



Understanding an ultra-fast market through ultra-accurate time synchronization

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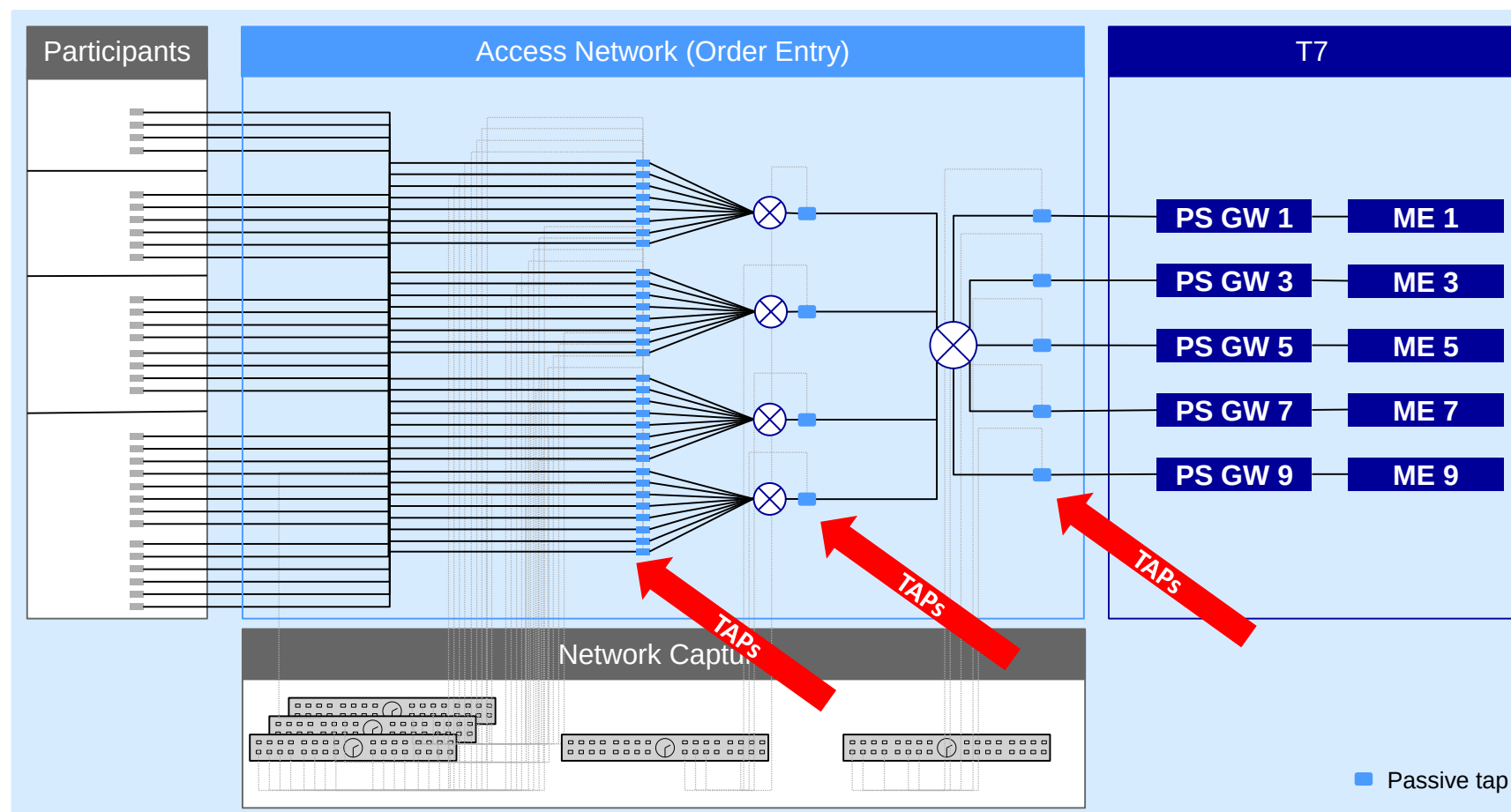
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Problem Statement

How to capture and timestamp all customer cross-connects in co-location?

- 500+ capture ports
- 60+ capture devices
- 4 data center modules
- PTP +/- 60ns jitter in our infrastructure at best
- Serialization time of order entry message = 120ns
- Goal of sub-10ns precision
- Distances too long for PPS over coax cables



What is White Rabbit?

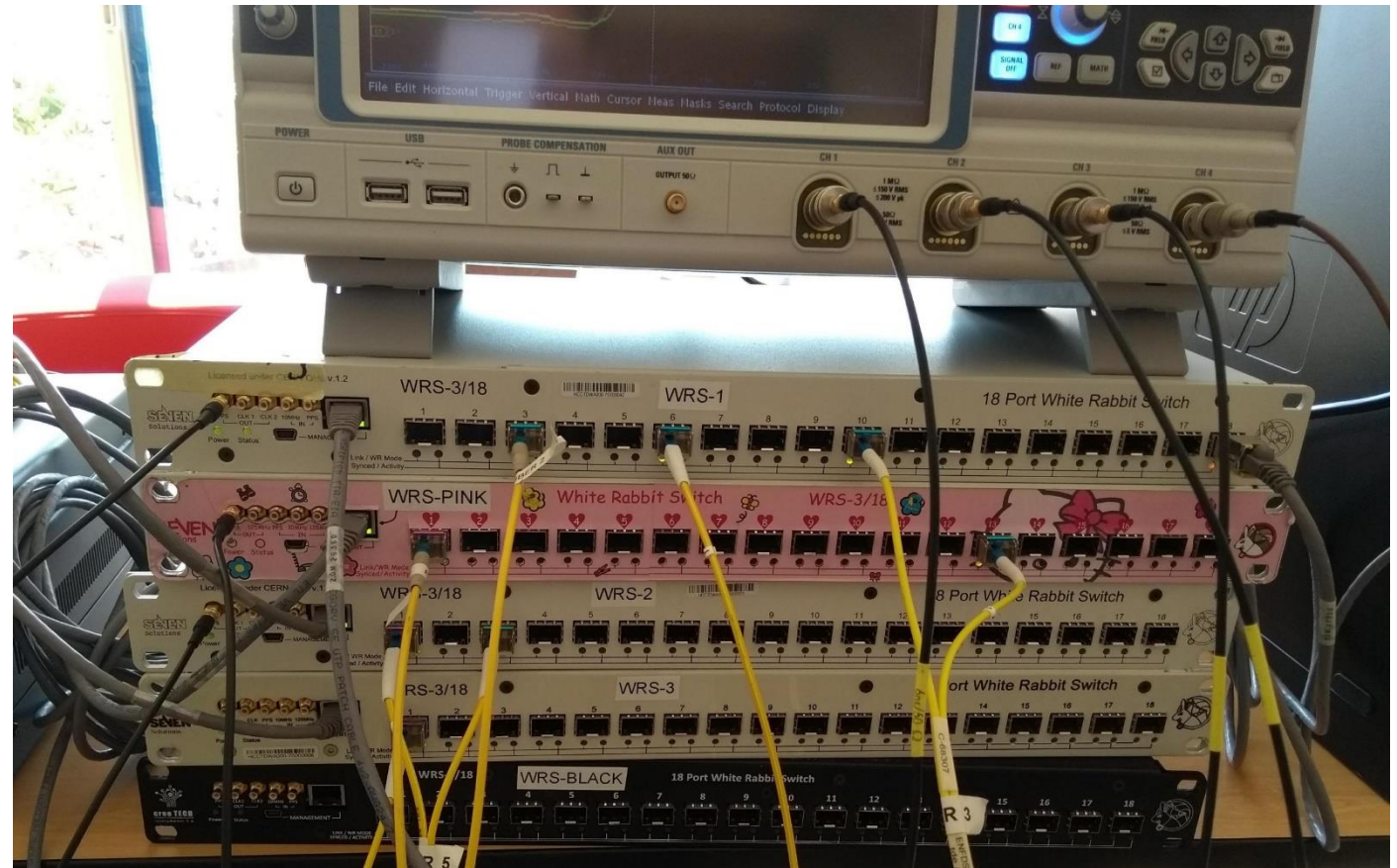
- White Rabbit is a fully deterministic Ethernet-based network for **data transfer** and **time synchronization**
- Initially developed at CERN
- Provides sub-nanosecond accuracy and picoseconds precision of synchronization
- Tried and tested
- PTP over Synchronous Ethernet
- White Rabbit is the High Accuracy profile of the future standard IEEE1588-20XX
- Commercially available (except the Hello Kitty model)

Issue for us:

No native White Rabbit support in NICs and switches

Solution:

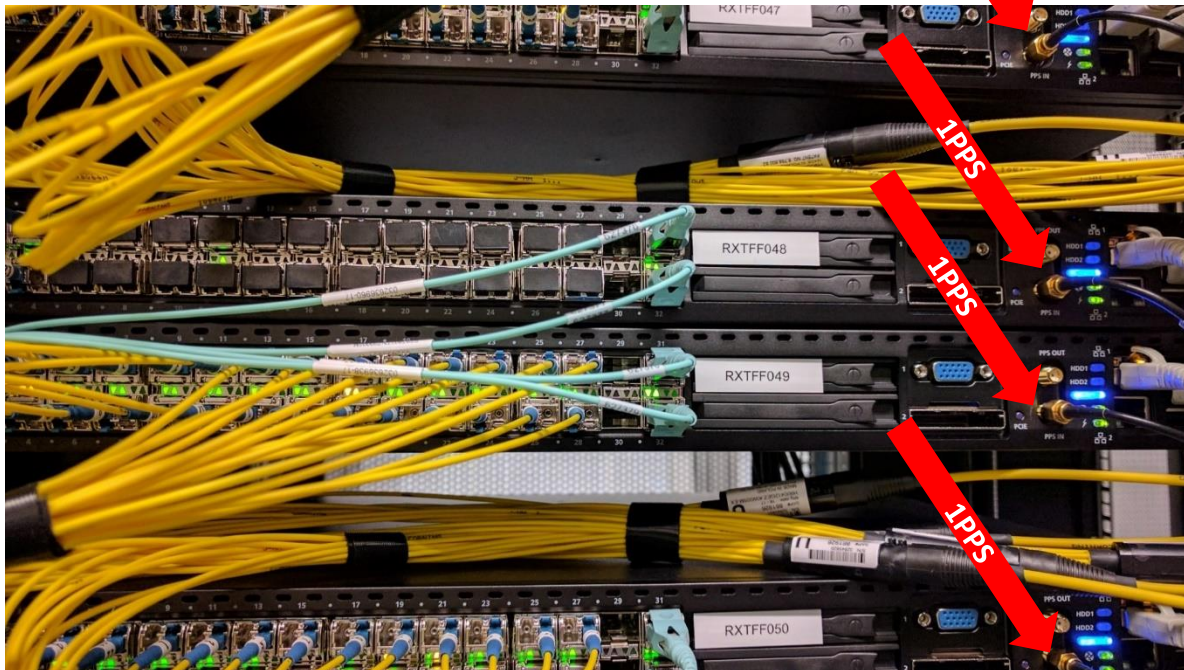
We use White Rabbit to distribute 1PPS



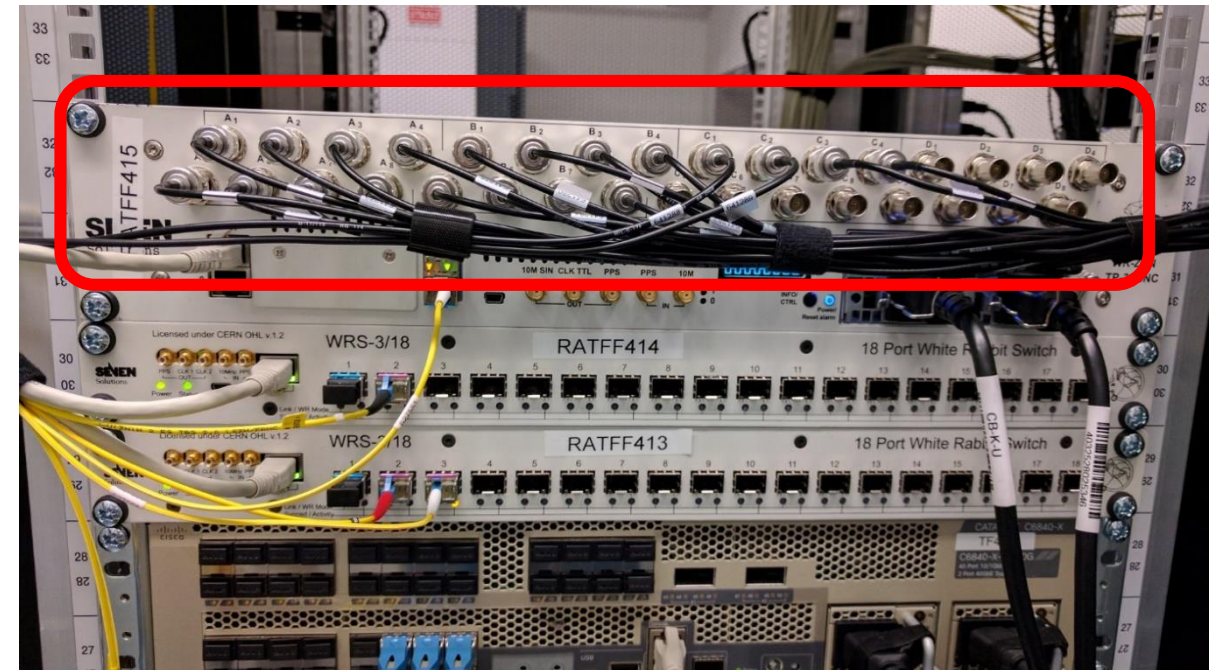
White Rabbit deployed hardware

Timestamping devices synchronized by 1PPS over White Rabbit

Capture Devices

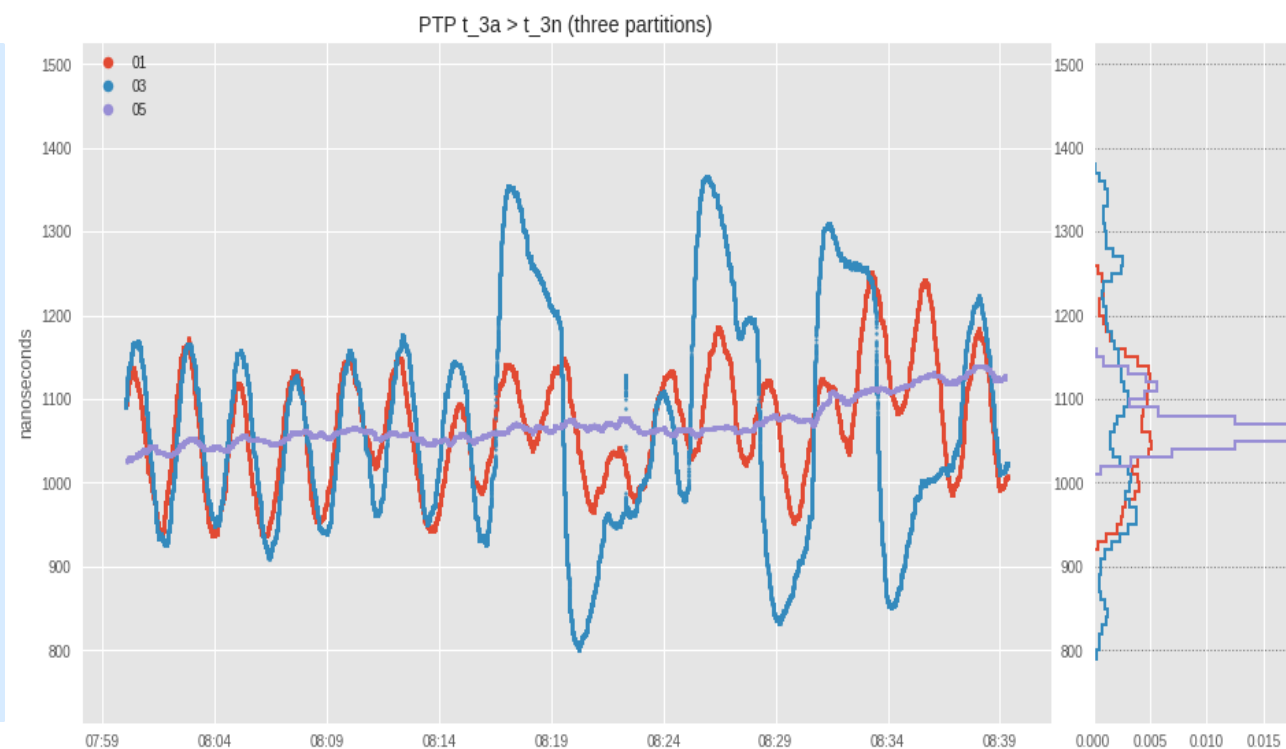
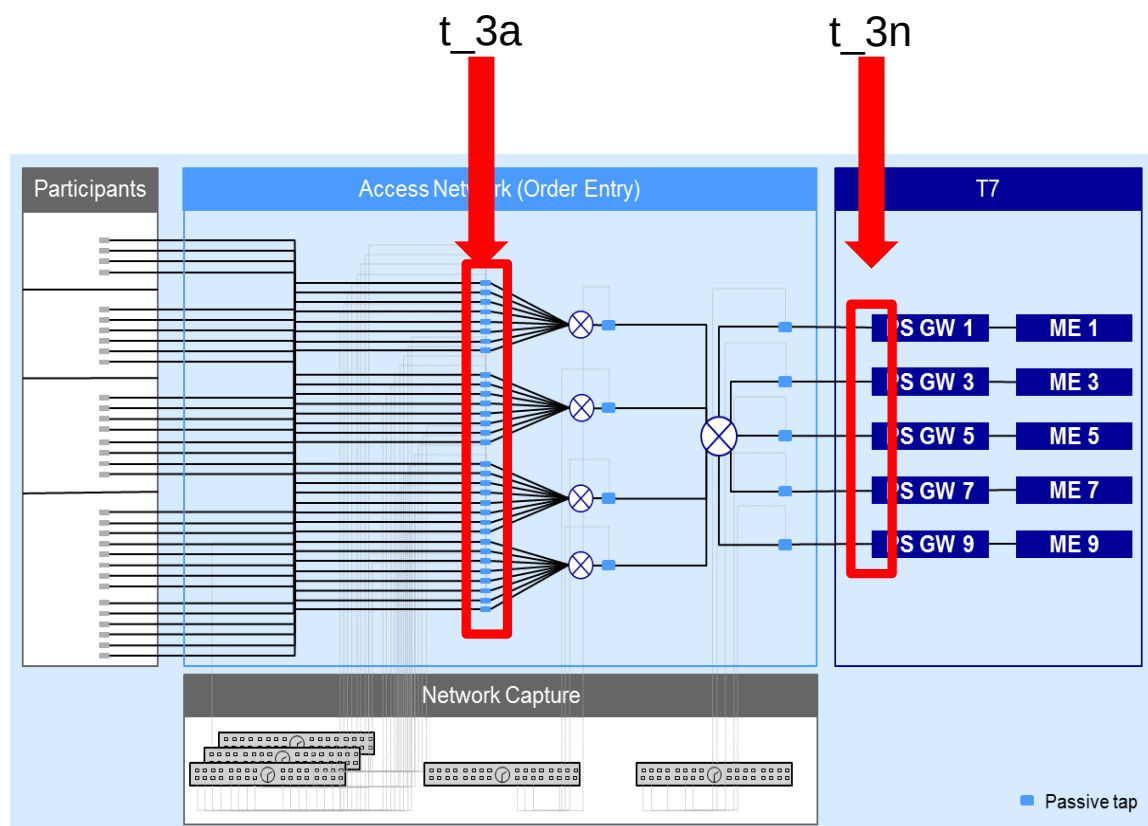


White Rabbit PPS Distribution Devices



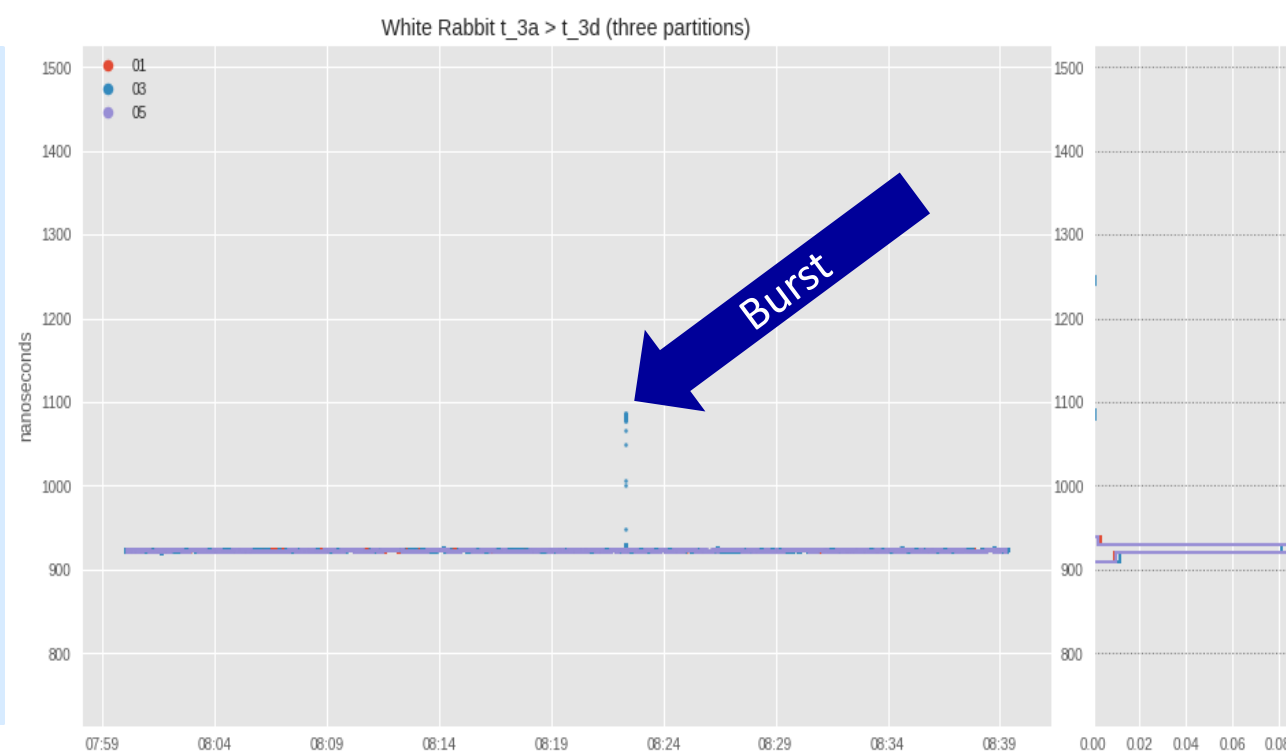
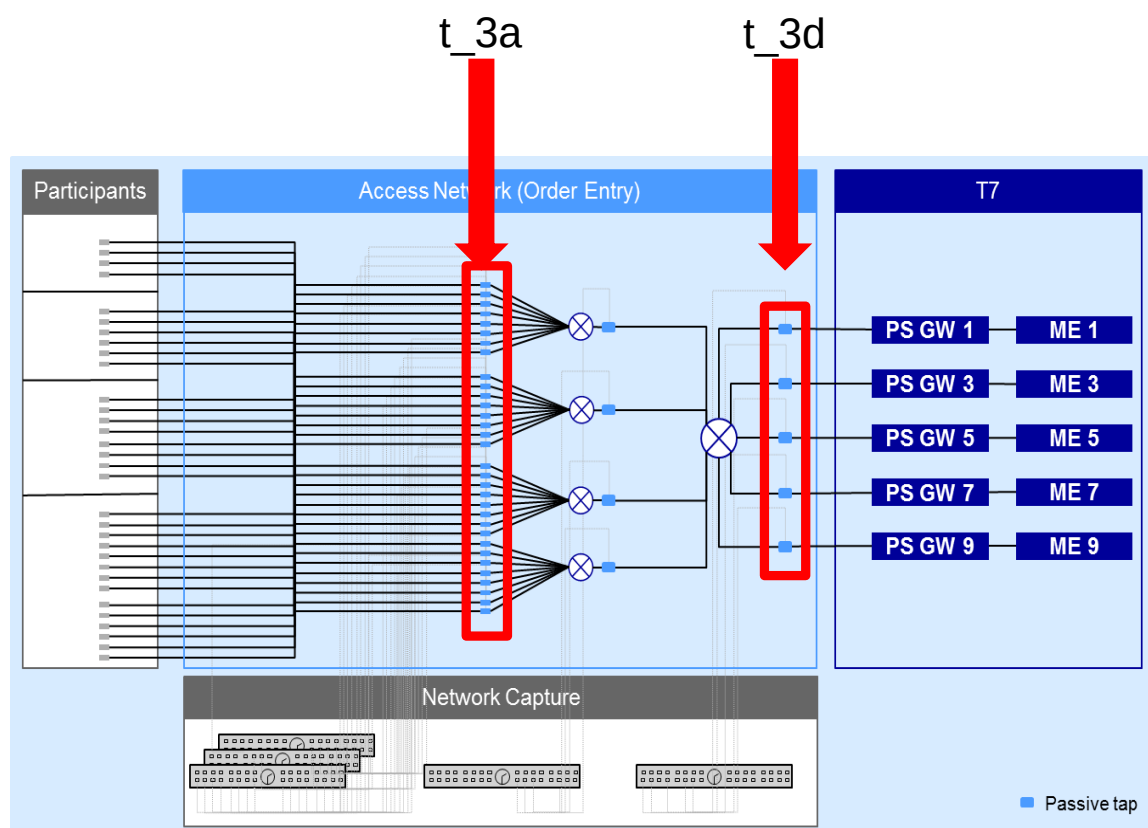
Time Synchronization

PTP Example



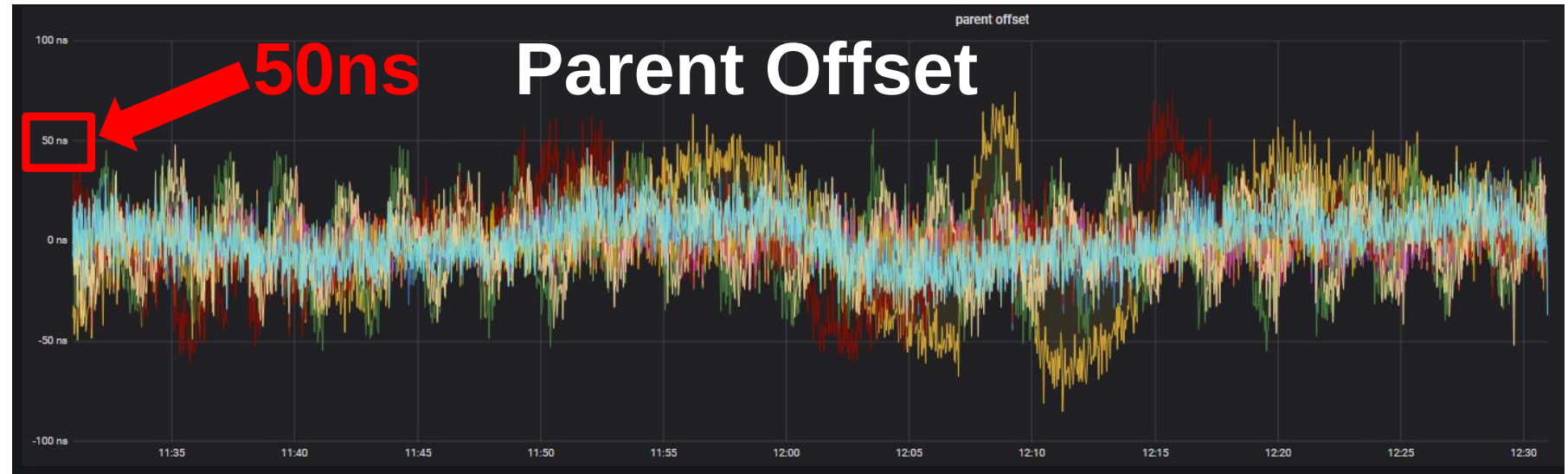
Time Synchronization

White Rabbit Example

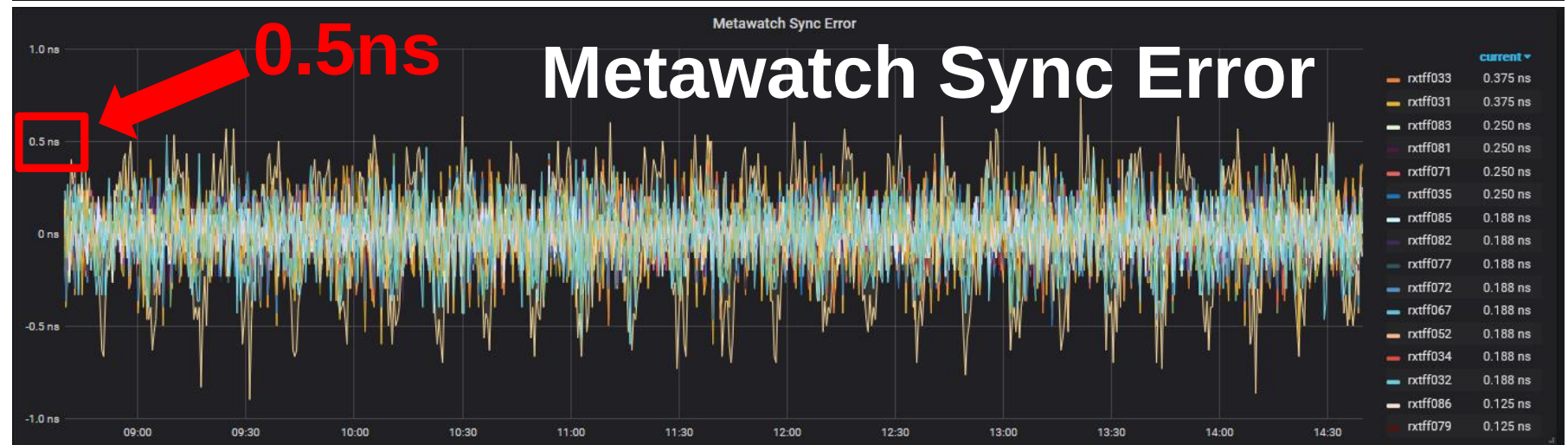


PTP / White Rabbit

PTP



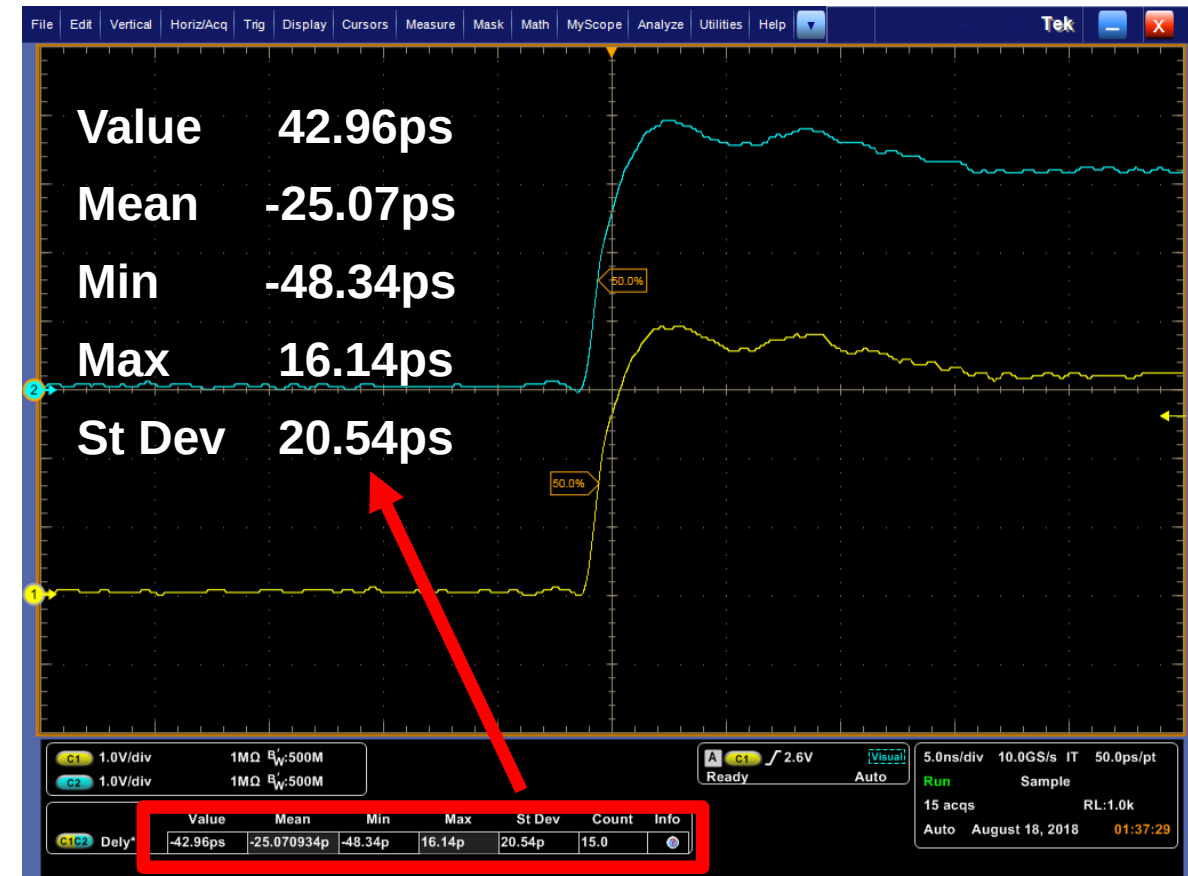
White Rabbit



White Rabbit Services for our Trading Customers

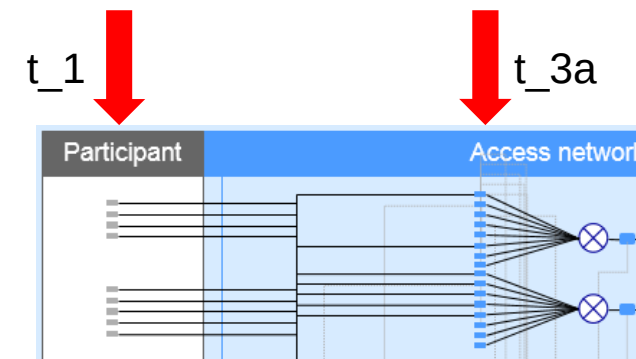
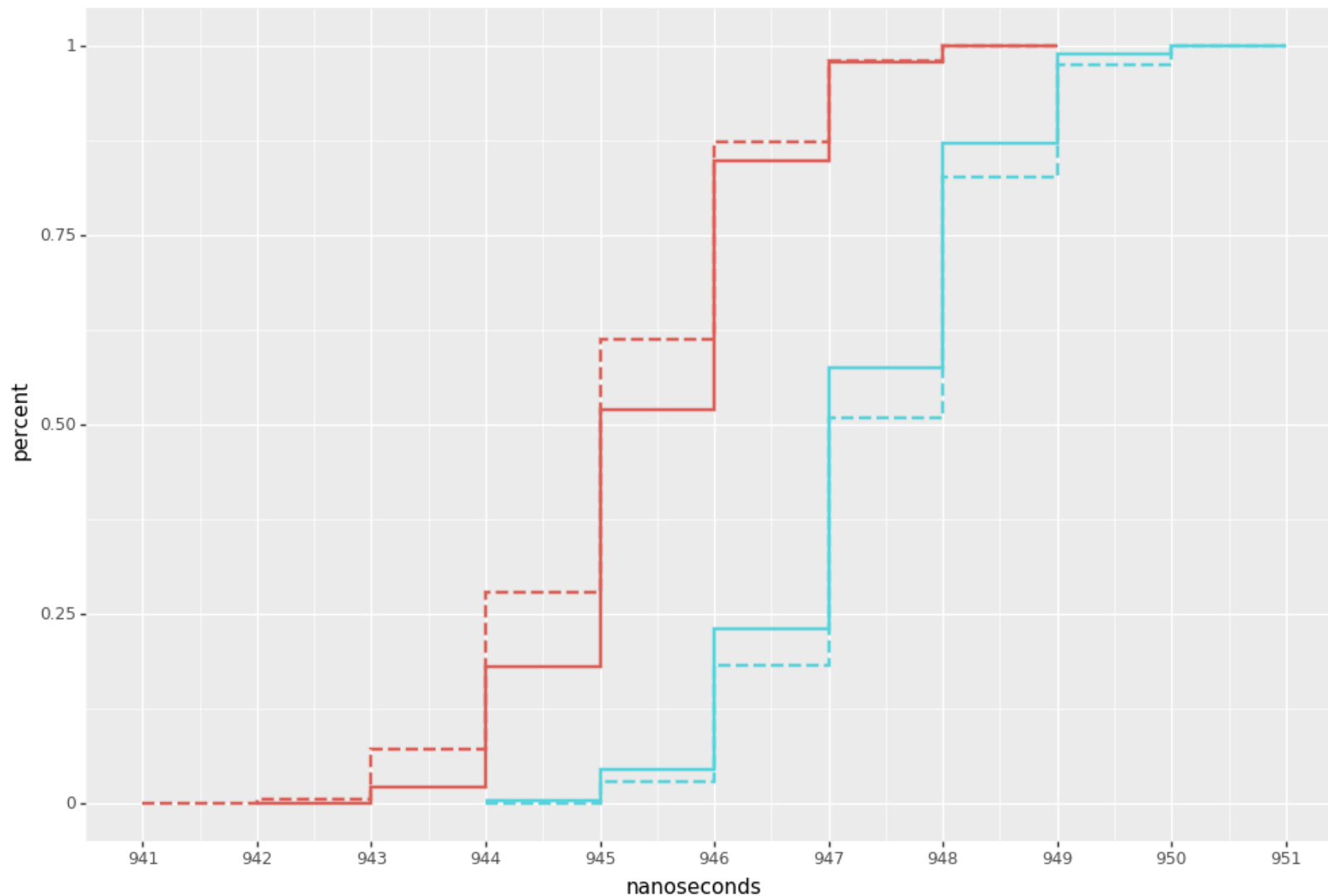
Launched two WR based services

1. High-Precision Timestamp (HPT) File (more in a moment)
2. High Precision Time Service (connect to our WR network)



White Rabbit Synchronized Timestamps

Latency from customer rack to t_3a (unadjusted, i.e. incl. cabling)



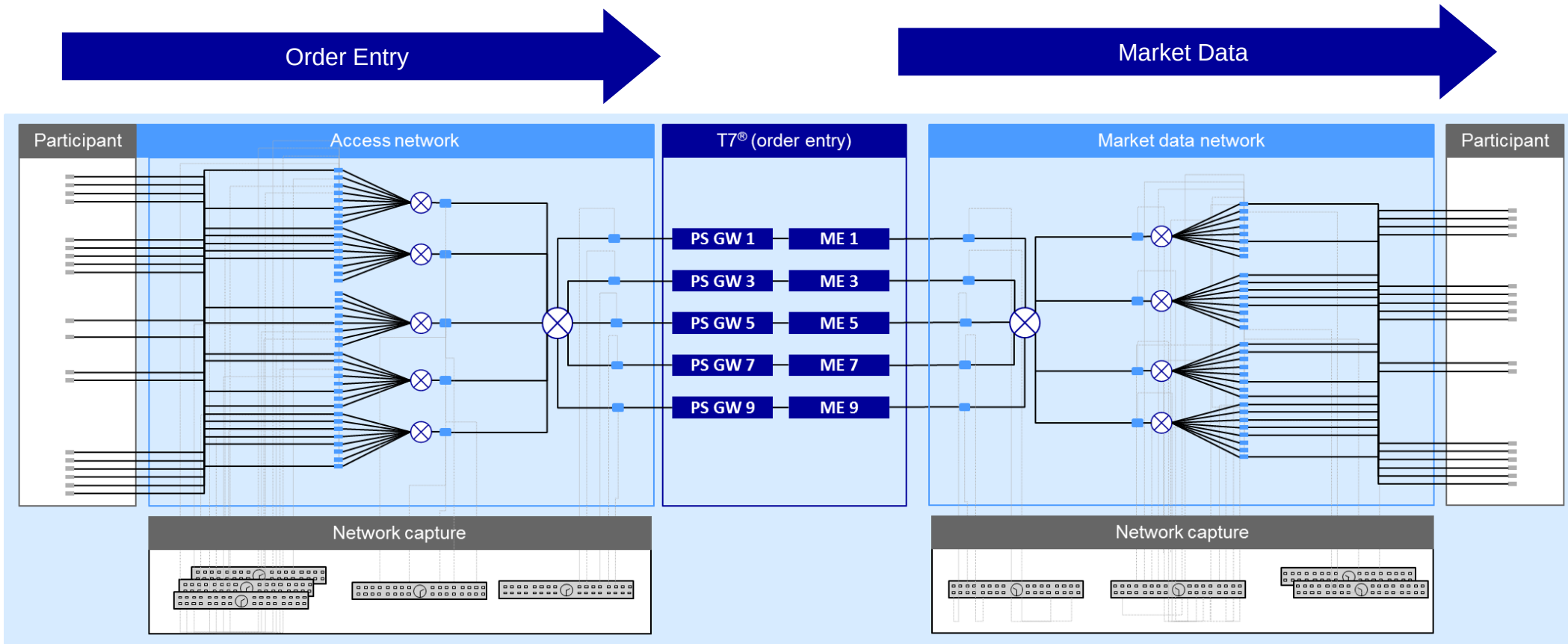
side	a	a	b	b
market	eurex	xetra	eurex	xetra
count	54007	53982	53989	53982
mean	945.4	945.2	947.3	947.5
std	1	1.2	1.1	1.1
min	942	941	944	944
5%	944	943	946	946
10%	944	944	946	946
25%	945	944	947	947
50%	945	945	947	947
75%	946	946	948	948
95%	947	947	949	949
99%	948	948	950	950
max	949	949	951	951
range	7	8	7	7

I will be right after the break



Network Design

Order Entry and Market Data Networks separated



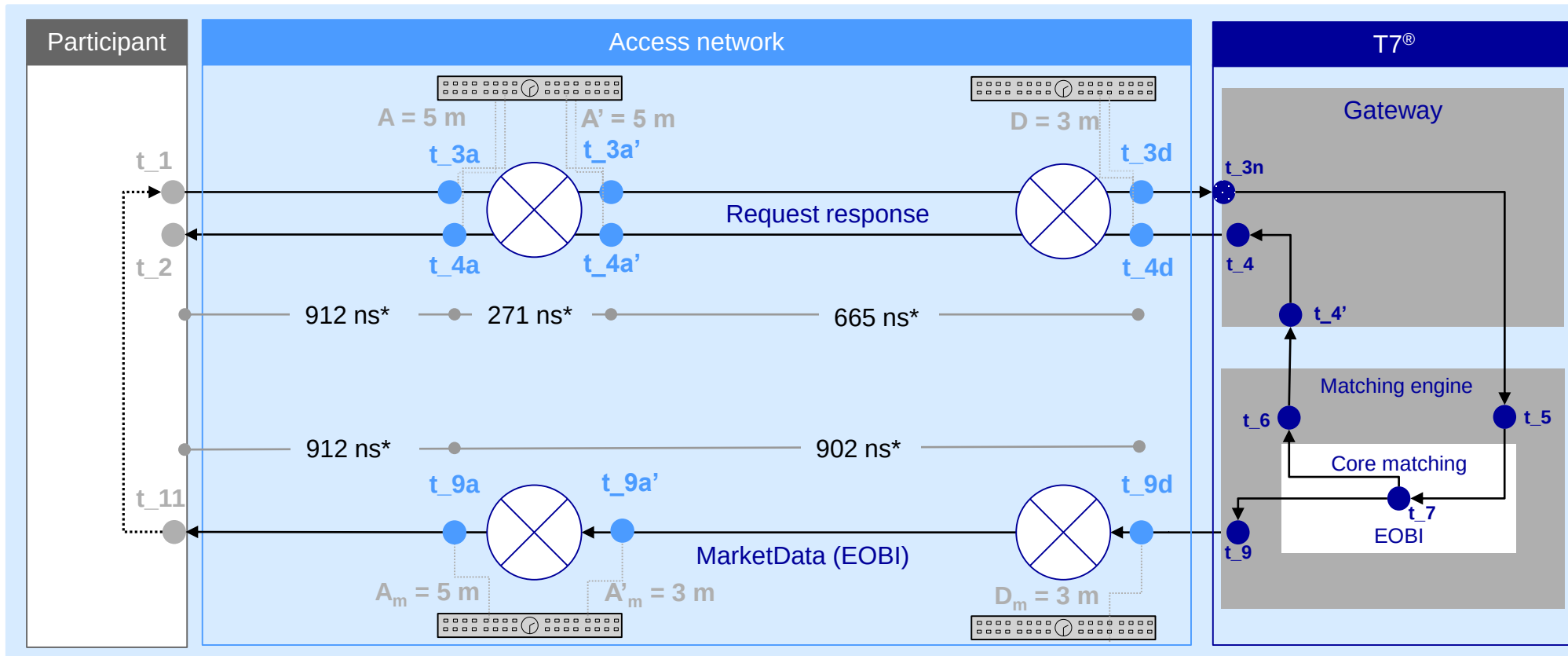
> 260 order entry lines individually captured (> 500 capture ports)

Identical set-up regardless of participant room location and assigned access switch

Only one side of one Market (Eurex) is shown for simplicity

Network Designs

Timestamps

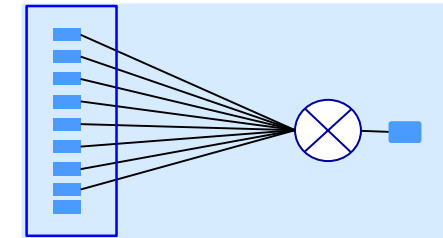
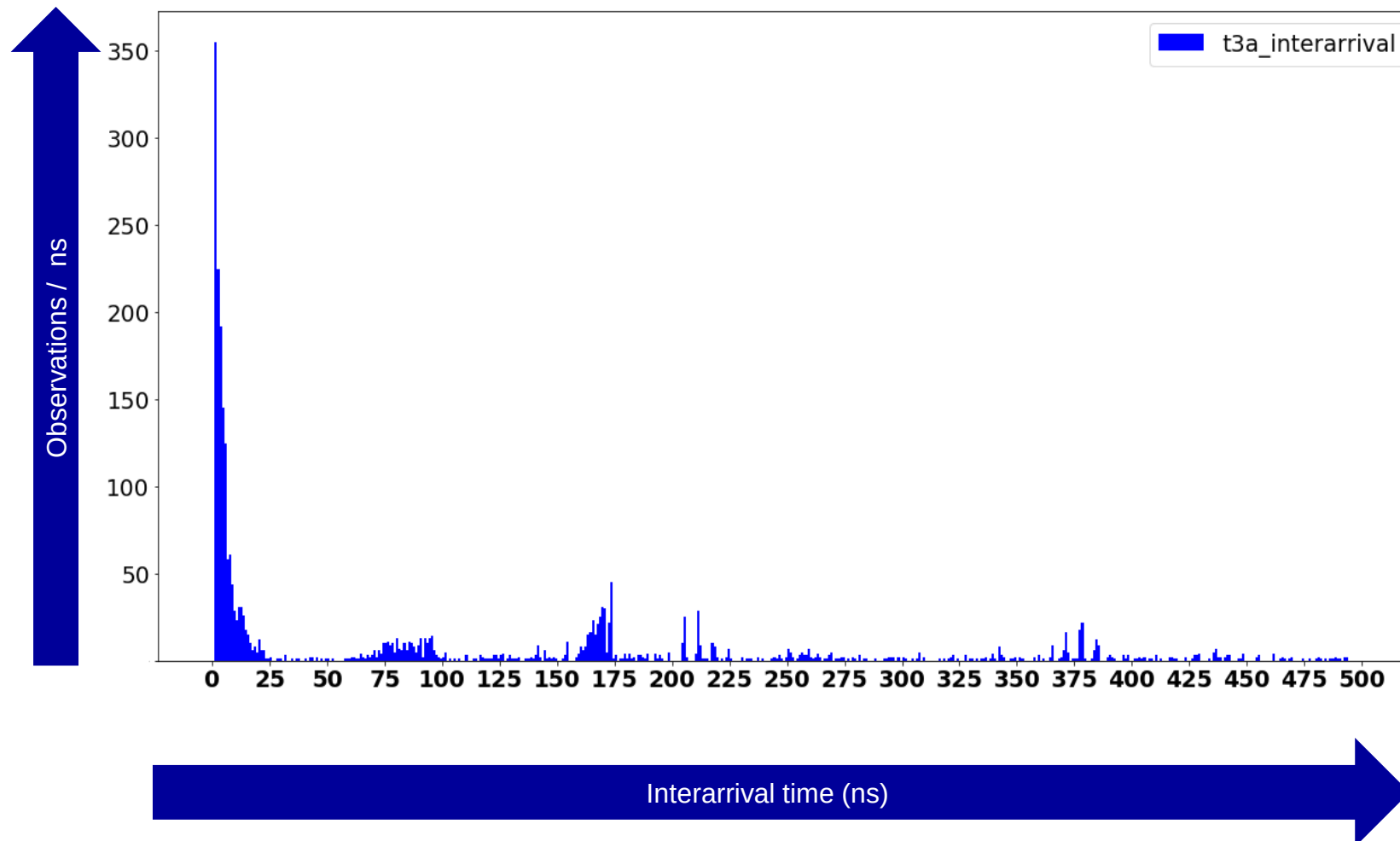


- Timestamps provided in T7 API (in real time) in dark blue (t_{3n} : taken by network card, other: application level)
- Network timestamps taken using taps and timestamping switches (Metamako)
- Timestamps possibly taken by participants shown in gray

*latencies are mid tap to mid tap on first bit

Why we need nanosecond precision and accuracy

Interarrival time at network entry (t_{3a})

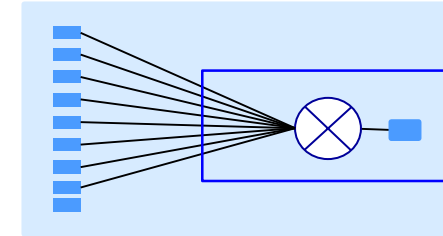
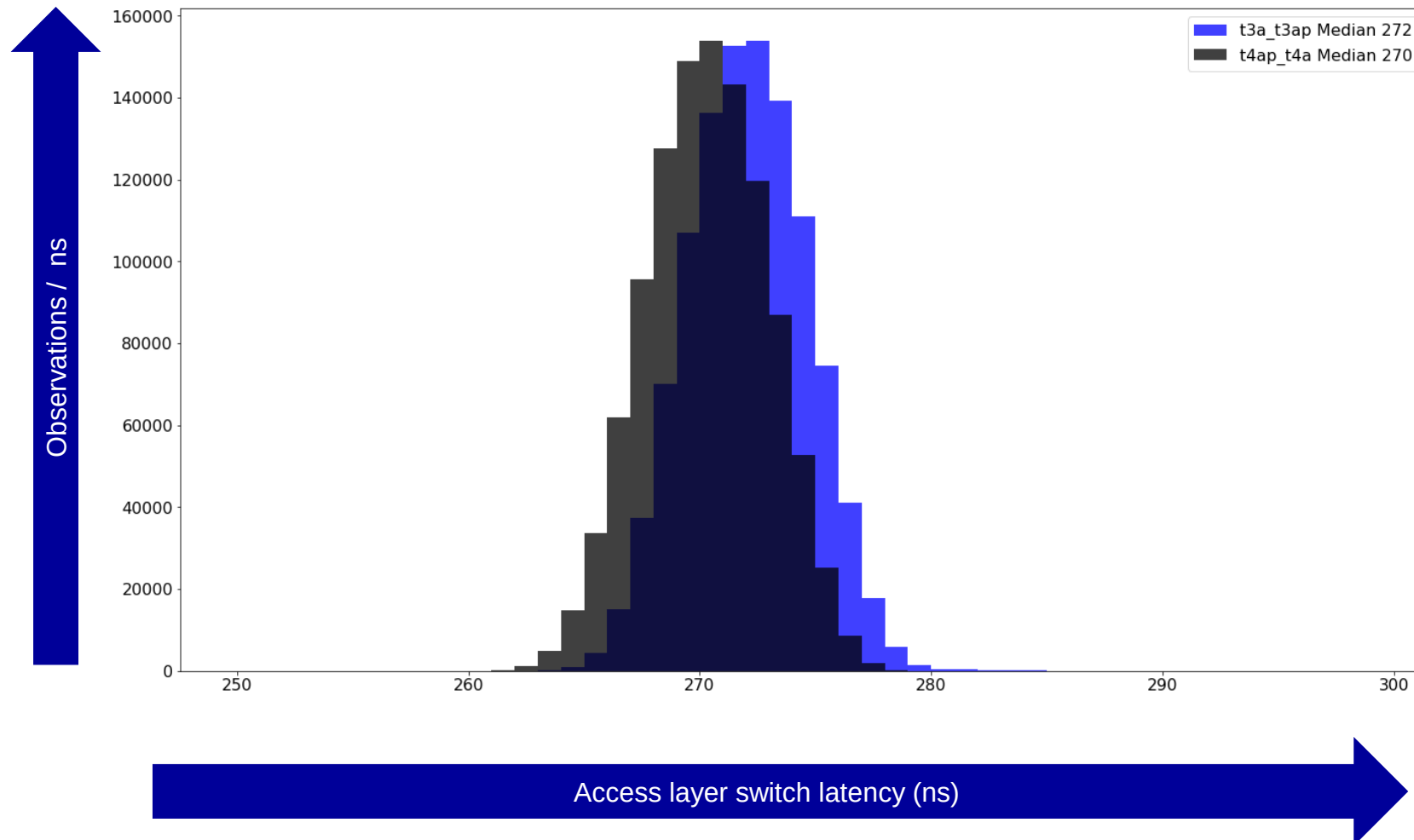


Interarrival time at t_{3a}
arbitrarily small

➔ Best precision and
accuracy needed

Why we need nanosecond precision and accuracy

Measuring switch jitter



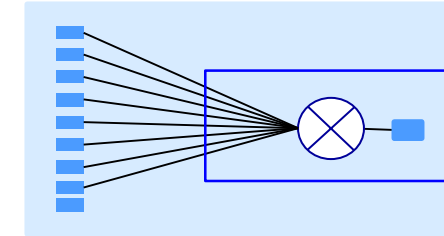
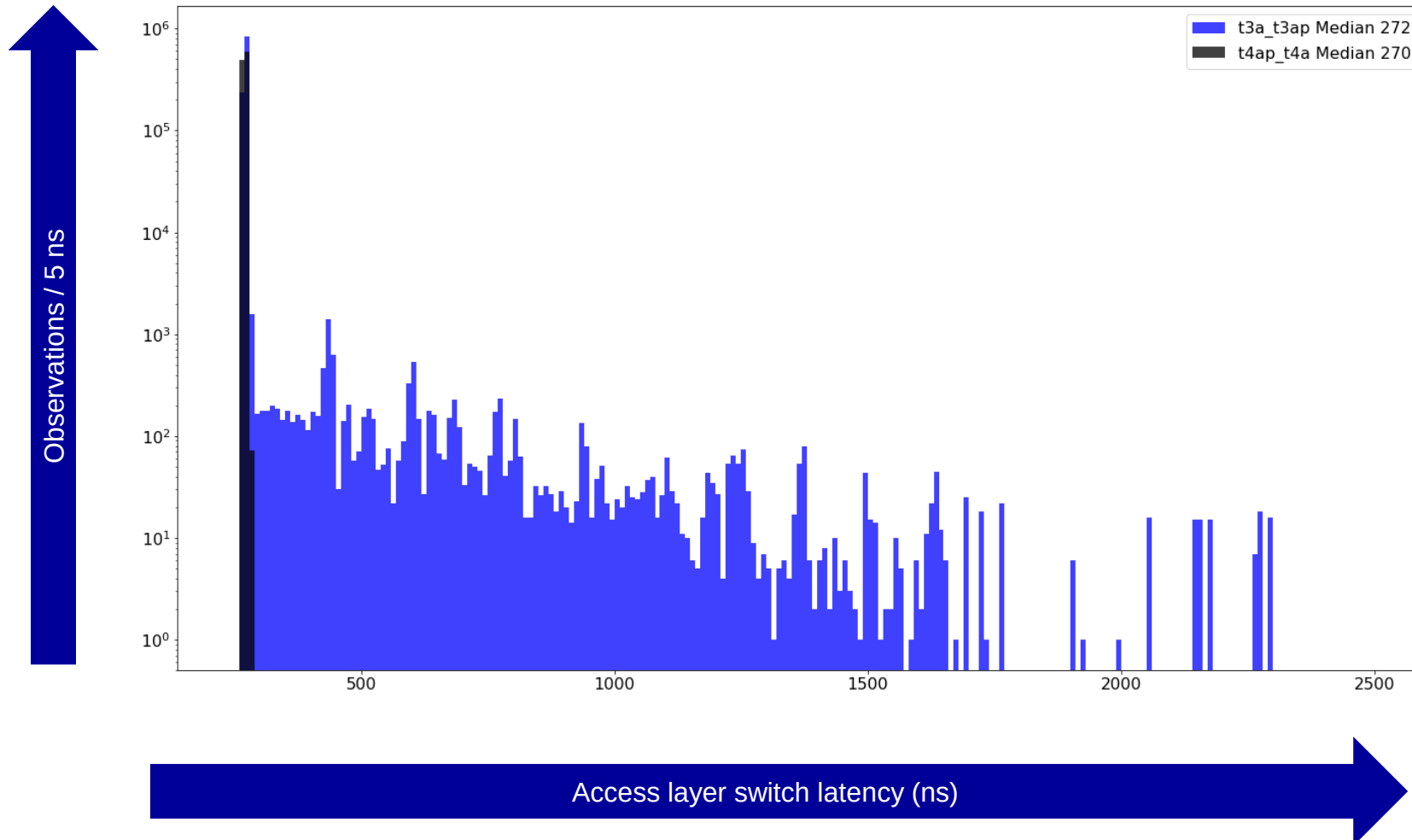
Order entry switch jitter
+/-5 ns*

➔ Best precision and
accuracy needed

*5th to 95th percentile: 9 ns

Why we need nanosecond precision and accuracy

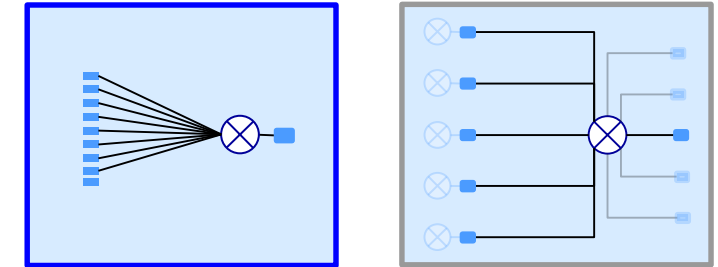
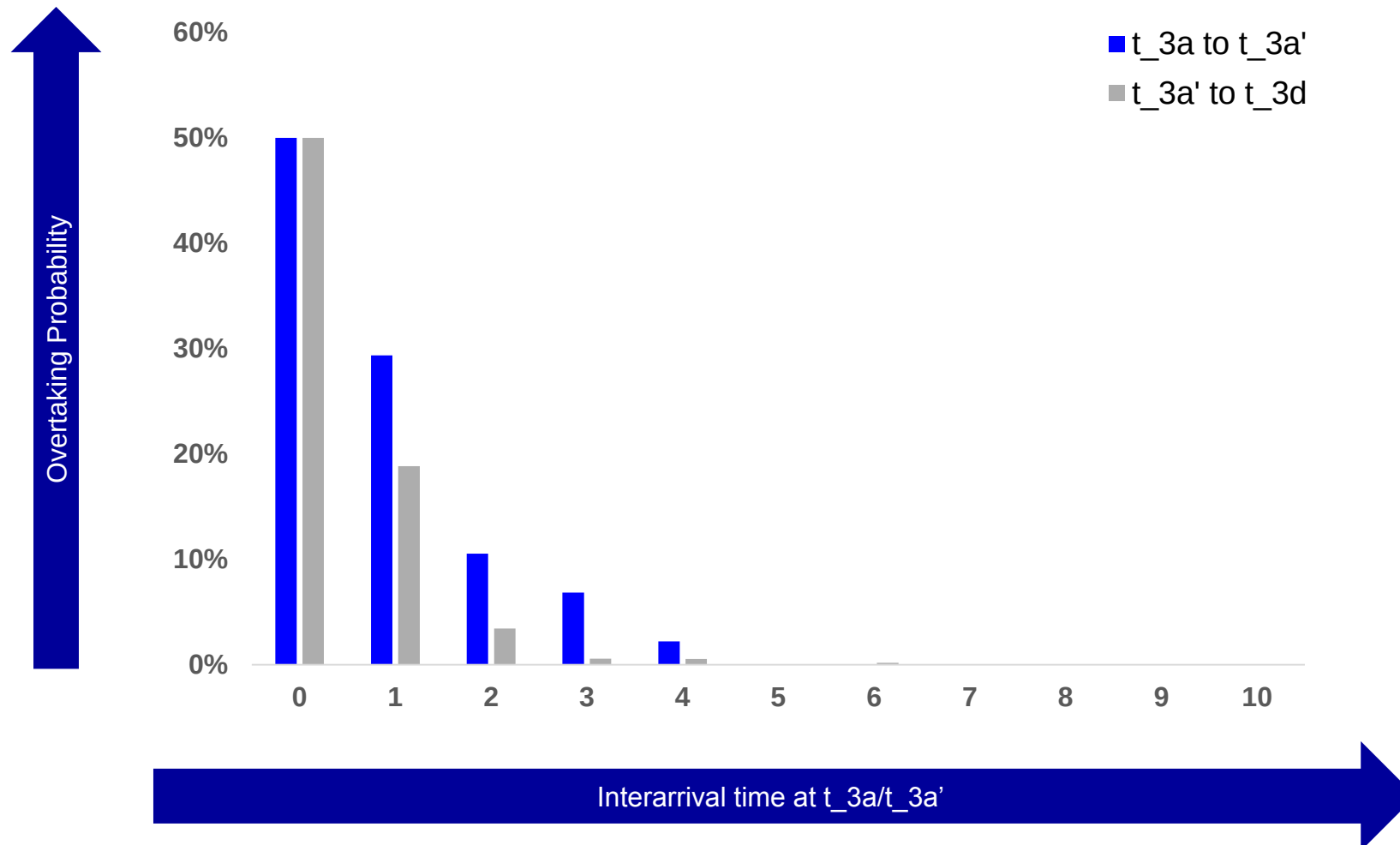
Measuring switch queuing



Nanobursts lead to queuing depending on number of packets and packet size.

Why we need nanosecond precision and accuracy

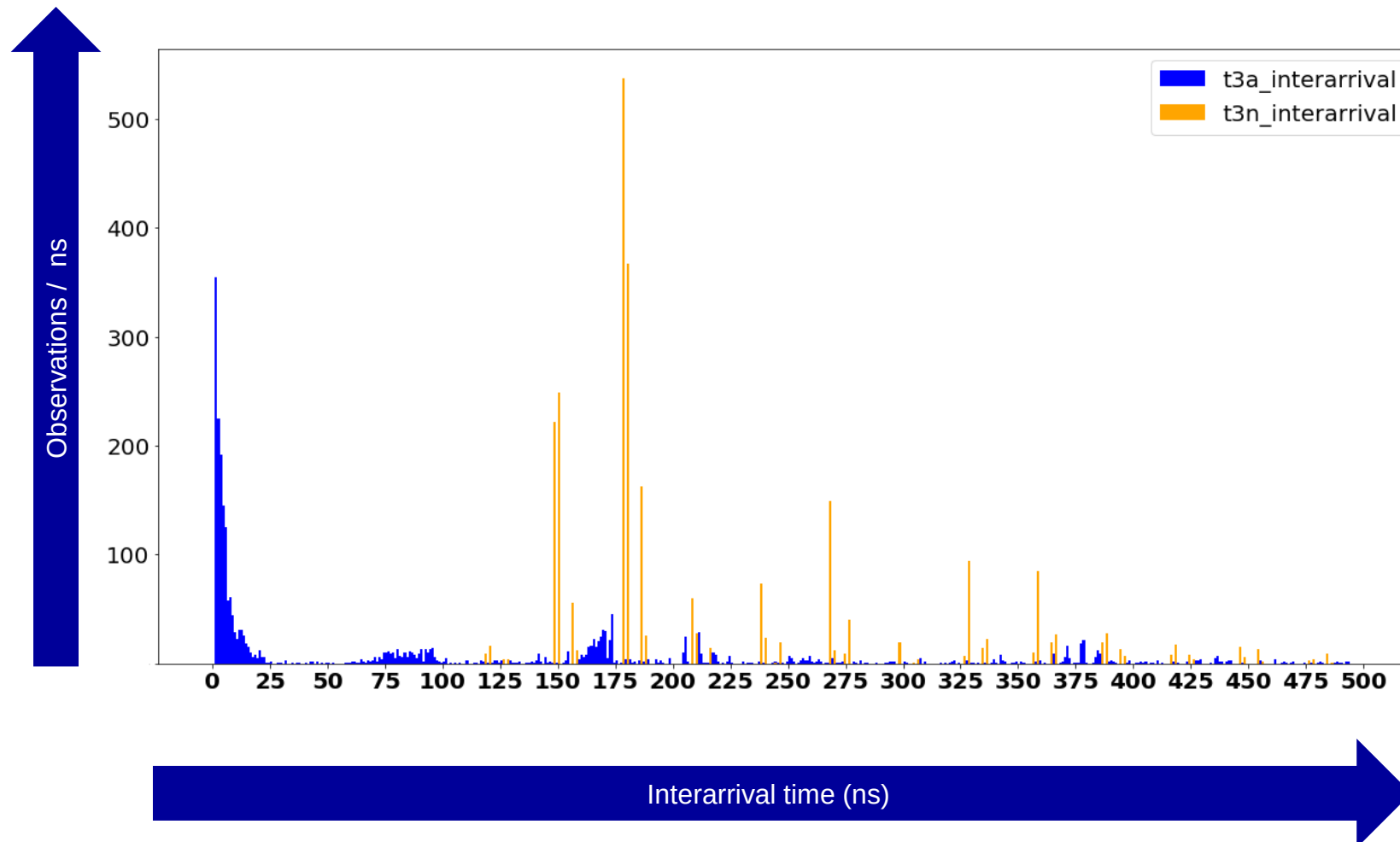
Switch determinism



Overtaking probability drops to zero above 5 ns interarrival time

Why we need nanosecond precision and accuracy

Interarrival time at network entry (t_{3a}) compared to gateway entry (t_{3n})



Interarrival time at t_{3a}
arbitrarily small

Interarrival time at t_{3n}
at least serialization time
of preceding packet
(> 100 ns)

Network card resolution
8 ns

→ t_{3a} for precise inter
arrival time

High Precision Timestamp File

Provides network timestamps to trading participants

- Order Entry timestamps at network entry point t_3a
- Market Data timestamps at common network measurement point t_9d

Takes time synchronization and queuing effects out of the equation

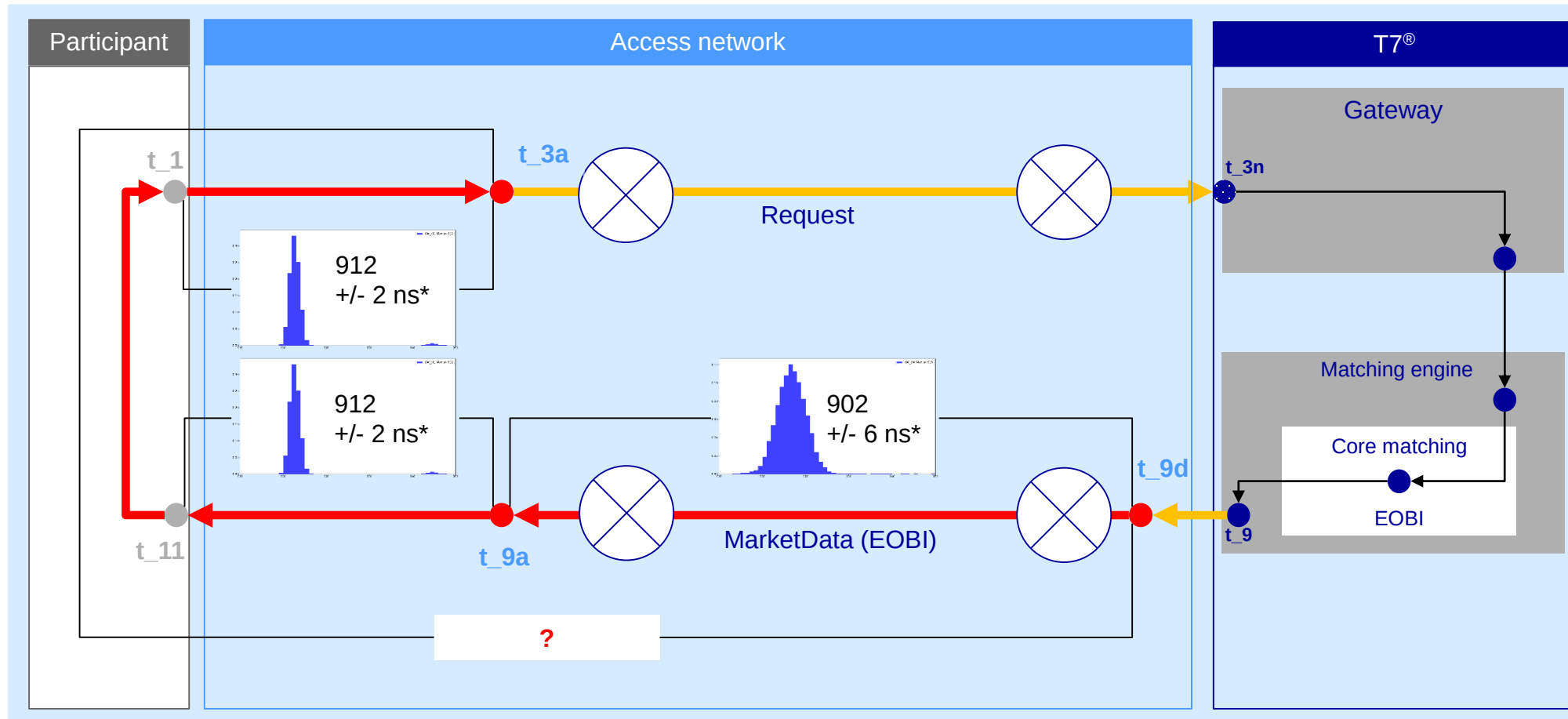
Allows more precise judgement on competition ("How far behind am I ?")

Allows back testing with highest timestamp quality

Is available as 'executions only' for all products and 'all market data updates' for futures and equities.

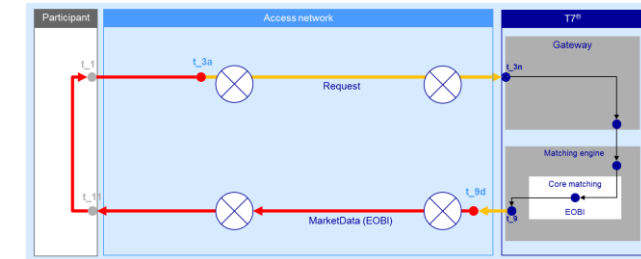
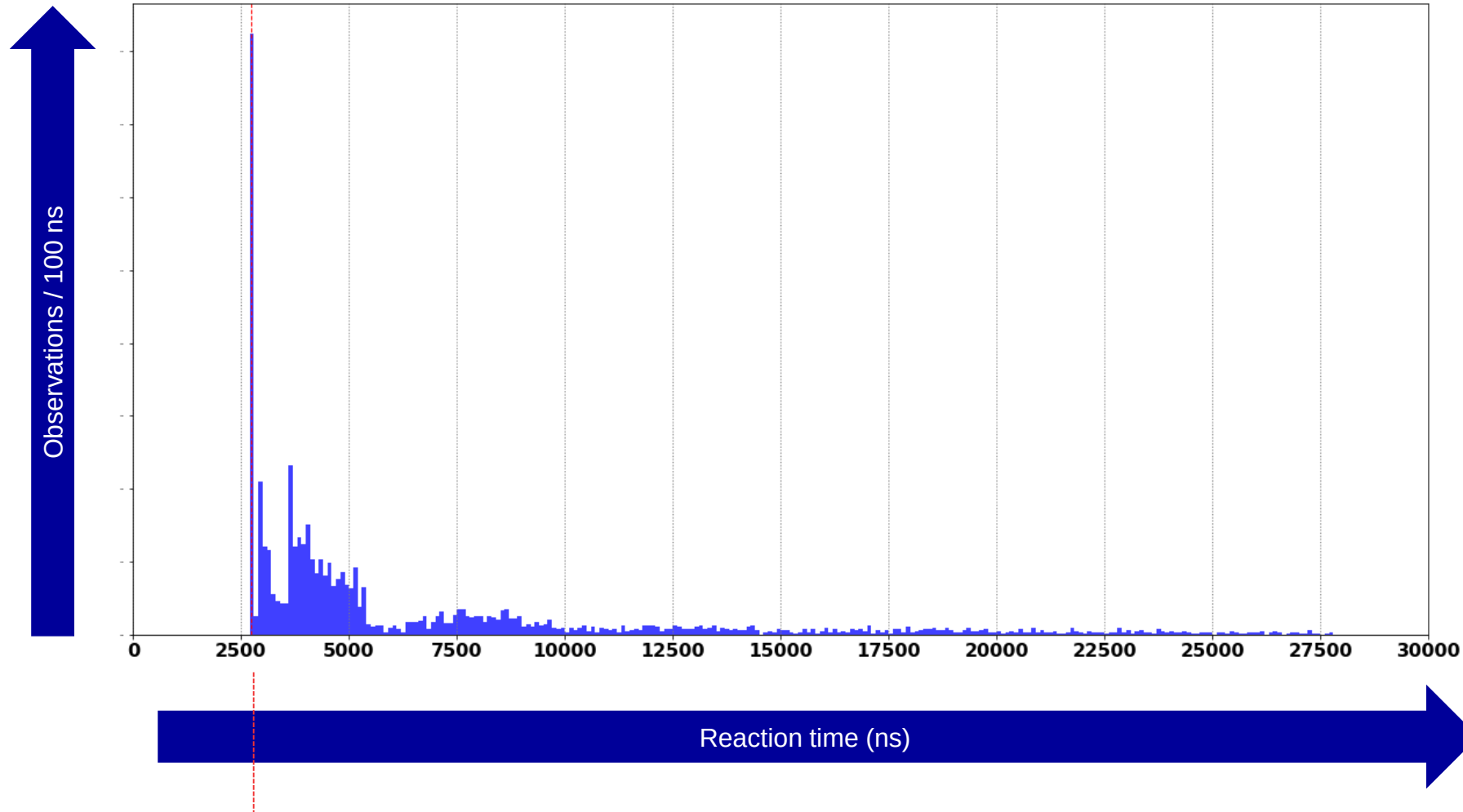
High Precision Timestamp File

Reaction times of trading participants



High Precision Timestamp File

FESX => FDAX Reaction time based on T7[®] times (t_9d to t_3n)*

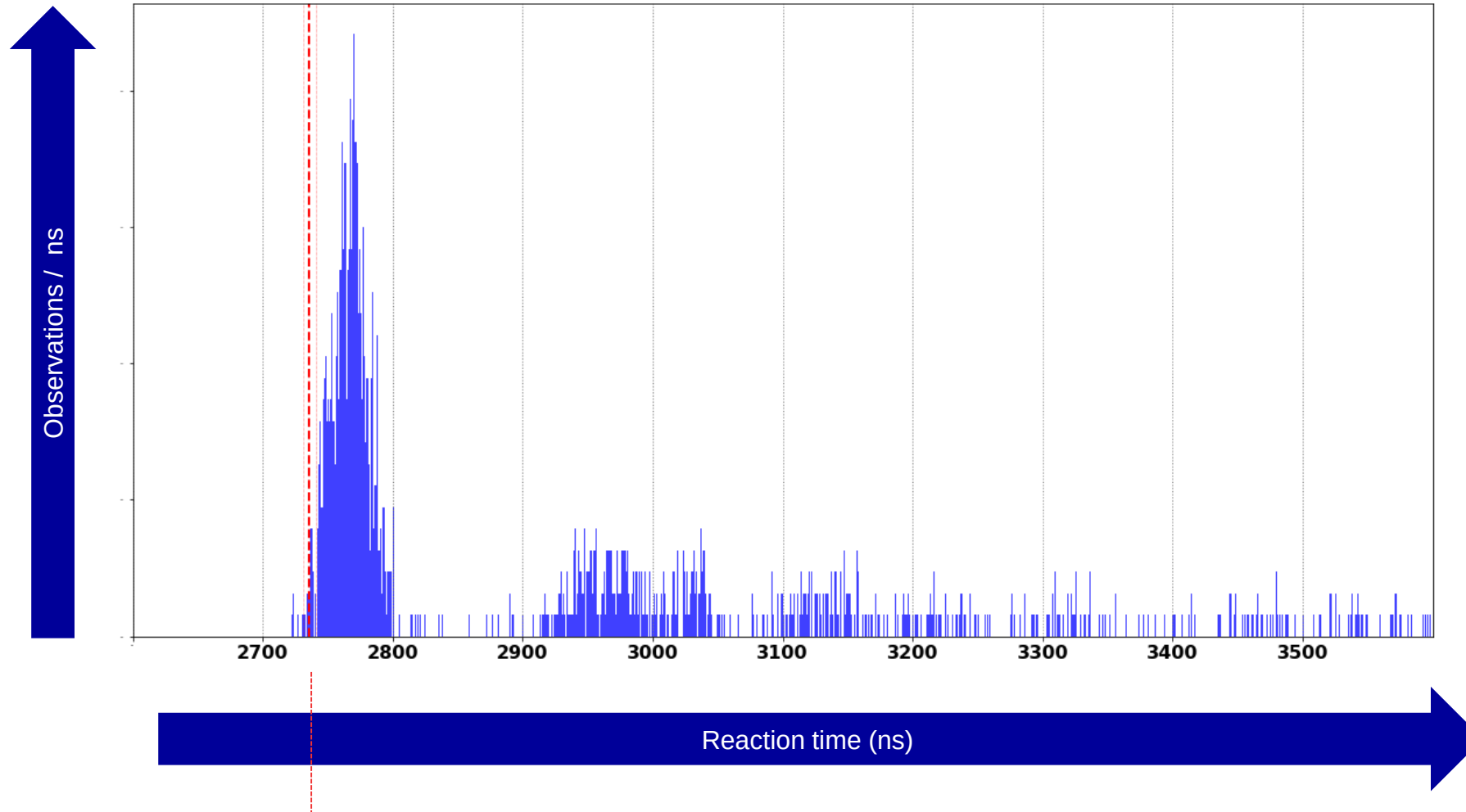


Median network transport latency (~2736 ns)

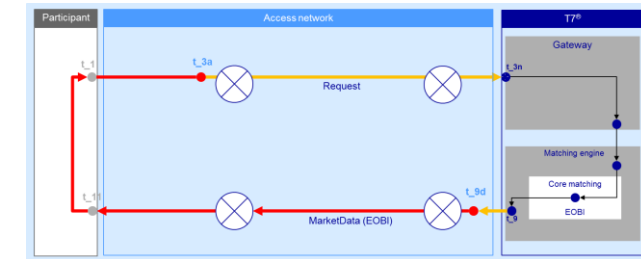
*Distribution of $t_{3n} - t_{9d} - \text{median}(t_{3n} - t_{3a})$ shown

High Precision Timestamp File

FESX => FDAX Reaction time based on T7[®] times (t_{9d} to t_{3n})* (close up)



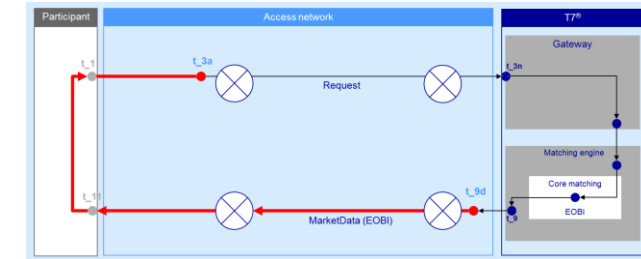
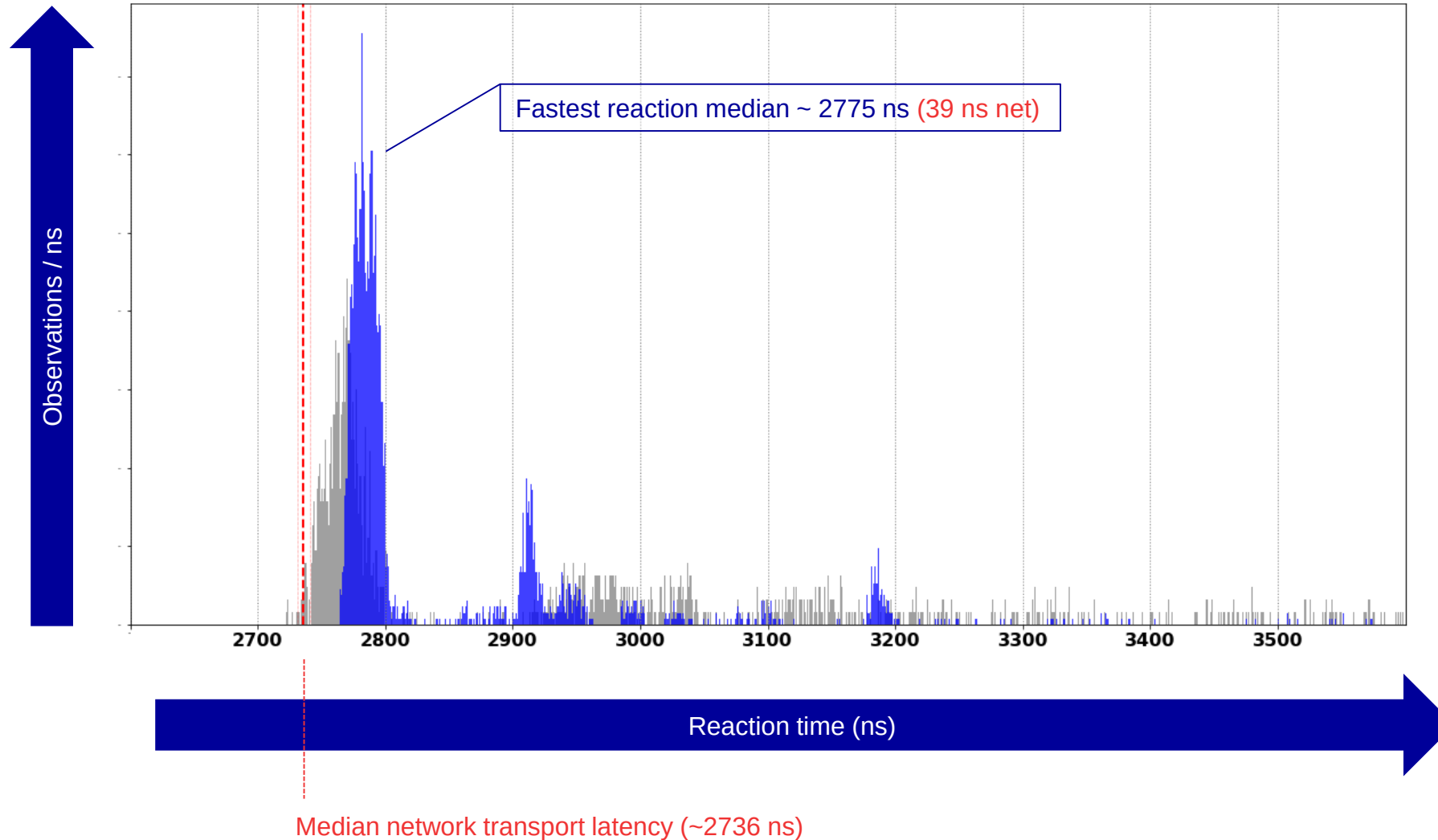
Median network transport latency (~2736 ns)



*Distribution of ($t_{3n} - t_{9d}$) – median ($t_{3n} - t_{3a}$) shown

High Precision Timestamp File

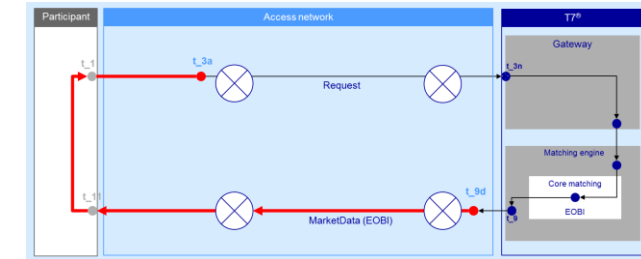
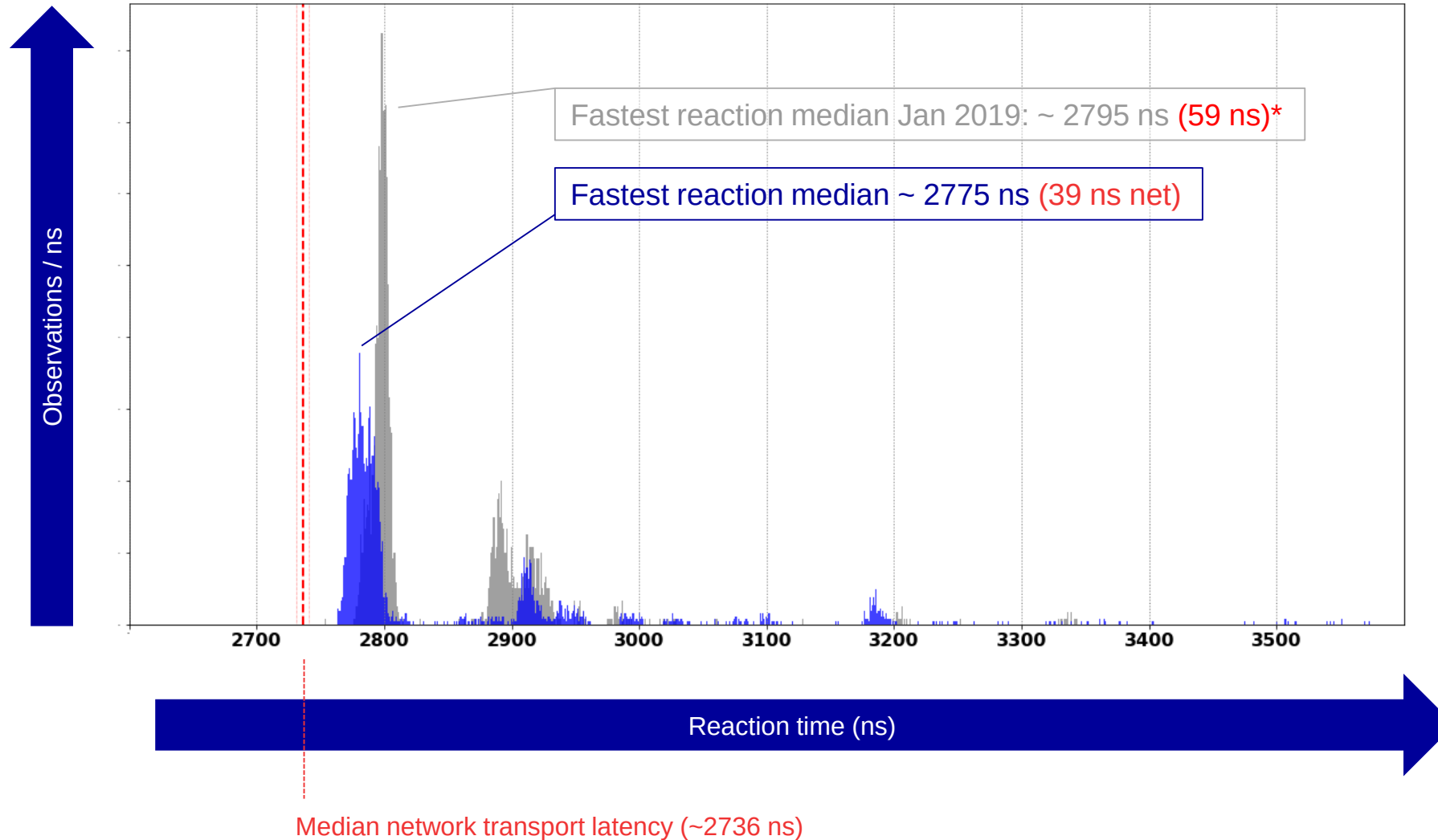
FESX => FDAX Reaction time based on network times (t_{9d} to t_{3a})



Gray distribution shows correction using $\text{median}(t_{3n} - t_{3a})$

High Precision Timestamp File

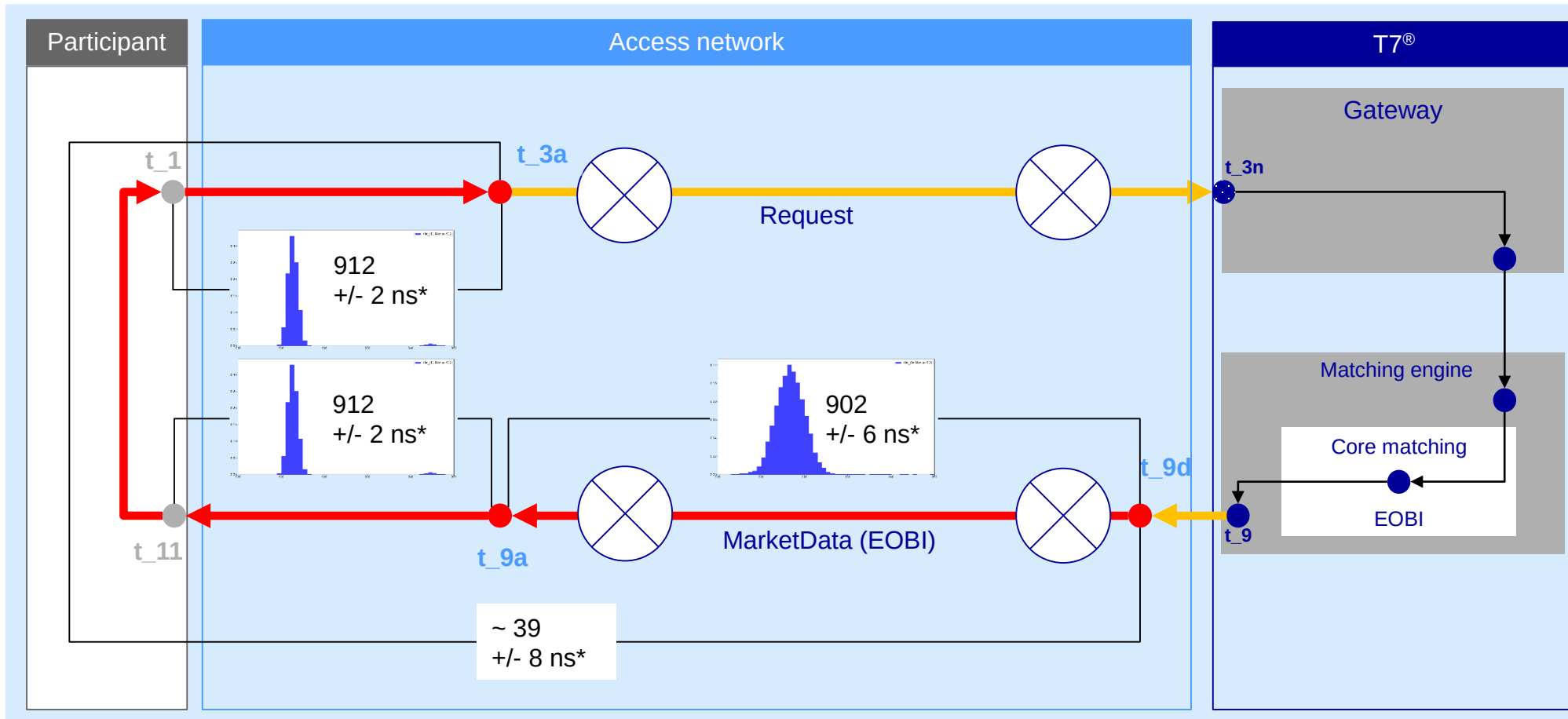
FESX => FDAX Reaction time – now compared to half a year ago



Gray distribution shows data from January 2019

High Precision Timestamp File

Reaction times of trading participants



* Confidence Interval: 5th to 95th percentile

I will be right after the break

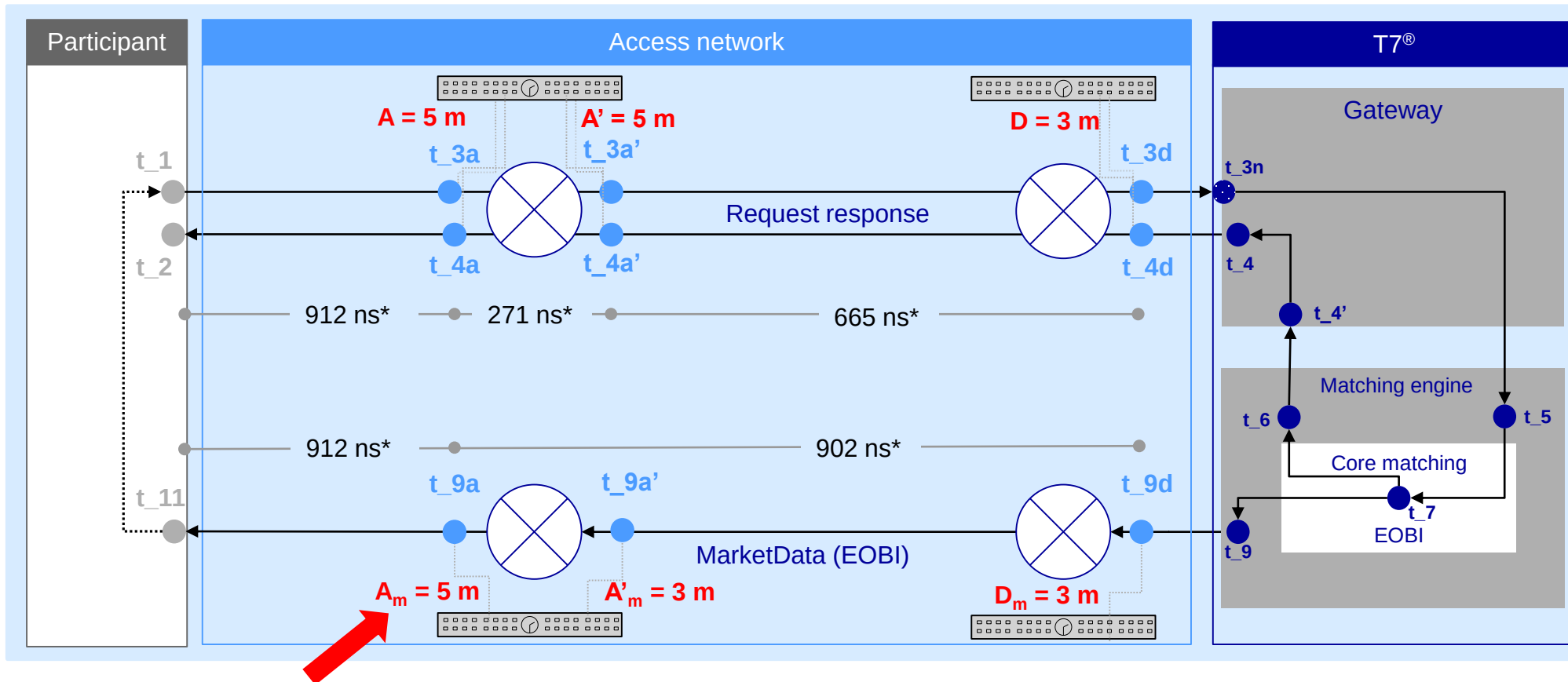


What could possibly go wrong?



What could possibly go wrong

Tap to timestamp cable length



*latencies are mid tap to mid tap, but measurements (e.g. t_{9d} , t_{3a}) include tap to timestamping cable length

Exhibit 1

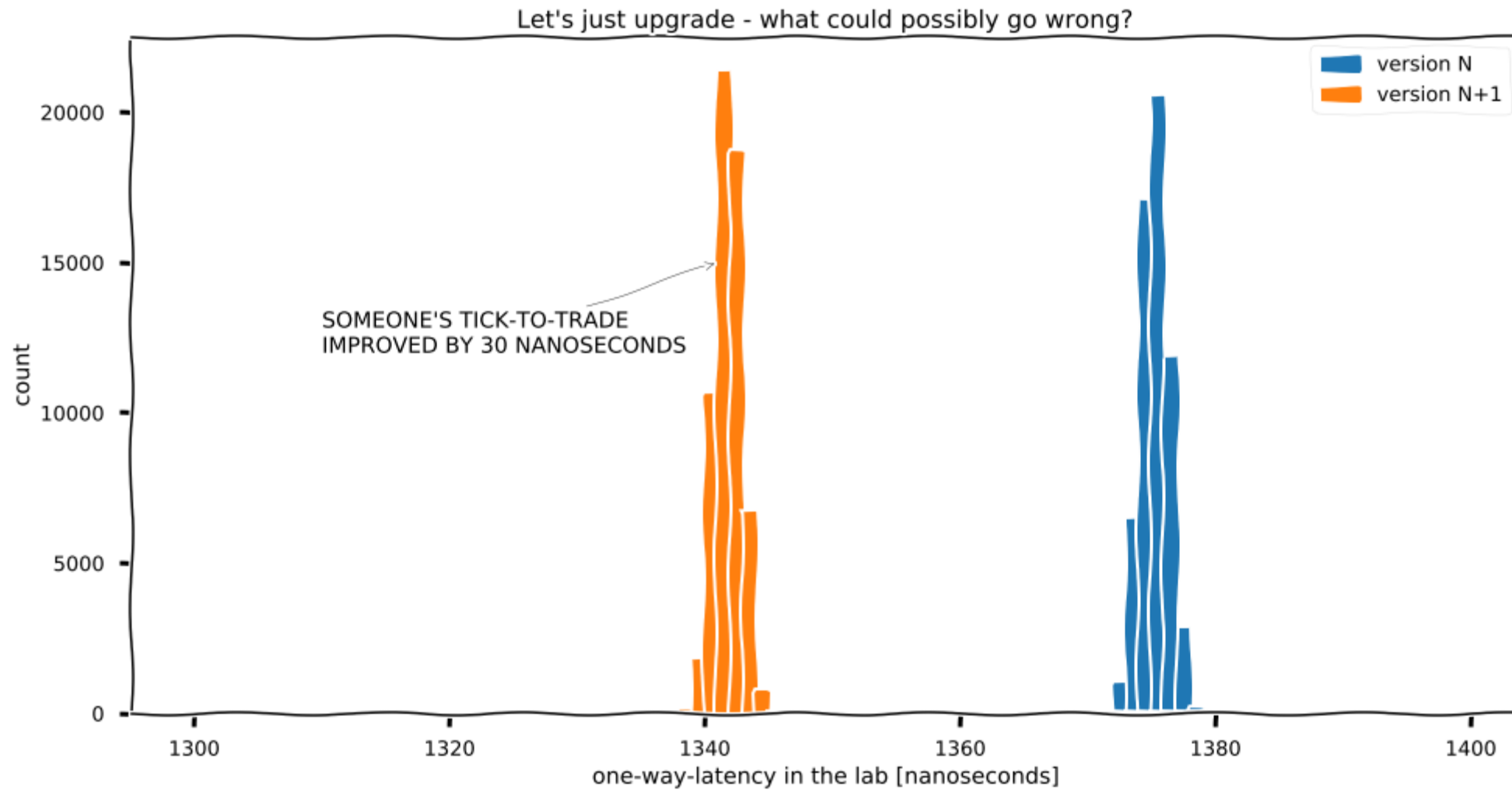
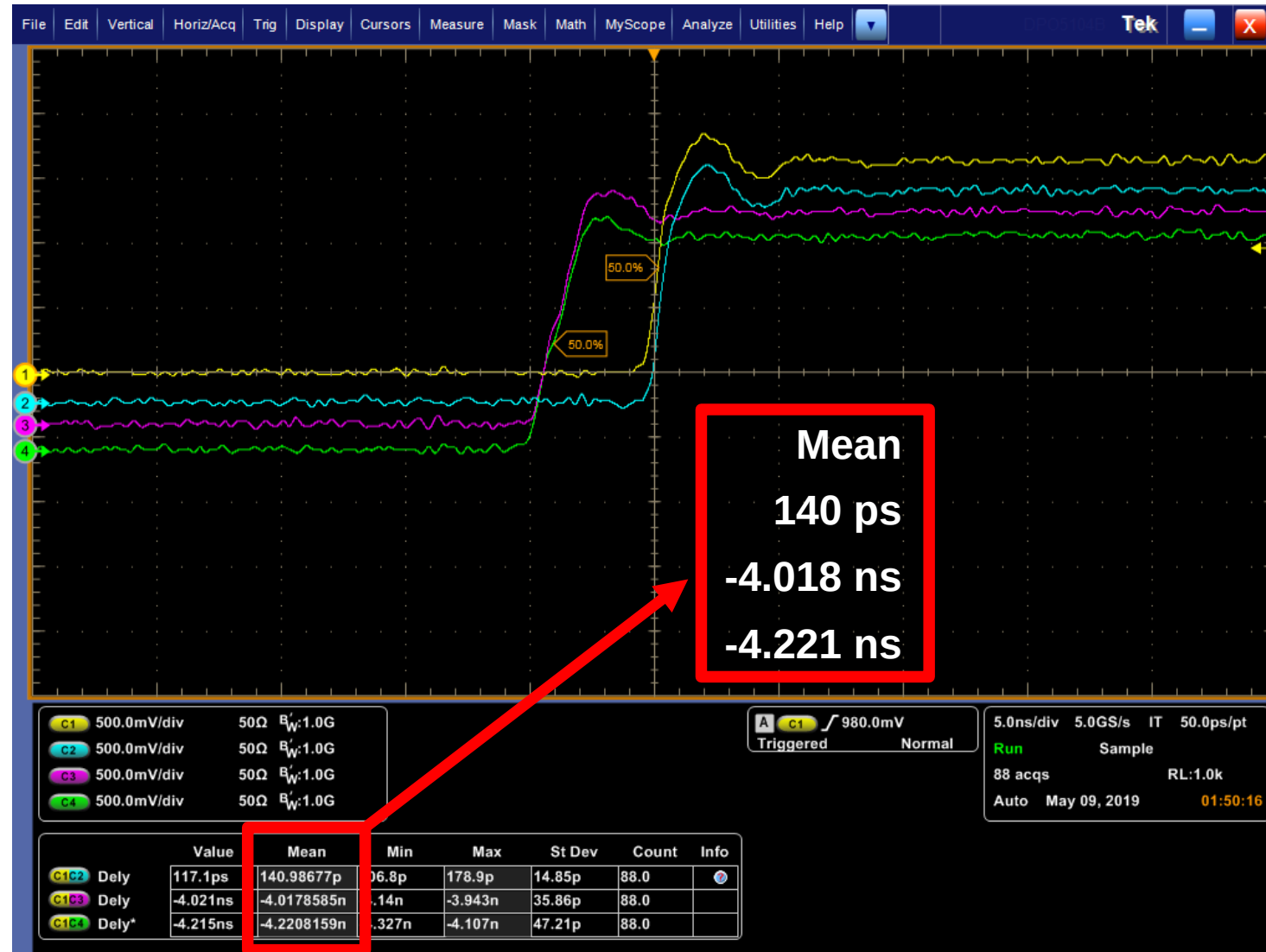


Exhibit 2





Thank you for your attention.

Contact

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6 June 2019

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