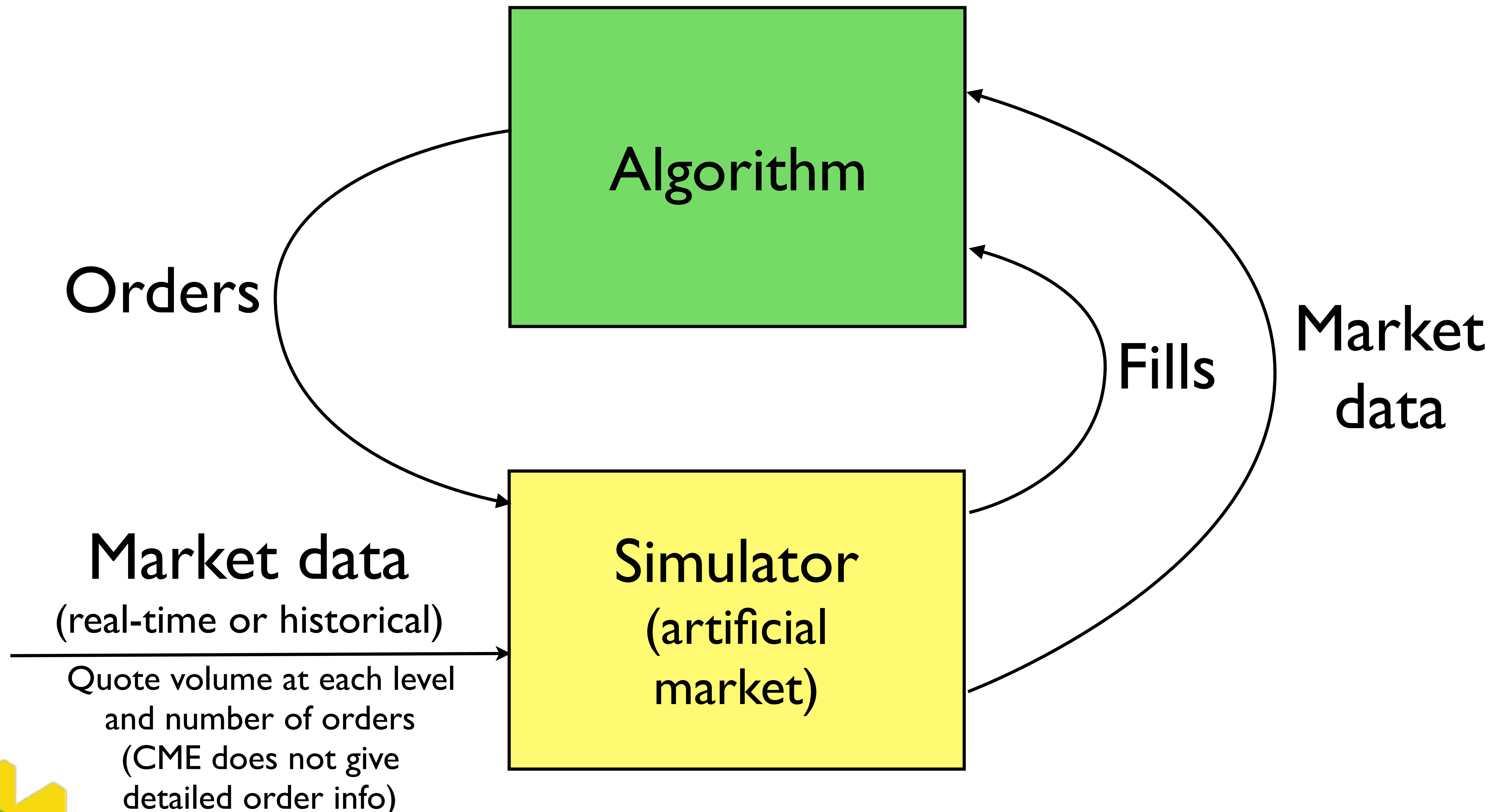
IEEE INTELLIGENT SYSTEMS

2003

Merge real market data



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Criteria for simulator

- If no algo orders, reproduce market data
- If no market data, reproduce match engine
- Challenge: combine market data with orders

NYU MS Students, May 2012

Project Report

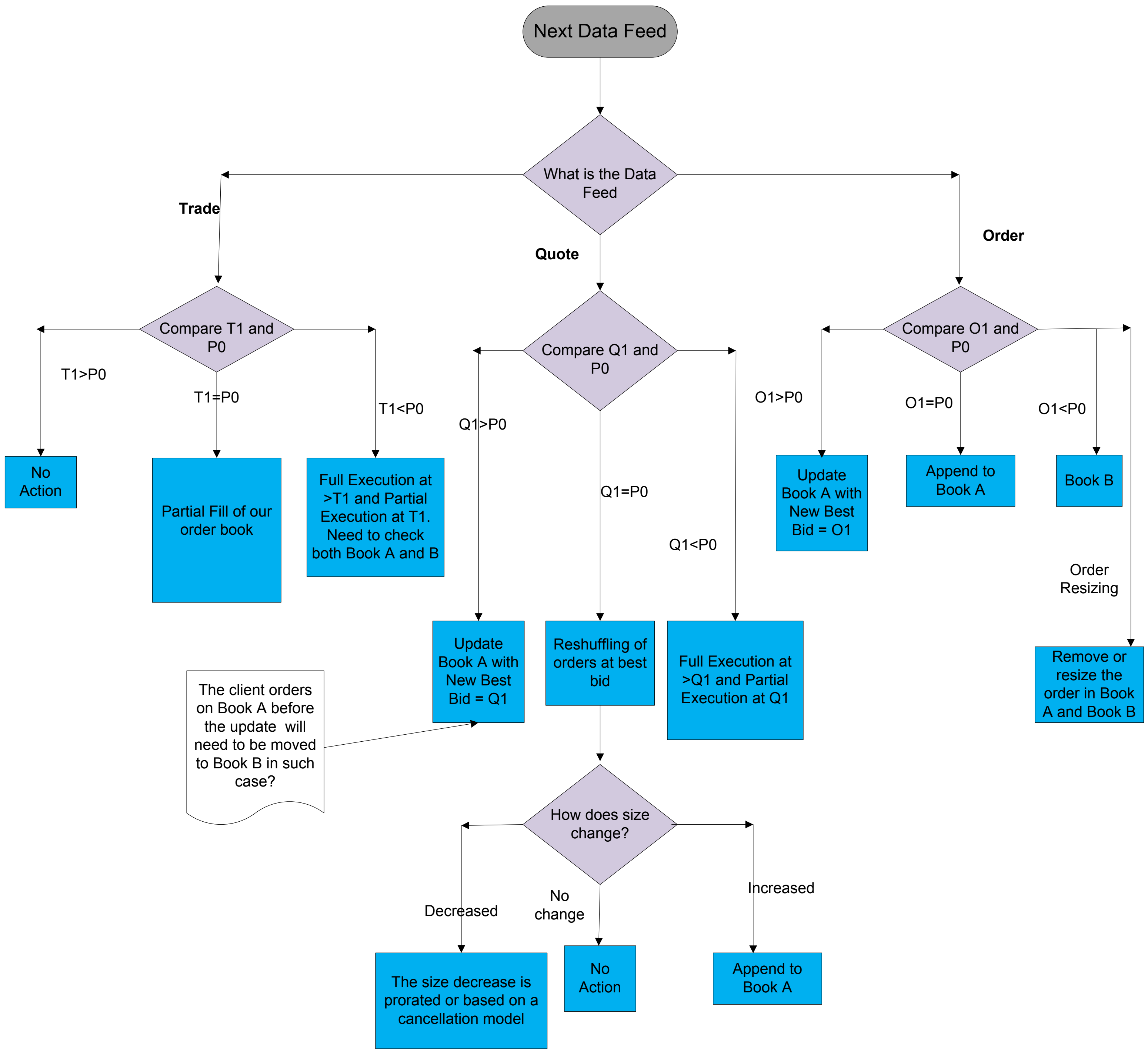
Combining historical data with a market simulator for testing algorithmic trading

Huang, Wensheng
Su, Li
Zhu, Yuanfeng

Advisor
Dr. Robert Almgren

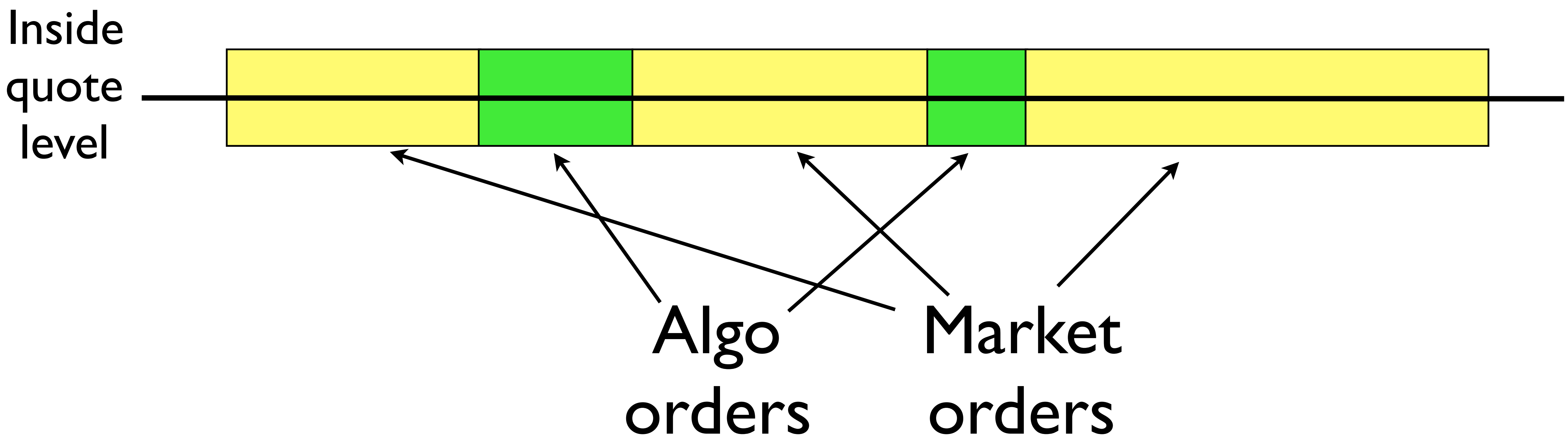
Abstract

In algorithmic trading field, it is very important to have a good market simulator to for back testing trading algorithms or trading strategies. Before trading algorithms or trading strategies are used in production environment, they are often required to be tested against historical data in a market simulator. One of the challenges is to merge the orders generated from algorithms or strategies into market quotes and trades. This project develops an algorithm to merge orders into historical data so that people can pragmatically back testing trading algorithms or strategies. This algorithm is applied to US Treasury Futures on CME and results are proved to be promising.



Huang, Su, and Zhou 2012

Interleave algo orders with market



Interleave algo orders and market orders,
respecting time priority
and implementing exchange match rules

Mkt data	Algo order	Book		
quote=100 lot		100	100	
	40 lot bid	140	100 | 40	
quote=150 lot		190	100 | 40 | 50	
trade=30 lot (20%) quote=120 lot	8 lot fill	152	trade=38 lot 80 | 32 | 40	pro rata
quote=110 lot (10 lot cancel)		142	80 | 32 | 30	cancel from back of queue
etc				

Simulator Assumptions

- Child orders always joining back of the queue
- Child orders use pessimistic queue position model, where;
  - Market Trades - reduce quantity from front of queue
  - Market Quote decreases - reduce quantity from back of queue
- Child orders receive passive fills based on matching algorithm:
- Aggressive child orders are fully executed at sweep price
- Child orders cannot establish a new price level
- If a price level is traded through, child orders at that level are filled
- Hidden liquidity (BML) is recreated from QB calculations
- Implied quotes are treated equally to direct quotes
- Static latency of 2ms on market data and 8ms on execution

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How to use simulator

Historical

- rerun scenarios for algo improvement
- backtests for potential clients

Real-time

- clients can connect to “test-drive” algos

Algorithm development

- test new signals on historical orders
- multi-market legging trades

Real-time splitting for testing

- compare simulator executions with real

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Signal development

1. Propose idea
   plausibility tests
2. Statistical tests on historical market data
   nonzero correlation with future price movement
3. Rerun actual orders executed
   show improvement in slippage

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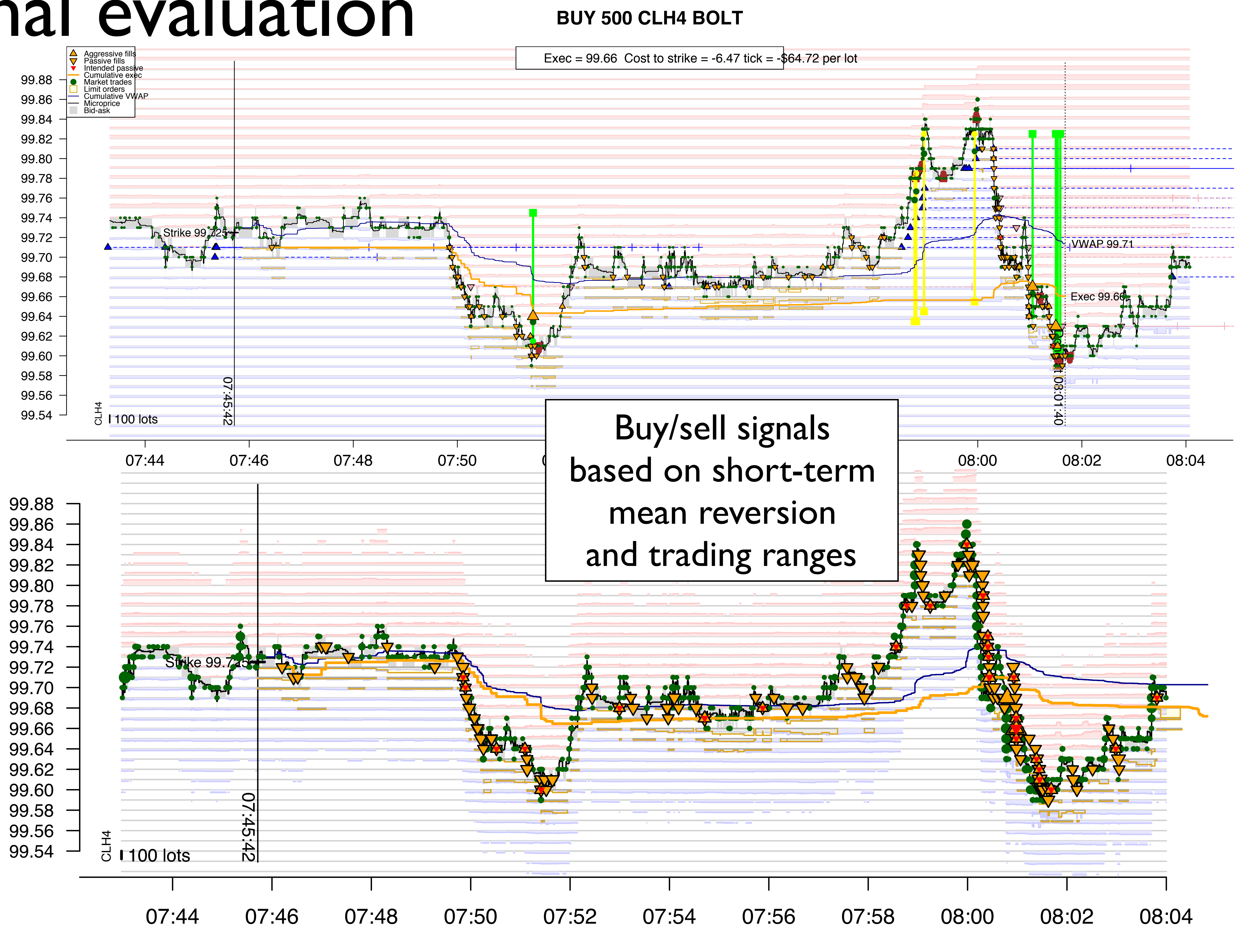
Signal evaluation



Produced by QB from CME and internal data

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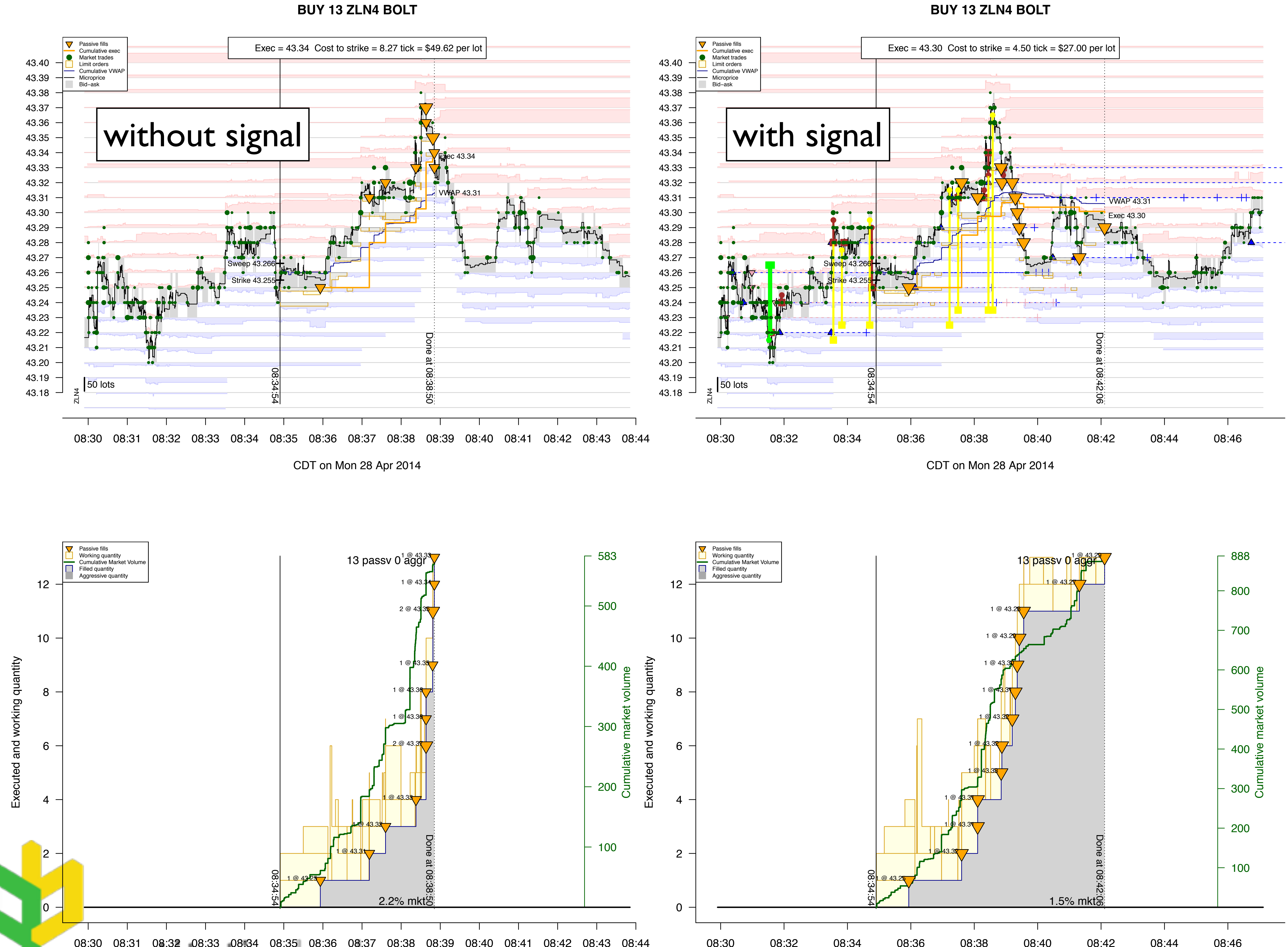
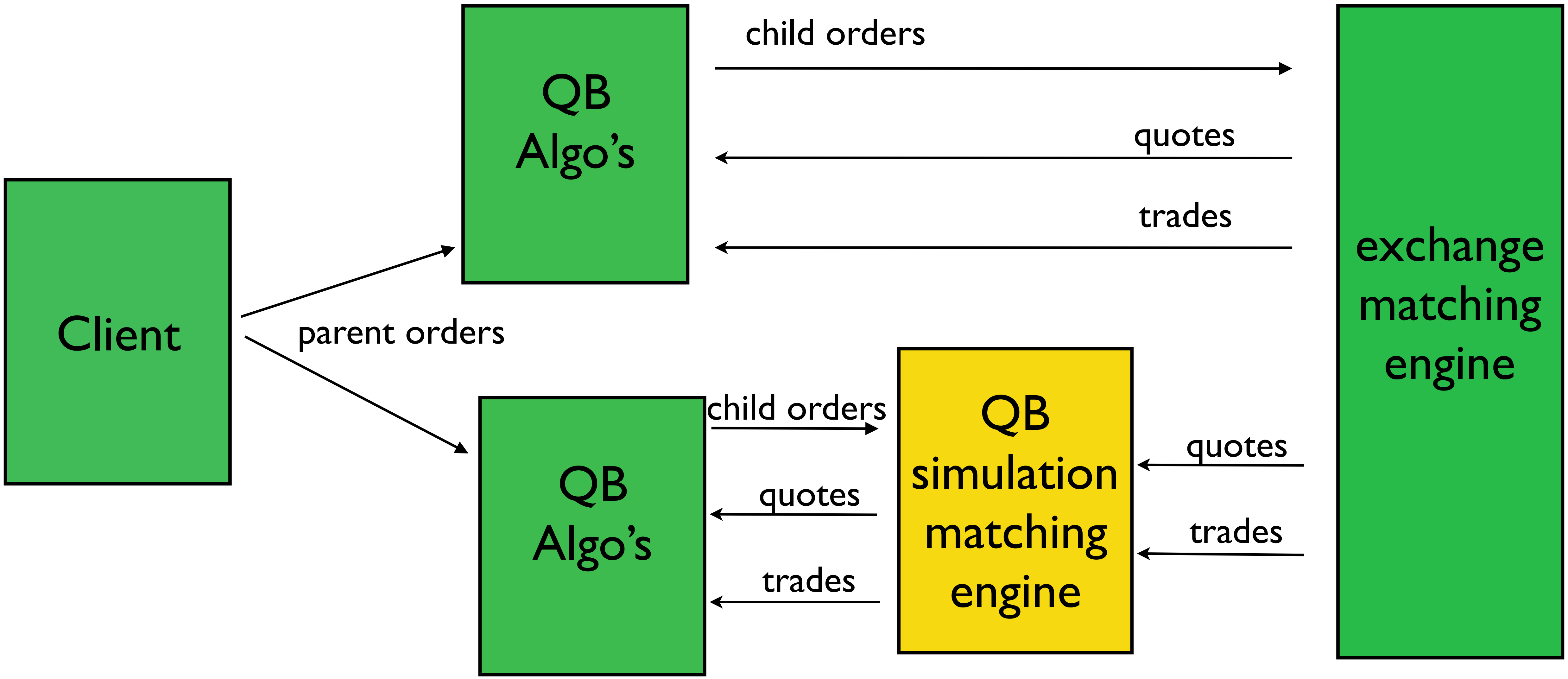


BUY 13 ZLN4 BOLT
Exec = 43.34 Cost to strike = 8.27 tick = $49.62 per lot
without signal
Passive fills
Cumulative exec
Market trades
Limit orders
Cumulative VWAP
Microprice
Bid−ask
Sweep 43.266
Strike 43.255
Exec 43.34
VWAP 43.31
Done at 08:38:50
08:34:54
50 lots
CDT on Mon 28 Apr 2014
BUY 13 ZLN4 BOLT
Exec = 43.30 Cost to strike = 4.50 tick = $27.00 per lot
with signal
VWAP 43.31
Exec 43.30
Done at 08:42:06
CDT on Mon 28 Apr 2014
Passive fills
Working quantity
Cumulative Market Volume
Filled quantity
Aggressive quantity
13 passv 0 aggr
2.2% mkt
1.5% mkt
Executed and working quantity
Cumulative market volume

Splitting of actual orders in real time



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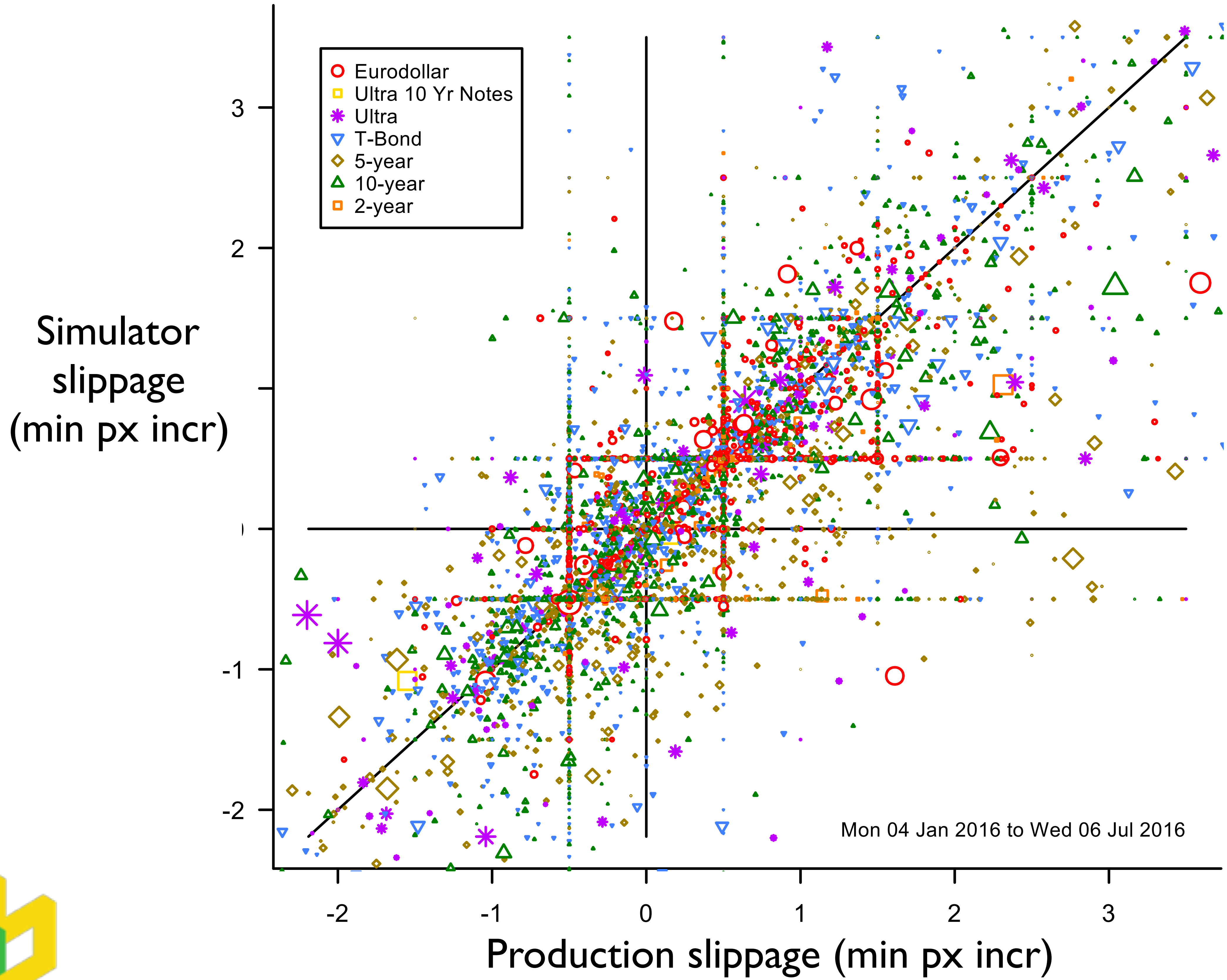
Comparison of simulator with real execution



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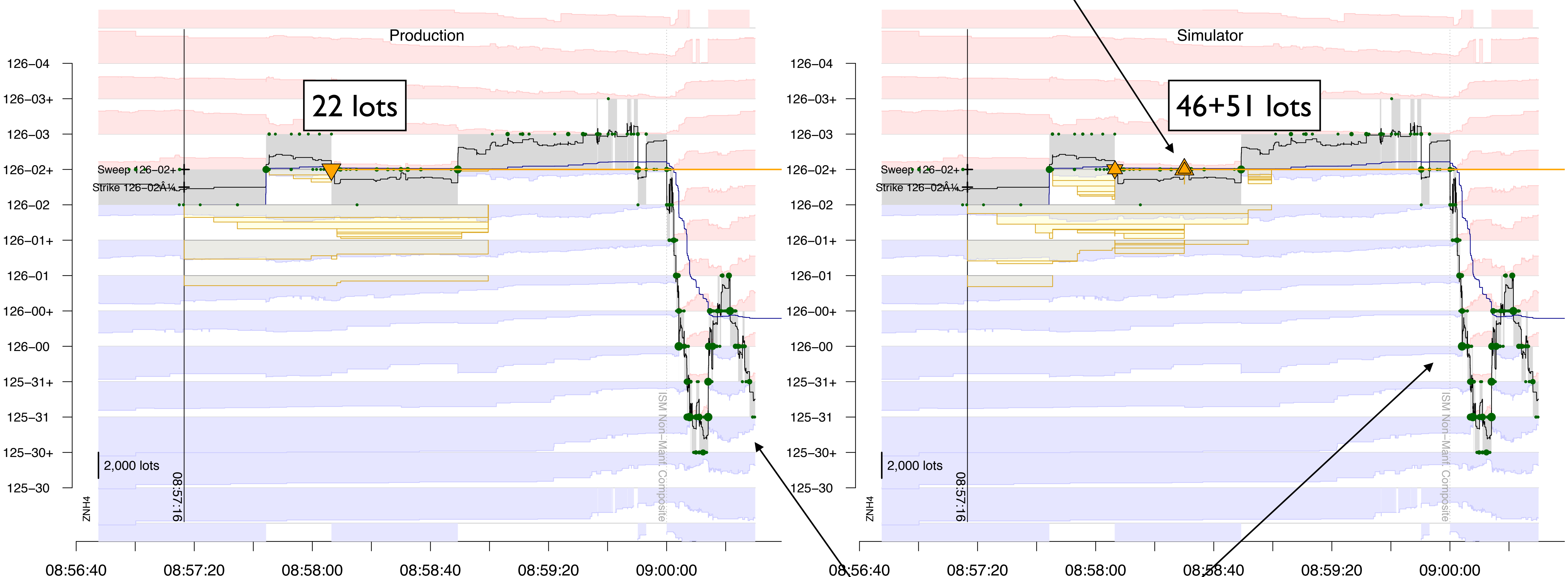
Simulator crosses spread
because of extra volume on bid side



Remaining size at much lower price level following event

Buy 148 ZNH4, 2014-02-05

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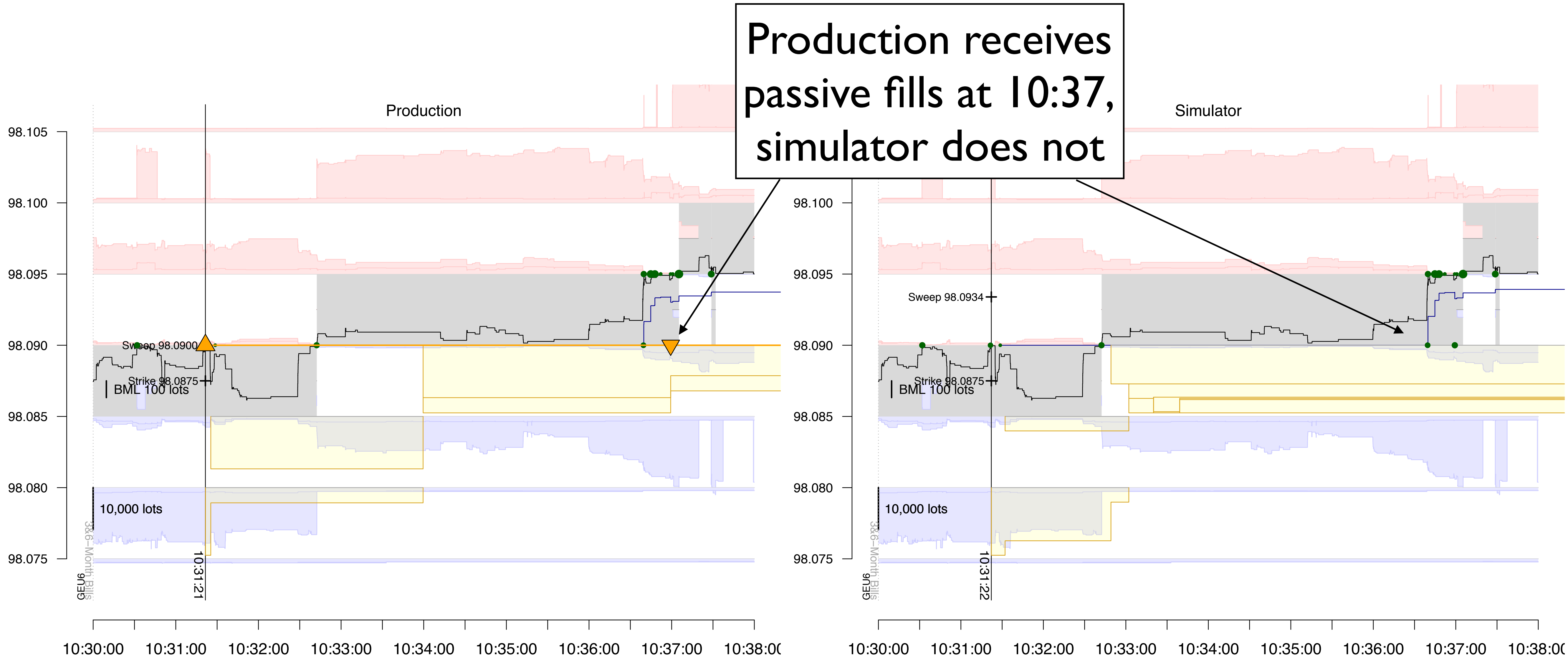
Pessimistic fill assumptions



2014-01-27: Buy 56 GEU6

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Produced by QB from CME and internal data

Main differences simulator/production:

- quote imbalance
- timing and latency
- random number sequences
- pessimistic fill model

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Summary

Fixed income trading is becoming electronic

Need full range of algo execution tools:

- Transaction Cost Analysis (TCA) reporting
- Market microstructure analysis
- Algorithm optimization
- Market simulator

Disclaimer

This document contains examples of hypothetical performance. Hypothetical performance results have many inherent limitations, some of which are described below. No representation is being made that any account will or is likely to achieve profits or losses similar to those shown. In fact, there are frequently sharp differences between hypothetical performance results and the actual results subsequently achieved by any particular trading program.

One of the limitations of hypothetical performance results is that they are generally prepared with the benefit of hindsight. In addition, hypothetical trading does not involve financial risk, and no hypothetical trading record can completely account for the impact of financial risk in actual trading. For example, the ability to withstand losses or to adhere to a particular trading program in spite of trading losses are material points which can also adversely affect actual trading results. There are numerous other factors related to the markets in general or to the implementation of any specific trading program which cannot be fully accounted for in the preparation of hypothetical performance results and all of which can adversely affect actual trading results.

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