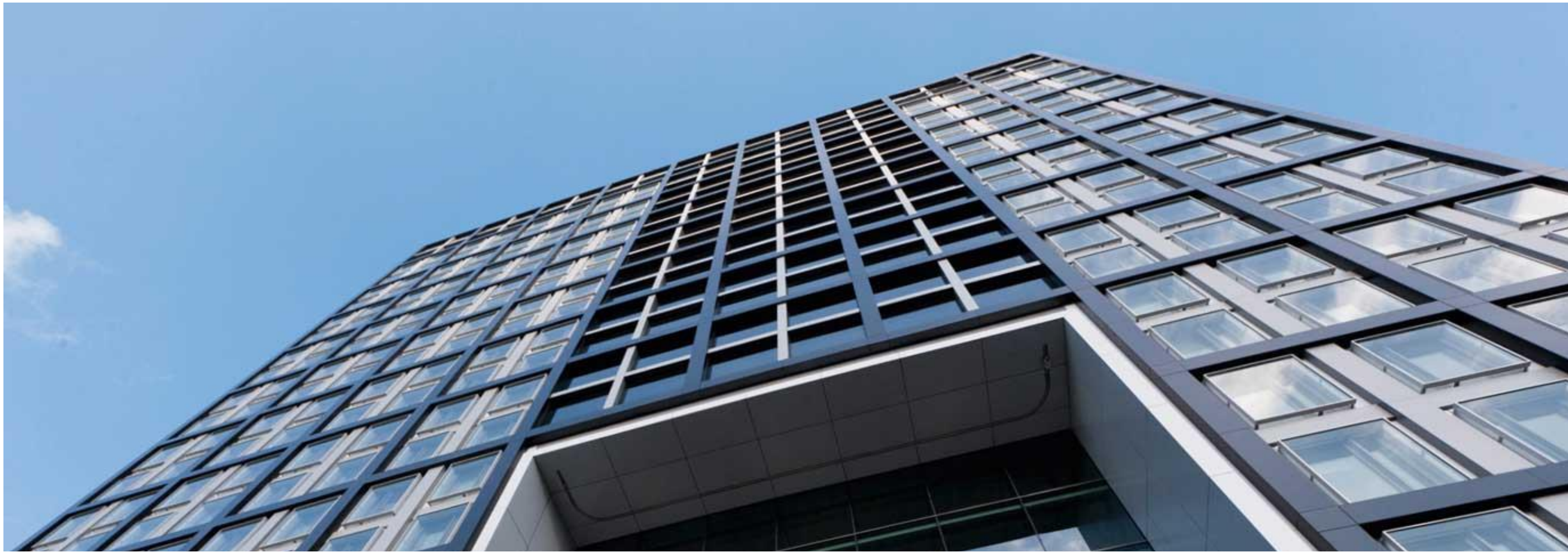


DEUTSCHE BÖRSE GROUP

White Rabbit in Financial Markets

Time Distribution in Deutsche Börse's T7® Trading Network

International Timing and Sync Forum | 6 November 2019 | Brighton

About the speaker

- Degree in computer science from University of Applied Sciences in Darmstadt (1994)
- Working in technology for financial trading since then
- Various roles in two investment banks (Frankfurt, London)
- Performance engineer in a technology-driven trading firm (Amsterdam)

Joined Deutsche Börse in 2016

- Trading IT, monitoring, infrastructure, co-location, and part-time chief cable measurer
- Deutsche Börse operates Xetra, the reference market for exchange trading in German shares and ETFs, and Eurex, a leading global derivatives exchange

Agenda

3 Overview

7 Central Limit Order Book

11 Asset Prices

18 T7® Co-Location

21 White Rabbit at Deutsche Börse

29 Services for our customers

33 Experiences

37 Conclusion

40 Appendix

3

Overview

Obsessed with Time

The New York Times

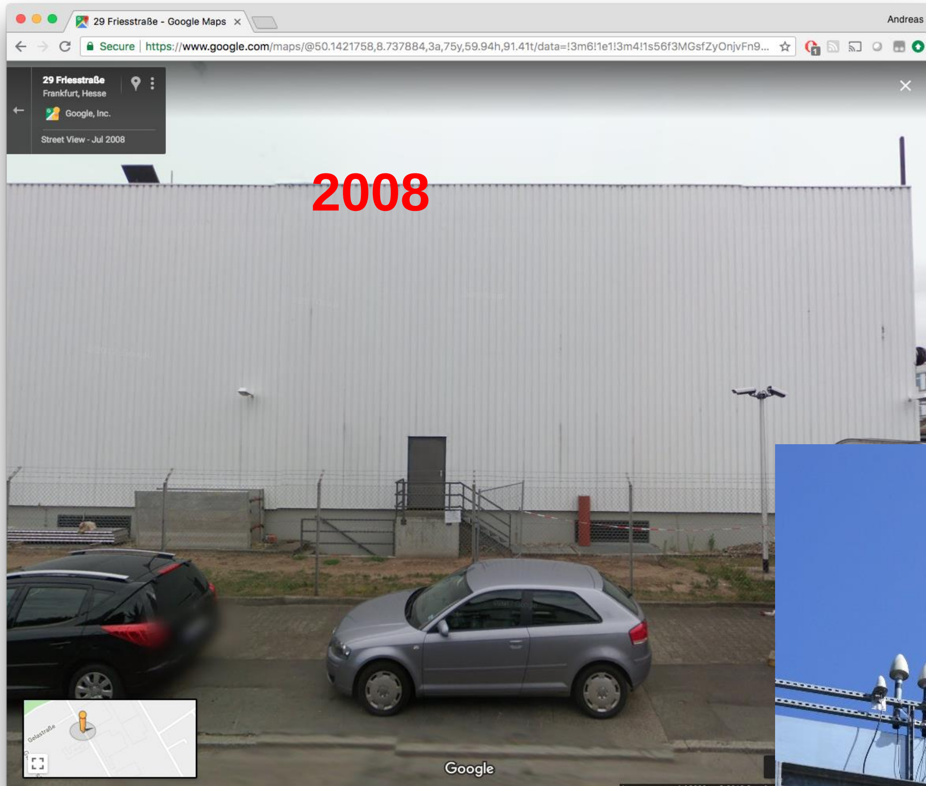
“Time Split to the Nanosecond Is Precisely What Wall Street Wants”

“The financial industry has easily become the most obsessed with time”

-Balaji Prabhakar, Stanford University

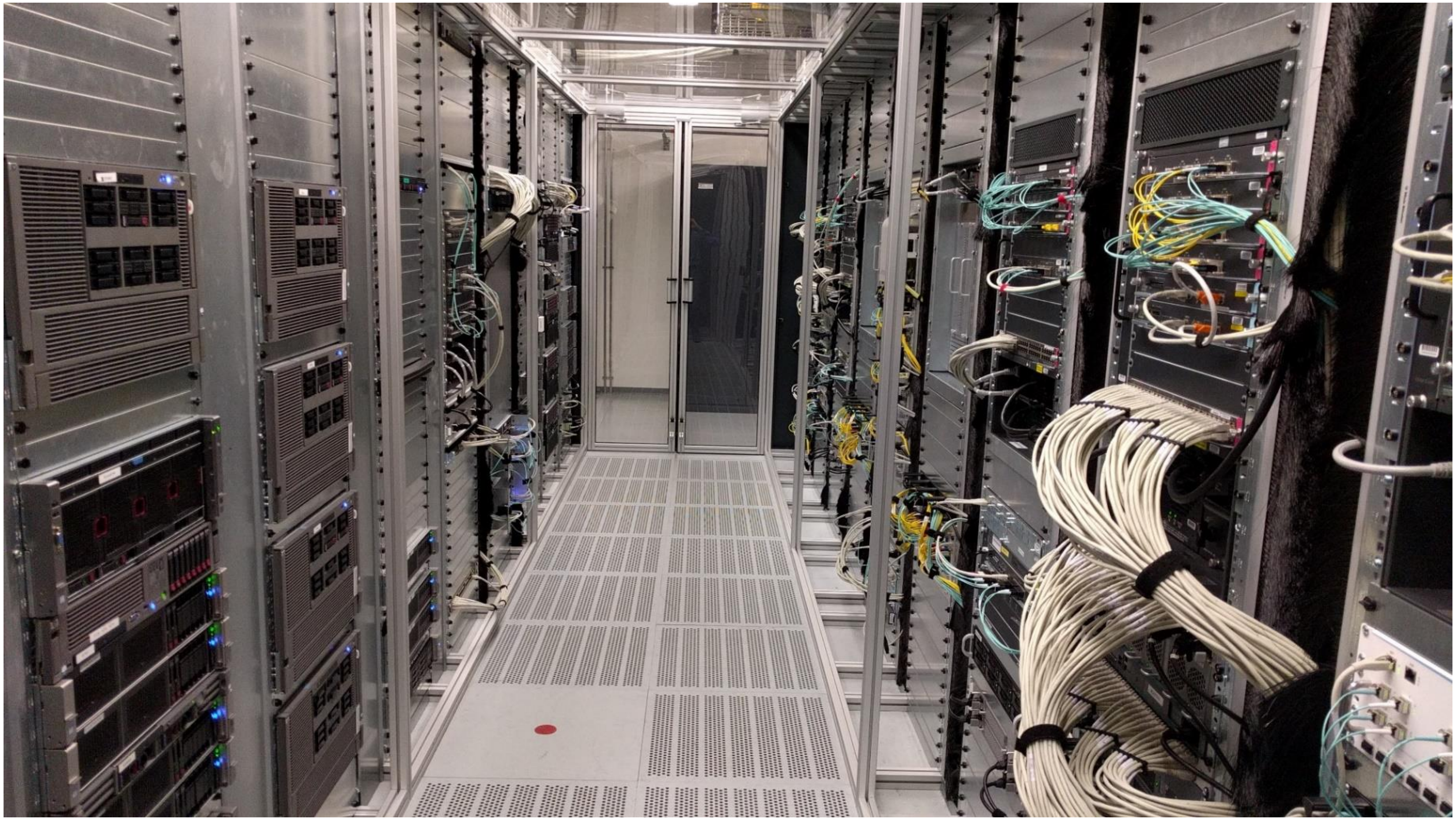
https://www.nytimes.com/2018/06/29/technology/computer-networks-speed-nasdaq.html

Obsessed with Time



Obsessed with Time
How did this happen?

From trading floor to electronic markets



7

Central Limit Order Book

Central Limit Order Book (1)

LastTime	LastVolume	Last			
10:20:10.123	165	73.04			
BidCount	**BidVolume**	**Bid**	**Ask**	**AskVolume**	**AskCount**
3	624	73.04	73.05	3081	5
10	1474	73.03	73.06	2662	15
14	2505	73.02	73.07	5854	17
16	2843	73.01	73.08	4284	14
10	1925	73.00	73.09	6388	15
12	2328	72.99	73.10	1908	11
11	2814	72.98	73.11	1151	5
7	967	72.97	73.12	534	4
10	1803	72.96	73.13	4090	5
8	938	72.95	73.14	1104	4

Ask	AskVolume	QueuePos
73.05	100	1
73.05	791	2
73.05	1368	3
73.05	685	4
73.05	137	5

- List of **buy** orders on the “Bid” side
- List of **sell** orders on the “Ask” side
- Sorted by price

- Priority on each price level by time
- Price-time priority is the most used electronic execution model

http://www.boerse-frankfurt.de/webinare-boersenwissen
https://www.bloomberg.com/view/articles/2018-07-02/dell-is-going-more-public-again
http://www.eurexchange.com/exchange-en/about-us/news/The-art-of-designing-markets.-Part-1/3458864

Central Limit Order Book (2)

LastTime	LastVolume	Last			
10:20:10.123	165	73.04			
BidCount	**BidVolume**	**Bid**	**Ask**	**AskVolume**	**AskCount**
3	624	73.04	73.05	3081	5
10	1474	73.03	73.06	2662	15
14	2505	73.02	73.07	5854	17
16	2843	73.01	73.08	4284	14

Ask	AskVolume	QueuePos
73.05	100	1
73.05	791	2
73.05	1368	3
73.05	685	4
73.05	137	5

New order: Buy 100 @ 73.05

LastTime	LastVolume	Last			
10:20:10.352	100	73.05			
BidCount	**BidVolume**	**Bid**	**Ask**	**AskVolume**	**AskCount**
3	624	73.04	73.05	**2981**	**4**
10	1474	73.03	73.06	2662	15
14	2505	73.02	73.07	5854	17
16	2843	73.01	73.08	4284	14

Example:

We want to buy 100 shares at a price of 73.05

Q: Which of the 5 sell orders is “matched” with our buy order?

A: The sell order which entered the order book the **earliest**.

Implication:

The faster you are, the higher the probability of an order being executed as desired. True for both sides of the trade (buyer and seller)

http://www.boerse-frankfurt.de/webinare-boersenwissen
https://www.bloomberg.com/view/articles/2018-07-02/dell-is-going-more-public-again
http://www.eurexchange.com/exchange-en/about-us/news/The-art-of-designing-markets.-Part-1/3458864

Matching Algorithms

Price Time

- Priority is determined by price then **time**
- FIFO queue per price level
- Higher queue priority increases probability of being matched
- The most common matching algorithm

11

Asset Prices

Asset Prices

Efficient-market hypothesis: asset prices fully reflect all available information

➔ New information (events) affect prices

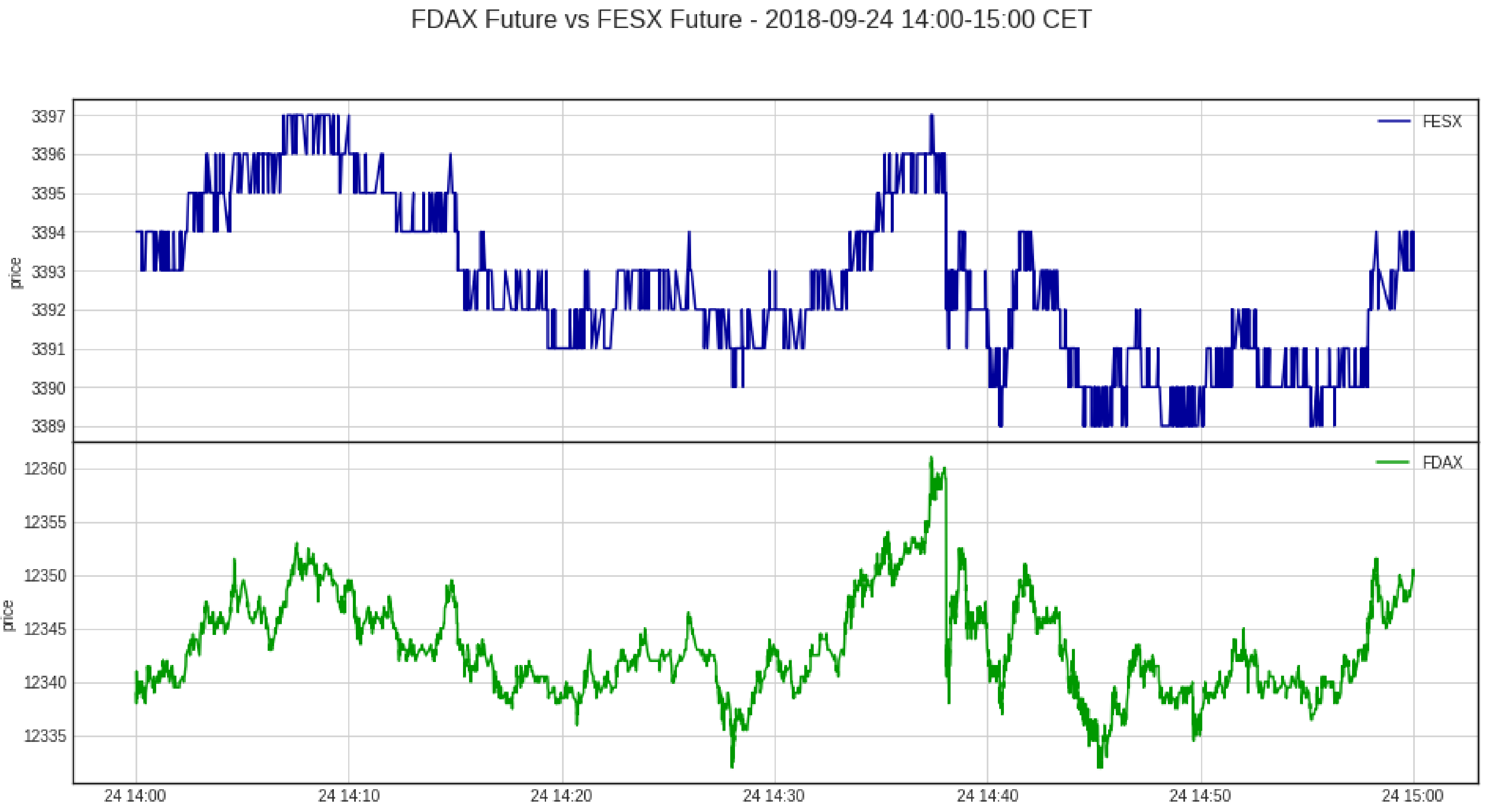
Examples:

- News
- Changes in interest rates
- Release of economic indicators (e.g. unemployment figures)
- The central limit order book of a financial instrument (e.g. stock, bond) itself
- Prices of correlated instruments

Event source can be:

- Remote (send information over WAN)
- Local (LAN, co-location)

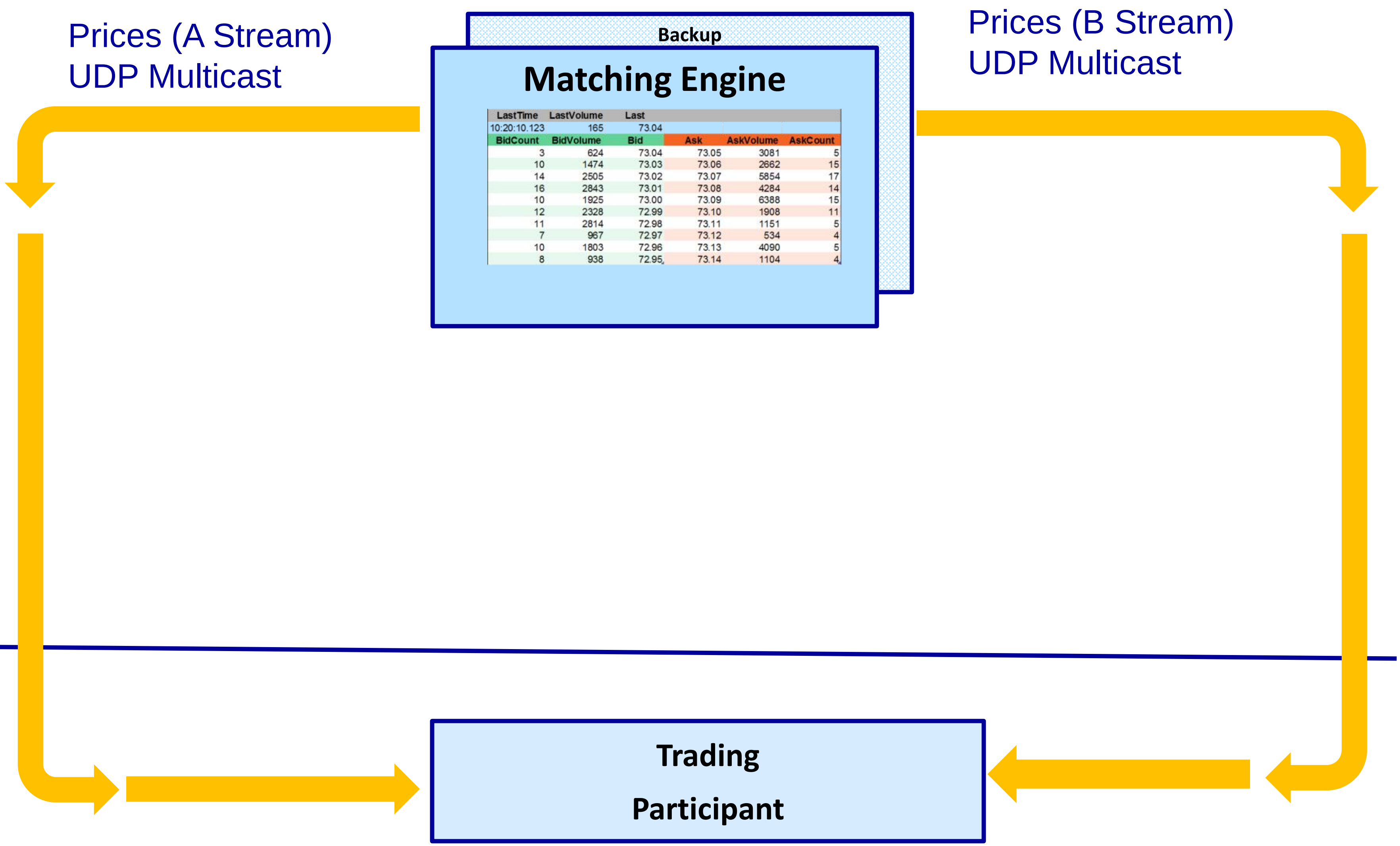
Correlated Asset Prices – Example



14

T7® Co-Location

T7® Architecture – Price Information



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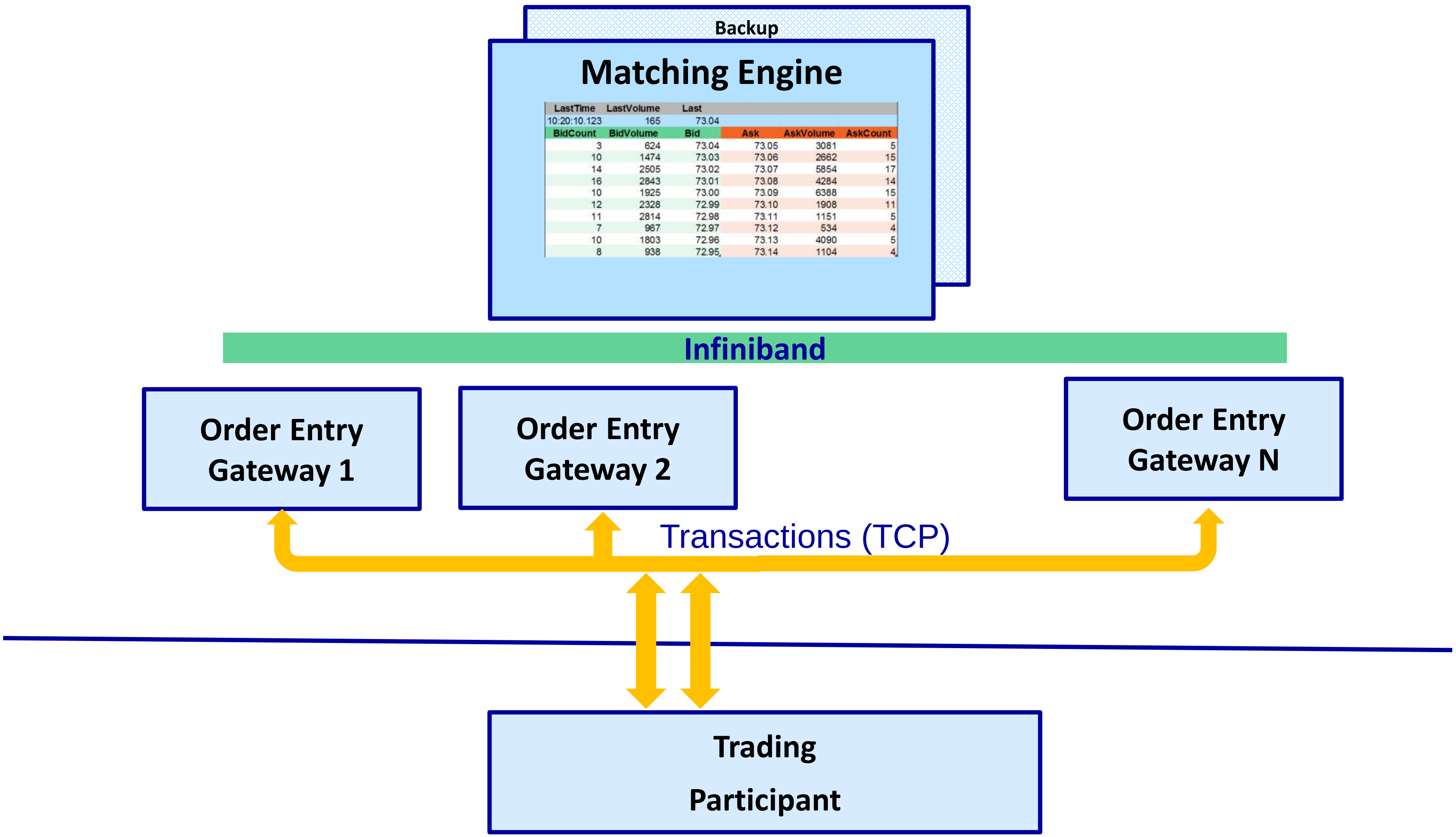
8	938	72.95	73.14	1104	4

T7® Architecture – Interaction (placing orders)



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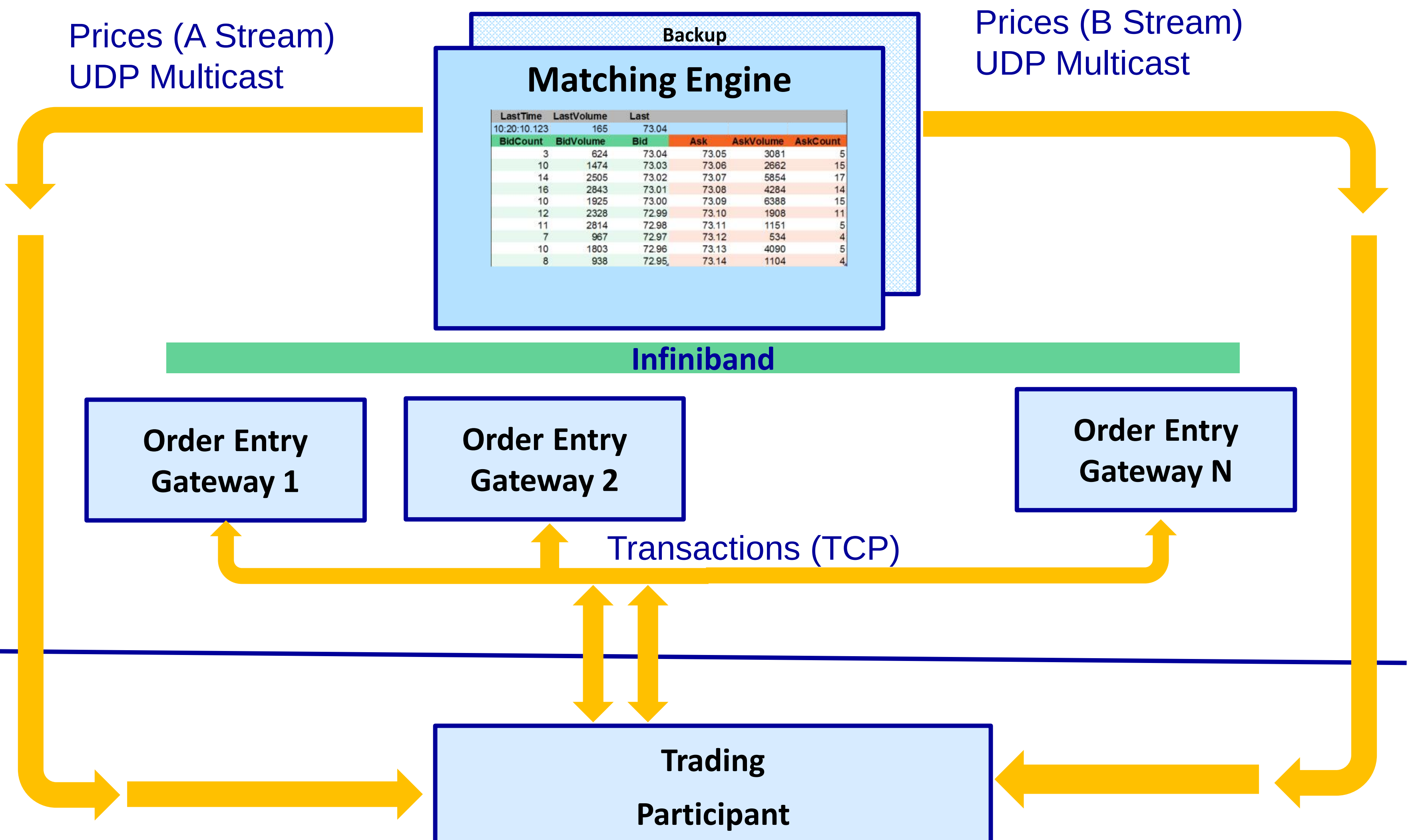
T7® Architecture



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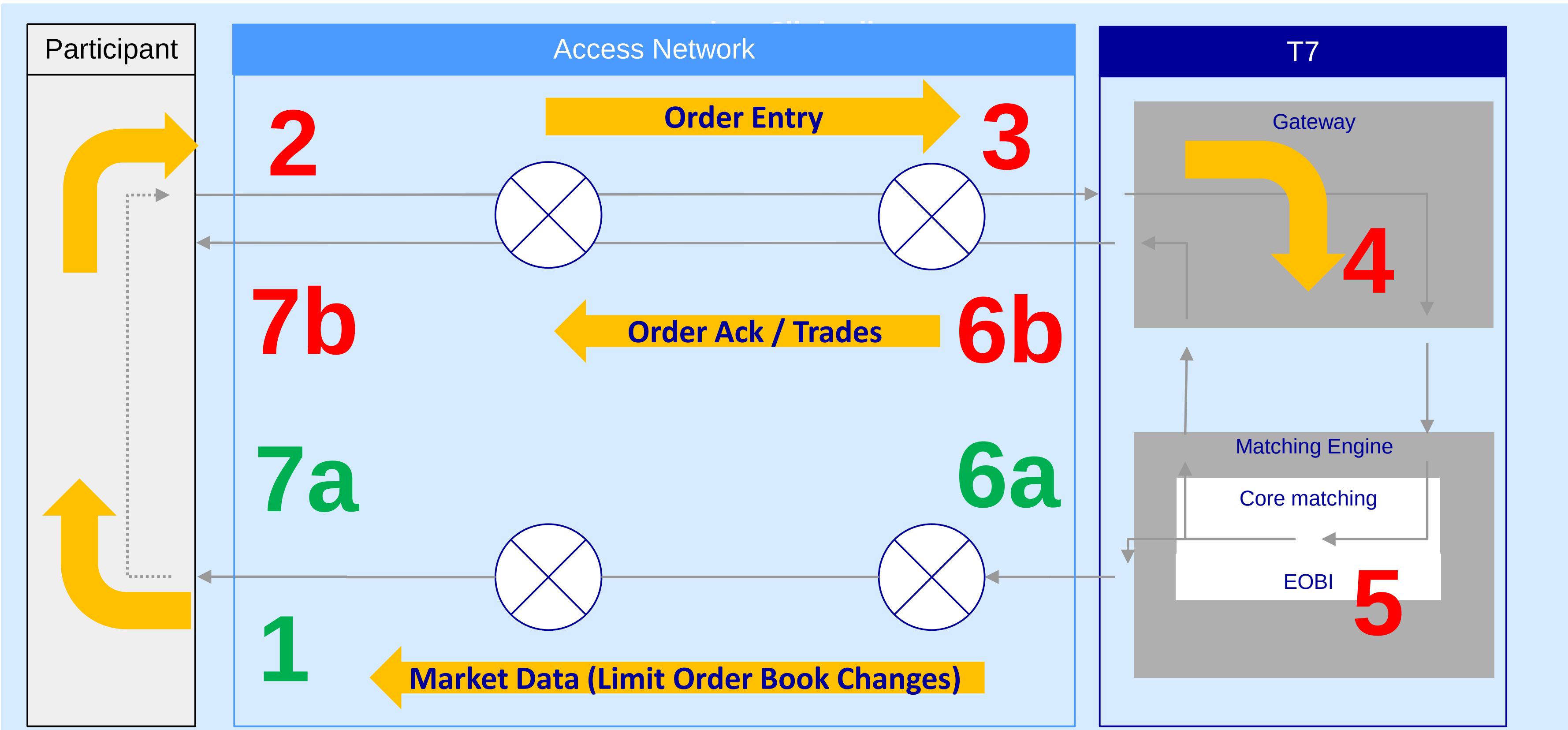
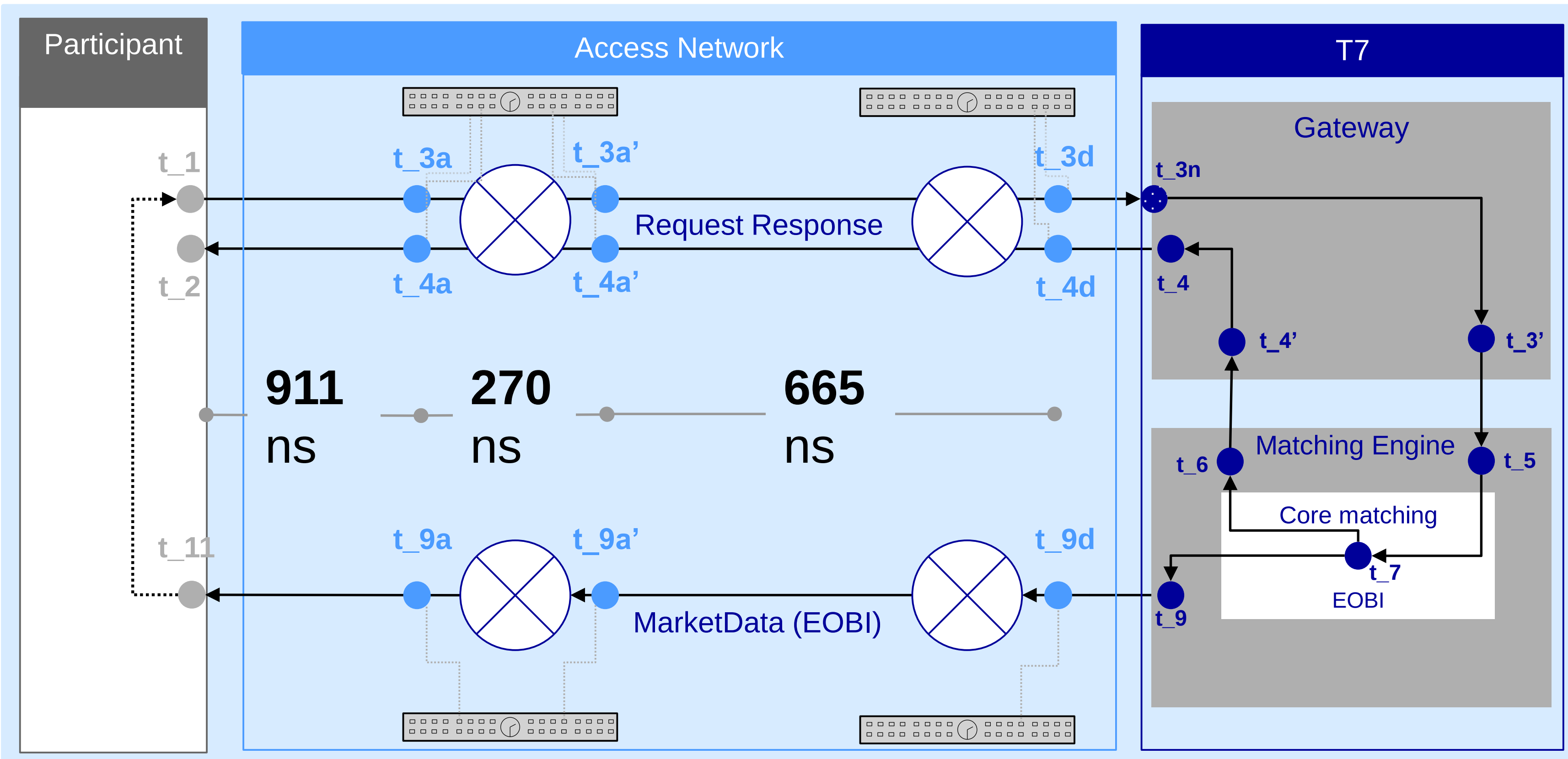
T7® Co-location

Zoom in to a single matching engine



Median round-trip from order entry to acknowledgement ≈ **60µs** (2) ➔ (7)
The fastest participants have **sub 100ns** response times (1) ➔ (2)

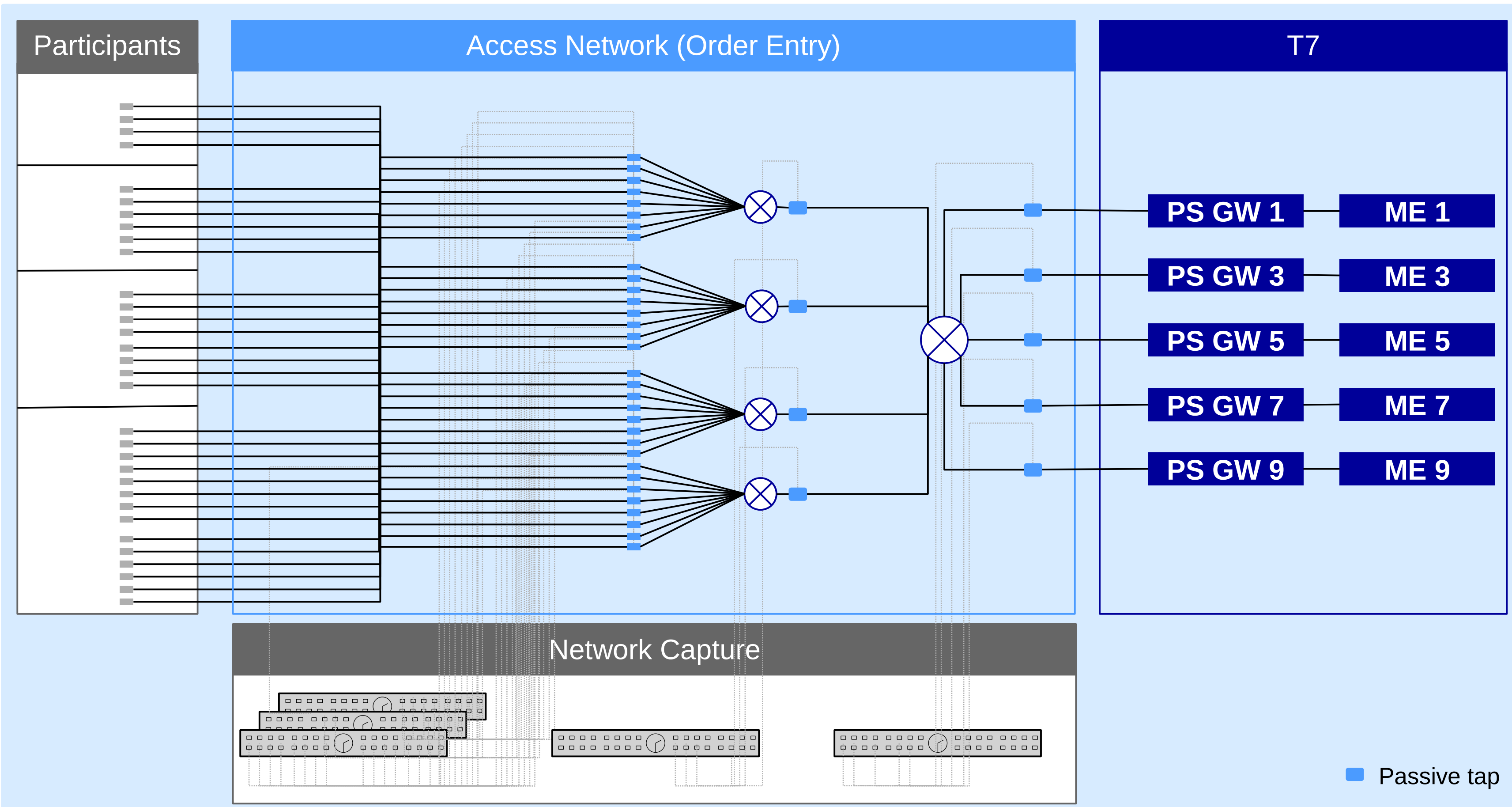
T7® Co-location
Timestamps



- Timestamps provided in T7 API (real-time) in dark blue (t_3n: taken by network card, other: application level)
- Network timestamps taken using taps & timestamping switches
- Timestamps possibly taken by participants are shown in grey

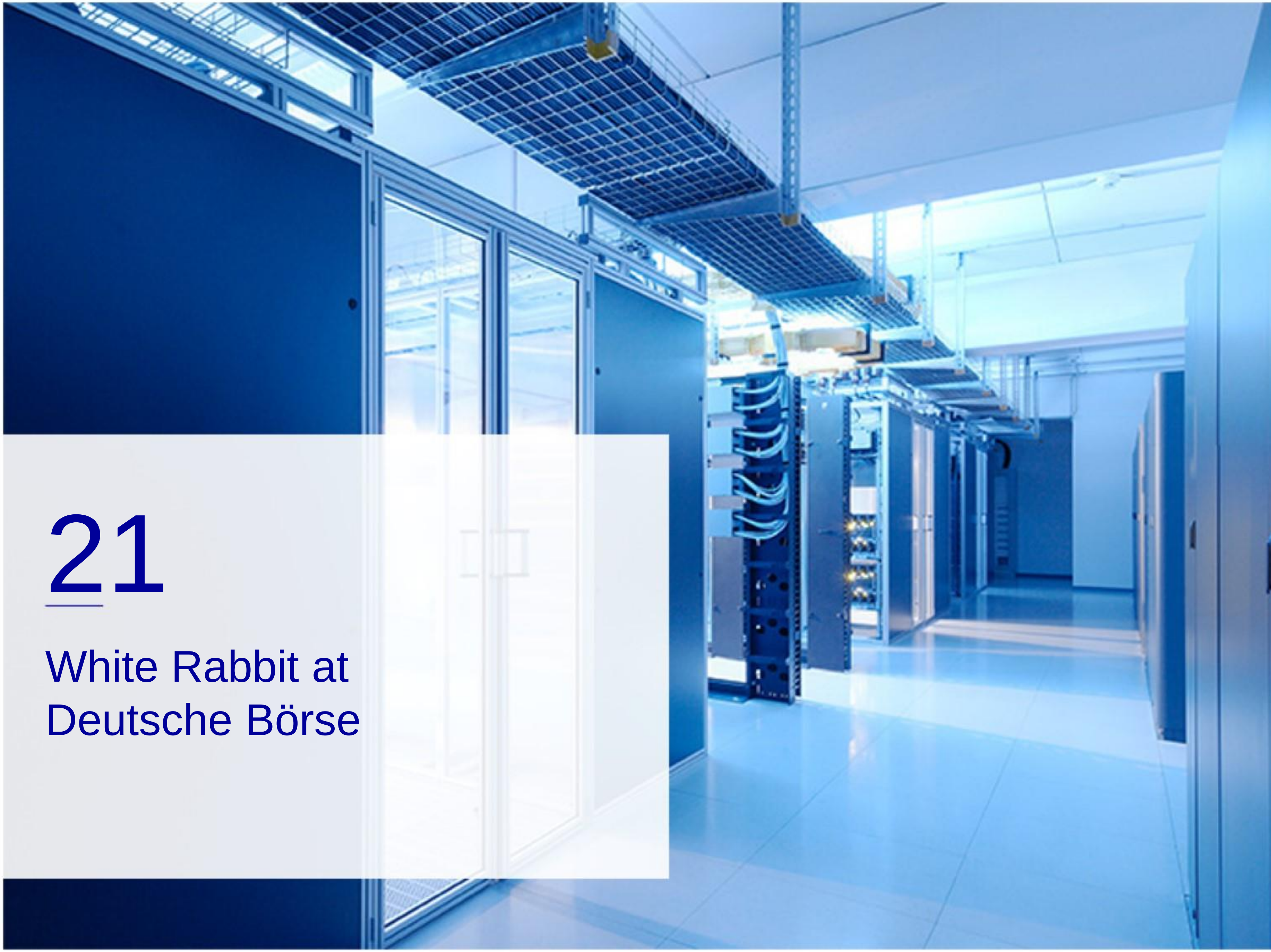
T7® Co-location

Scale (> 500 capture ports, > 60 timestamping devices)



> 260 Order Entry lines captured (> 500 capture ports)

Identical setup regardless of participant room location and assigned access switch

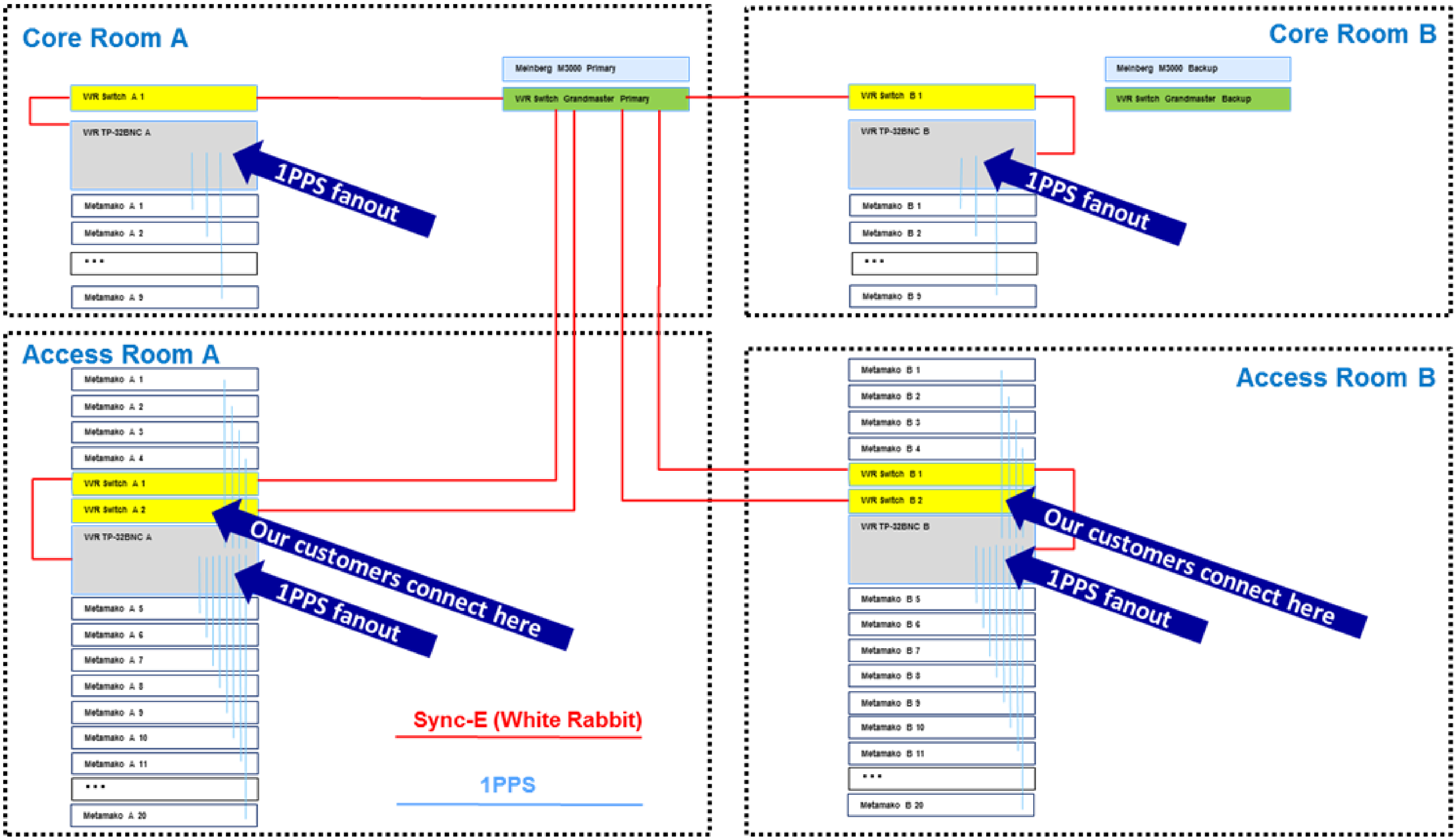


21

White Rabbit at Deutsche Börse

White Rabbit in T7® Co-location

60+ timestamping devices in 4 datacentre modules



Networking at an exchange is atypical (bursts)

How do we measure this?

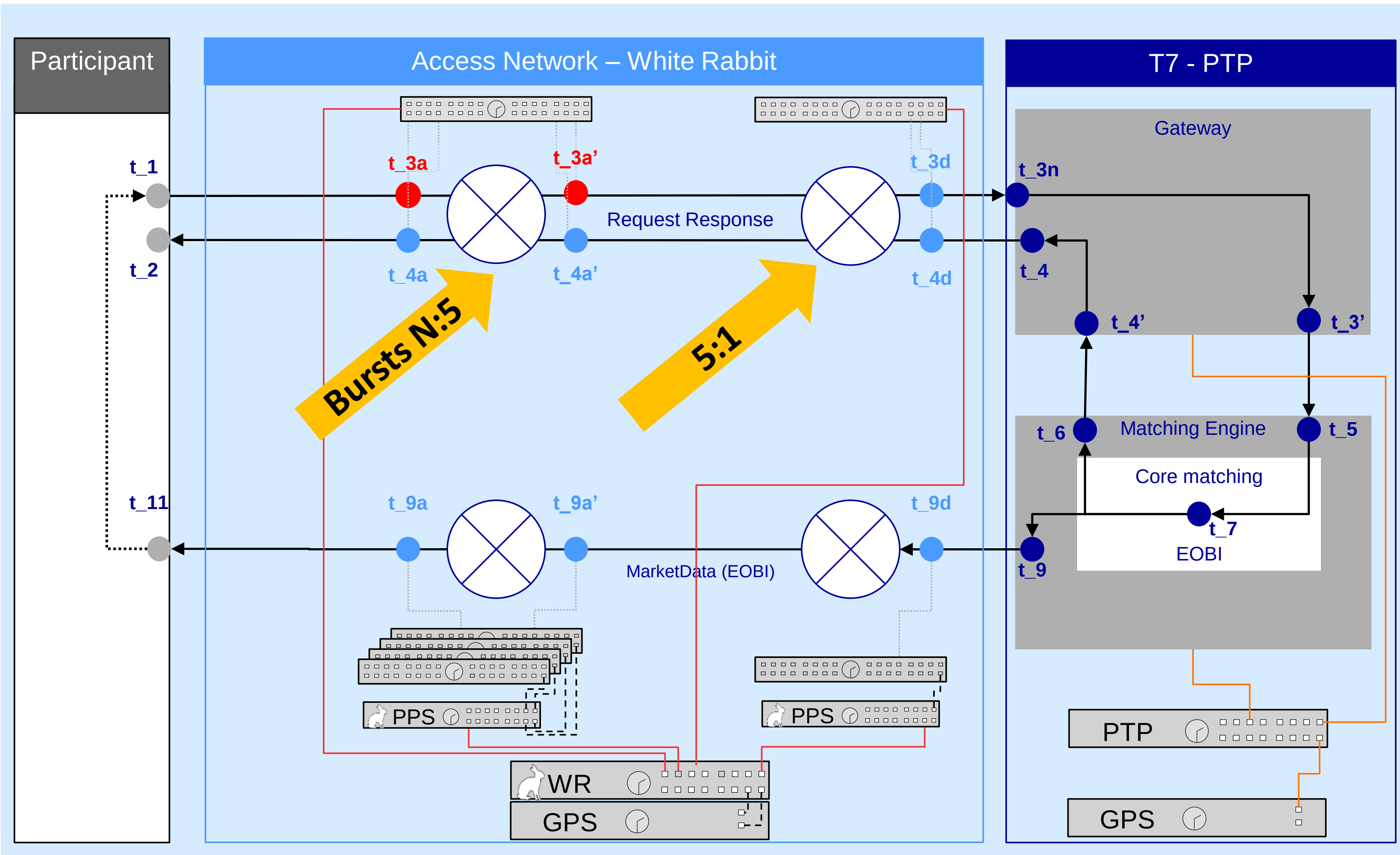
Why do we need something as precise as White Rabbit is?

Access Network – White Rabbit

	switch.in	switch.out	delta.I	delta.o	latency
1	15:38:58.056,303,467	15:38:58.056,303,736	0	0	269
2	15:38:58.056,303,473	15:38:58.056,303,855	6	119	382
3	15:38:58.056,303,477	15:38:58.056,304,095	4	240	618
4	15:38:58.056,303,478	15:38:58.056,303,976	1	-119	498
5	15:38:58.056,303,505	15:38:58.056,304,217	27	241	712
6	15:38:58.056,303,542	15:38:58.056,304,335	37	118	793
7	15:38:58.056,303,548	15:38:58.056,304,457	6	122	909
8	15:38:58.056,303,589	15:38:58.056,304,575	41	118	986
9	15:38:58.056,303,593	15:38:58.056,304,697	4	122	1104
10	15:38:58.056,303,651	15:38:58.056,304,815	58	118	1164
...					
50	15:38:58.056,305,335	15:38:58.056,309,250	44	99	3915
51	15:38:58.056,305,390	15:38:58.056,309,365	55	115	3975
52	15:38:58.056,305,446	15:38:58.056,309,464	56	99	4018
53	15:38:58.056,305,492	15:38:58.056,309,580	46	116	4088
54	15:38:58.056,305,561	15:38:58.056,309,679	69	99	4118
55	15:38:58.056,305,592	15:38:58.056,309,794	31	115	4202
56	15:38:58.056,305,674	15:38:58.056,309,894	82	100	4220

T7® Time synchronisation

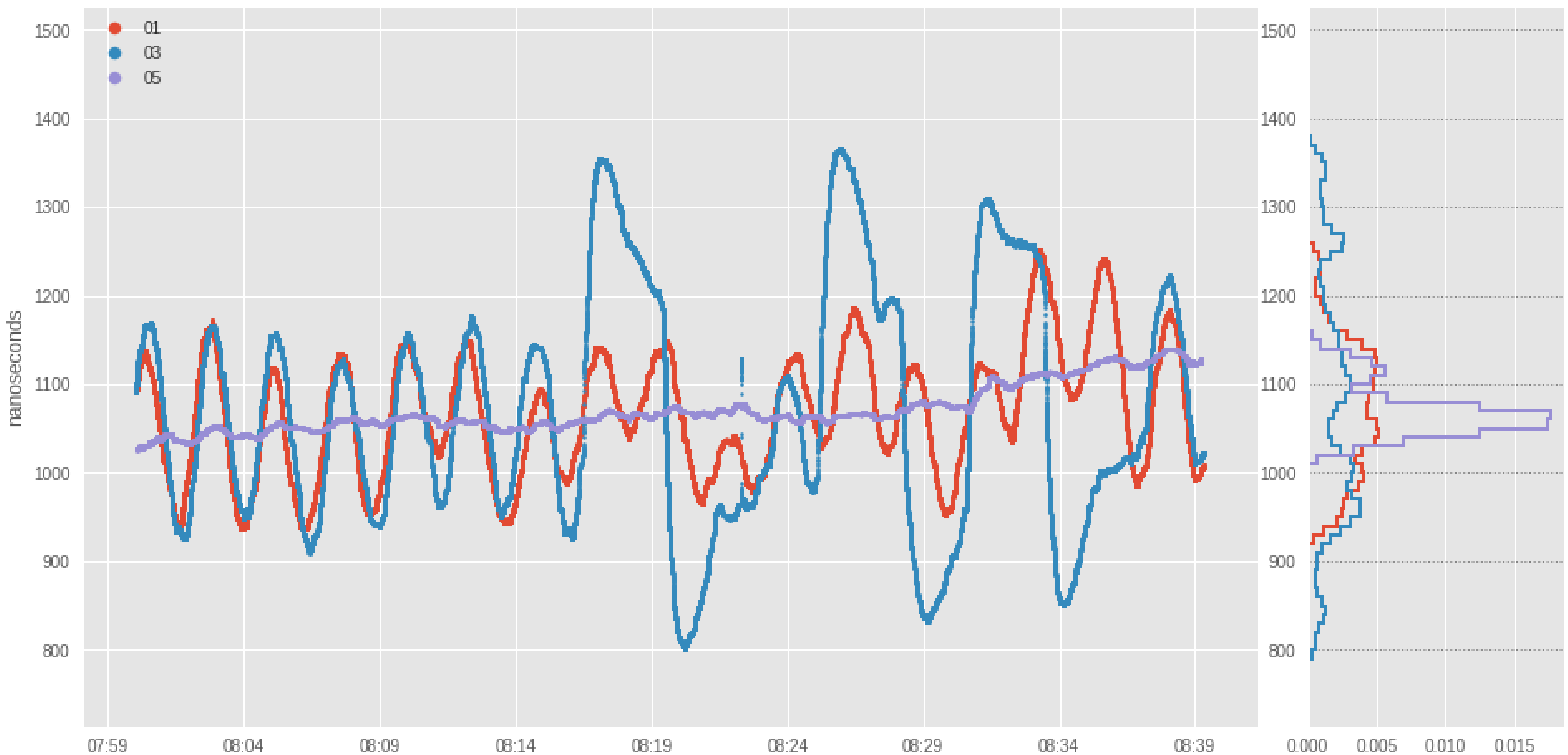
White Rabbit synchronised timestamps



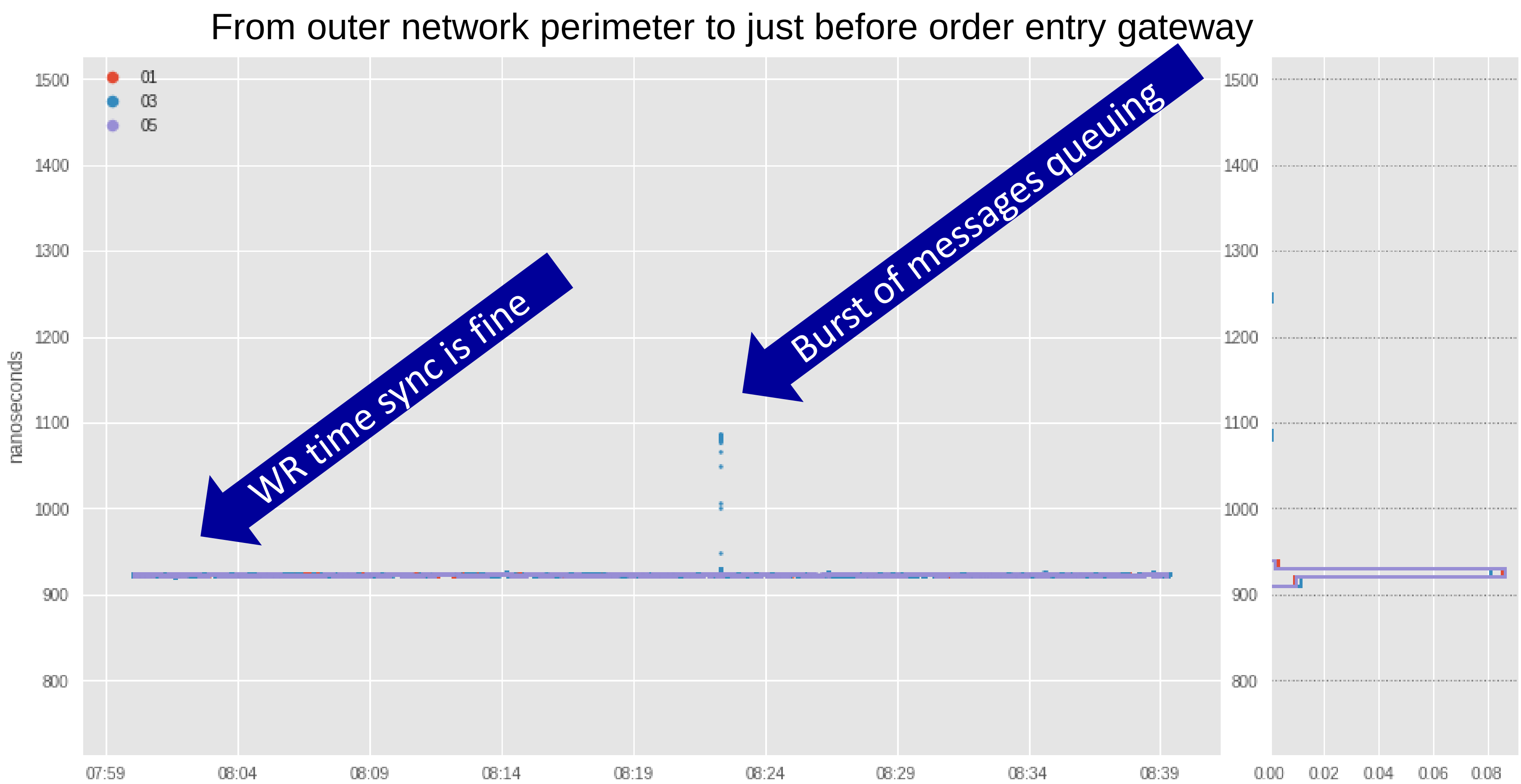
T7® Time synchronisation

How would we cope with PTP?

From outer network perimeter to order entry gateway

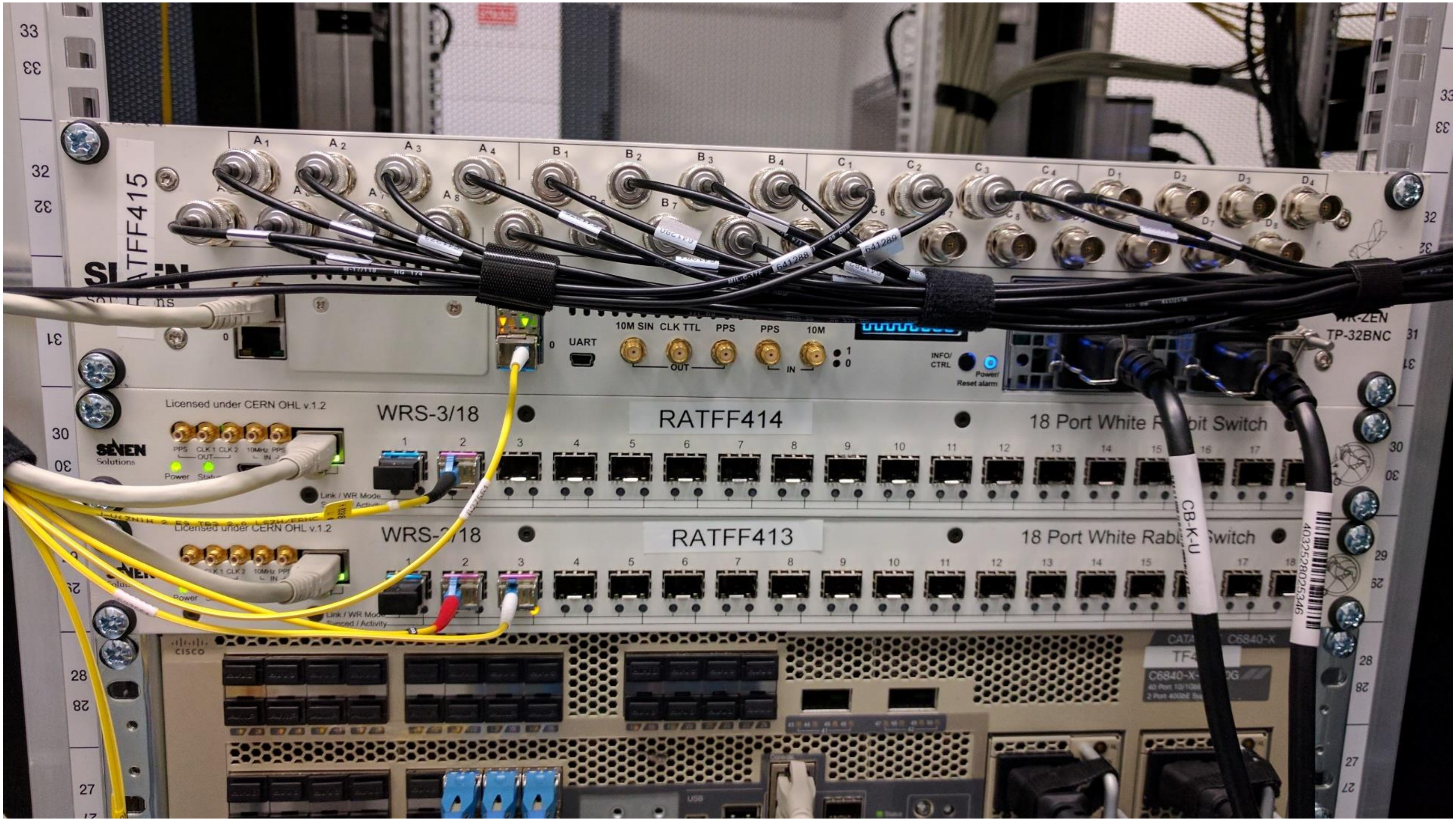


T7® Time synchronisation
We use White Rabbit



White Rabbit

Timestamping Devices synchronised by 1PPS



White Rabbit

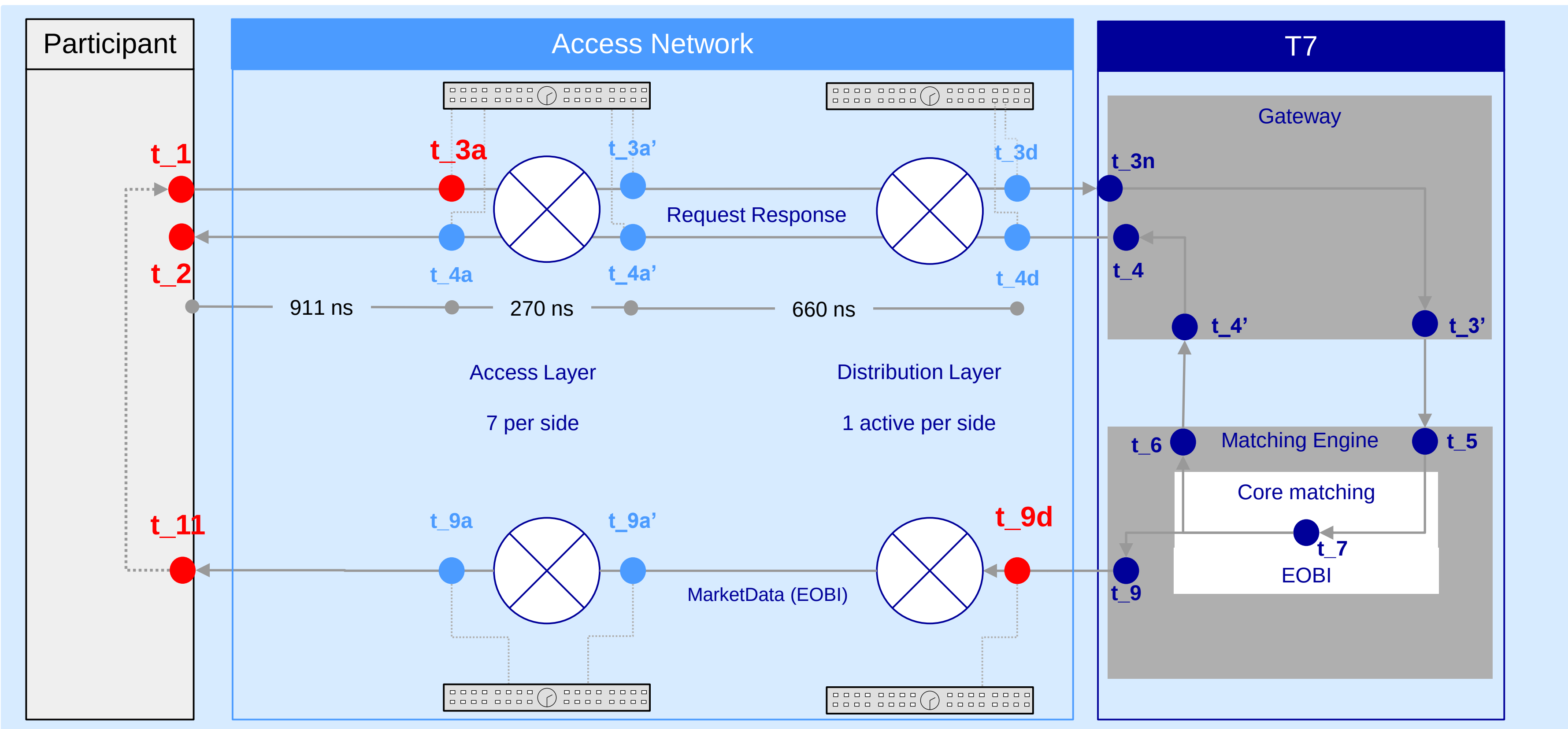
Timestamping Devices synchronised by 1PPS

29

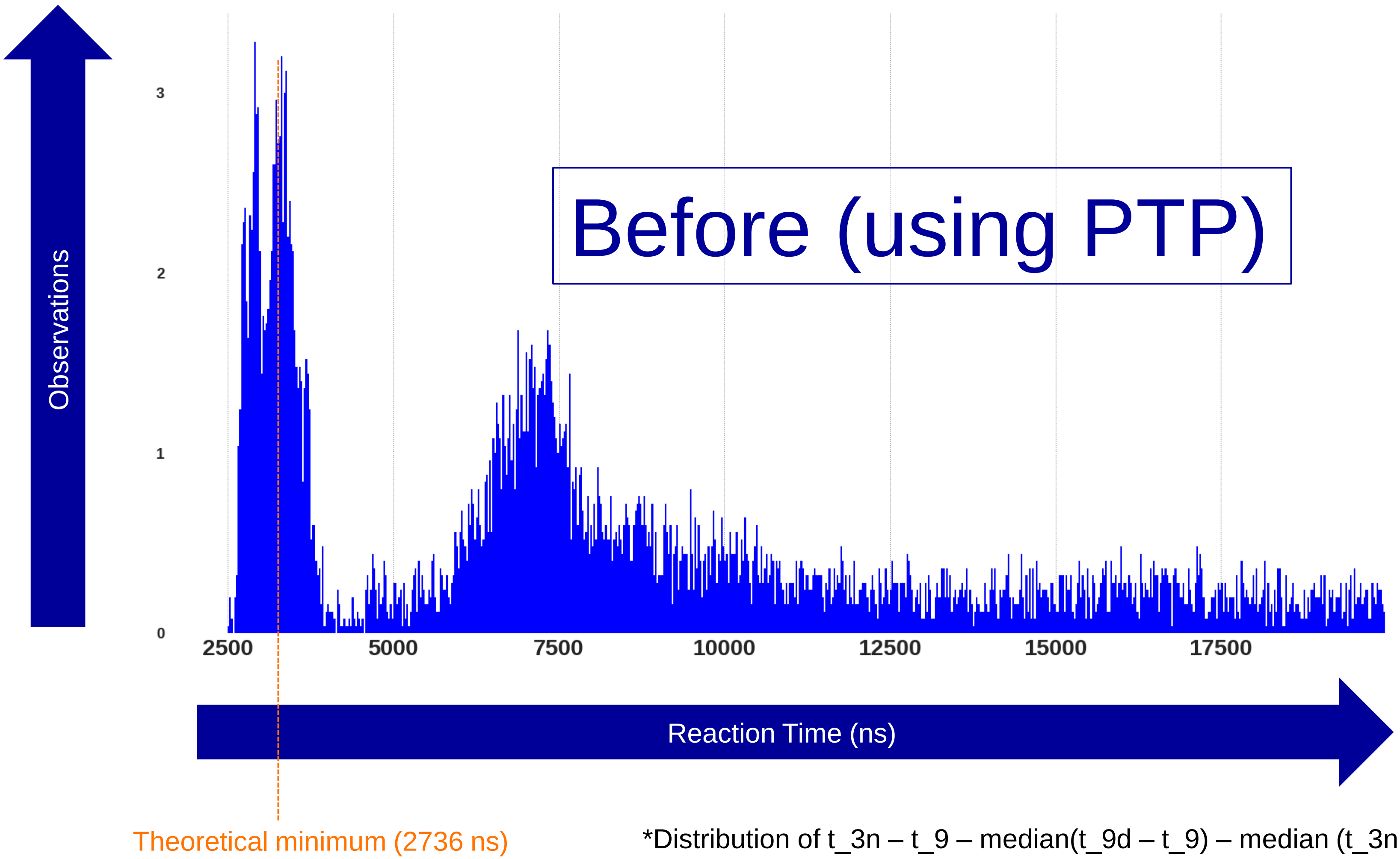
Services for our customers

Services for our customers

1. High-Precision Timestamp File (what is my delta to faster competitors)
2. Customer can now synchronise with out WR master
3. Customer can now get UTC from our WR

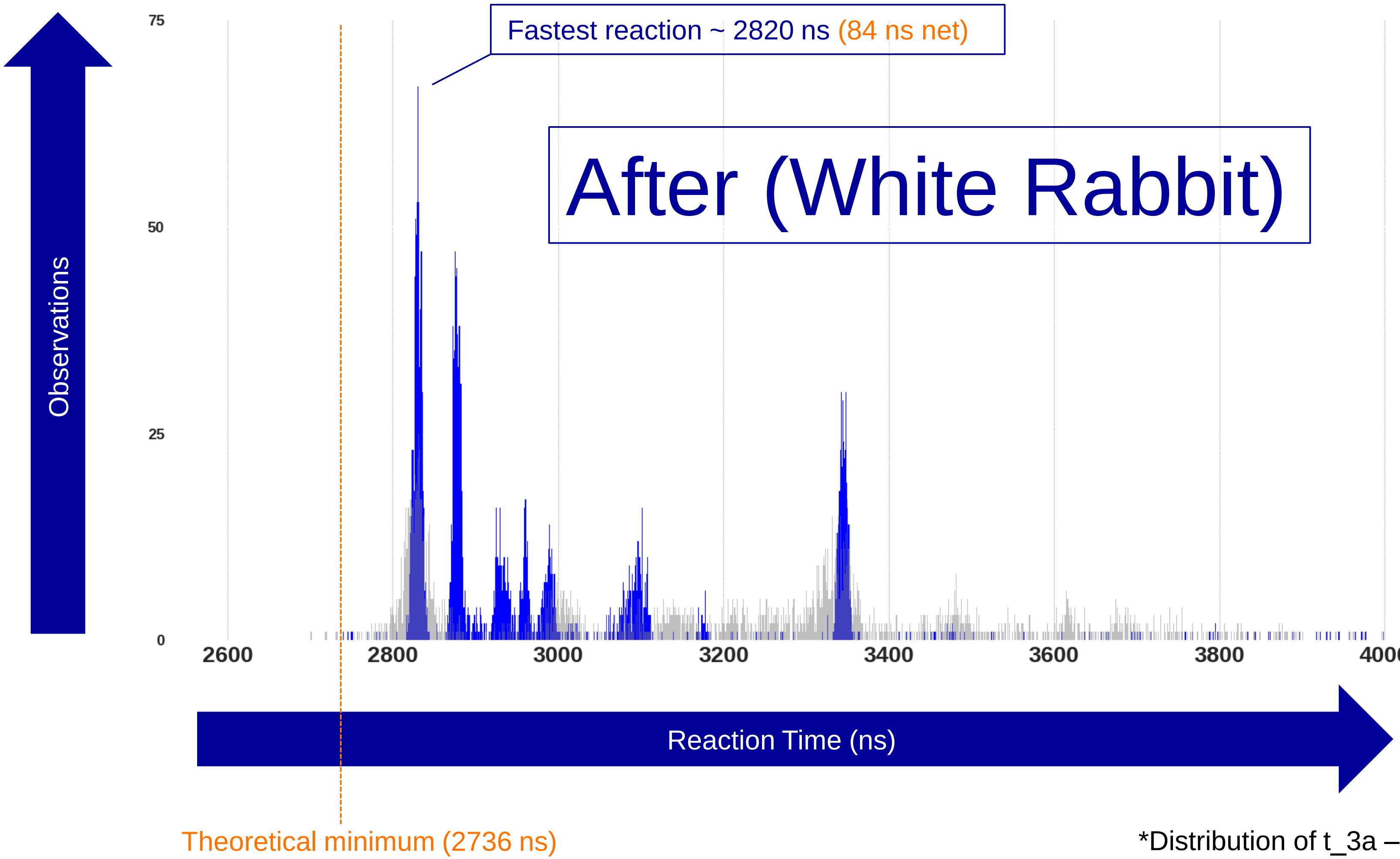


High Precision Timestamp File



*Distribution of t_3n – t_9 – median(t_9d – t_9) – median (t_3n-t_3a) shown

High Precision Timestamp File



*Distribution of t_3a – t_9d

33

Experiences

Experiences

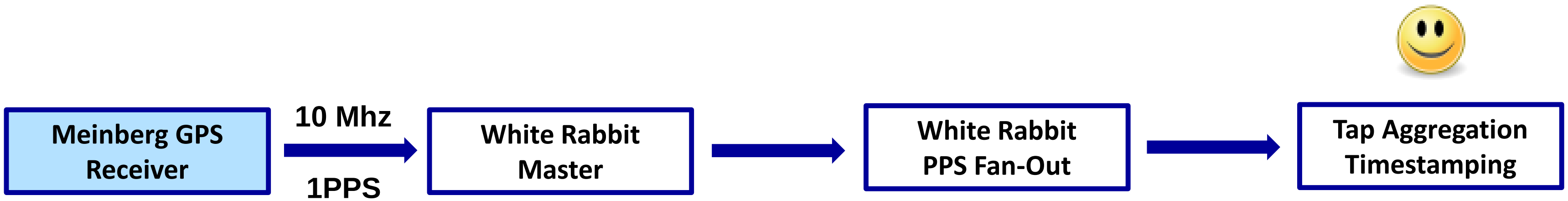
Our data centre cabling infrastructure not a good fit the single strand fibre cables we use for White Rabbit. The patch panels always come with two connectors (for RX and TX), but we need only one of those connectors. We cannot tell in advance which of the two connectors will actually be used.

The White Rabbiot switches and PPS fan-out devices do not have standard serial “console” port for remote management. This will hopefully be addressed in the next switch design.

White Rabbit grandmaster picked up a wrong time-of-day information at startup. The time distribute via WR was off by precisely 1 or 2 seconds. This was a software bug fixed by vendor in the meantime.

Feedback

Normal Operation – Sync error in timestamping devices is less than +/- 1ns

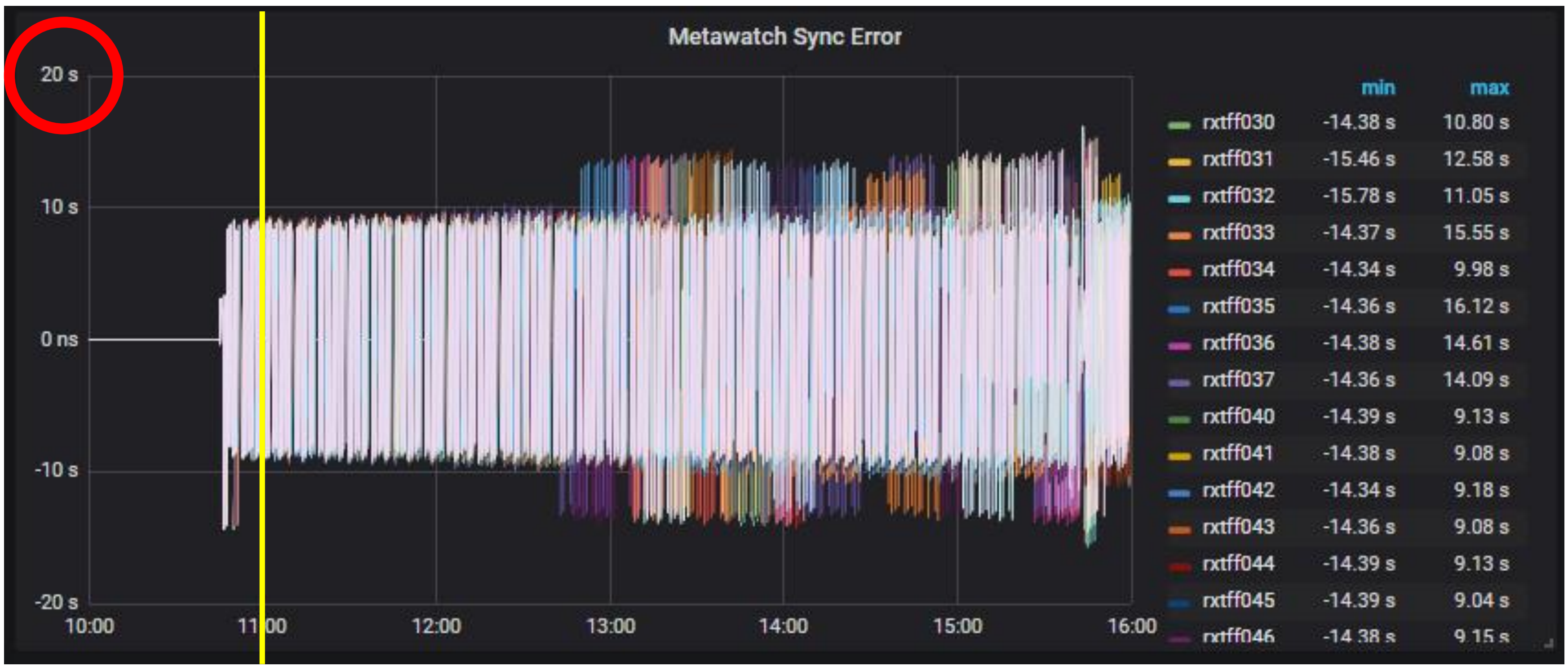


Feedback

Planned work on GPS receiver on a Saturday
GPS service was restored by 11:00 (yellow bar)

~~Meinberg GPS Receiver~~

White Rabbit Master → White Rabbit PPS Fan-Out → Tap Aggregation Timestamping



37

Conclusion

Conclusion

We have reached our goal of sub 10ns synchronisation of all capture devices.

We realize that we are not using all of White Rabbit's features. Essentially, we use it to distribute 1PPS over fibre optic cables. We look forward to having more vendor support for White Rabbit in the future. This would enable full end-to-end White Rabbit time distribution.

We are confident enough to provide White Rabbit based services to real, paying customers.

We would like to thank the White Rabbit project and community for all their hard work.

Also, many thanks to Cesar Prados and Ralph Baer at GSI for giving us our first White Rabbit demonstration.

Thank you for your attention

Contact
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E-Mail andreas.lohr@deutsche-boerse.com

40

Appendix

Matching Algorithms
Measures to Reduce Need for Speed

Actual

- Various “Speed Bumps”
  – Magic shoe box = long box of coiled up cable
  – “Latency floor”

- Passive Liquidity Protection on Eurex
  – New orders that could match with resting orders in the limit order book will be deferred
  – Pilot phase launched German (1ms delay) and French (3ms delay) equity options

- Last Look
  – Liquidity provider has additional time to device whether to accept a trade or not
  – Used in foreign exchange markets (currencies)

Matching Algorithms
Measures to Reduce Need for Speed

Proposals

- Frequent Batch Auctions
  - https://faculty.chicagobooth.edu/eric.budish/research/HFT-FrequentBatchAuctions.pdf