Chopper control system
IKON 15

Markus Olsson
Control system engineer

www.europeanspallationsource.se
12 September, 2018

Agenda

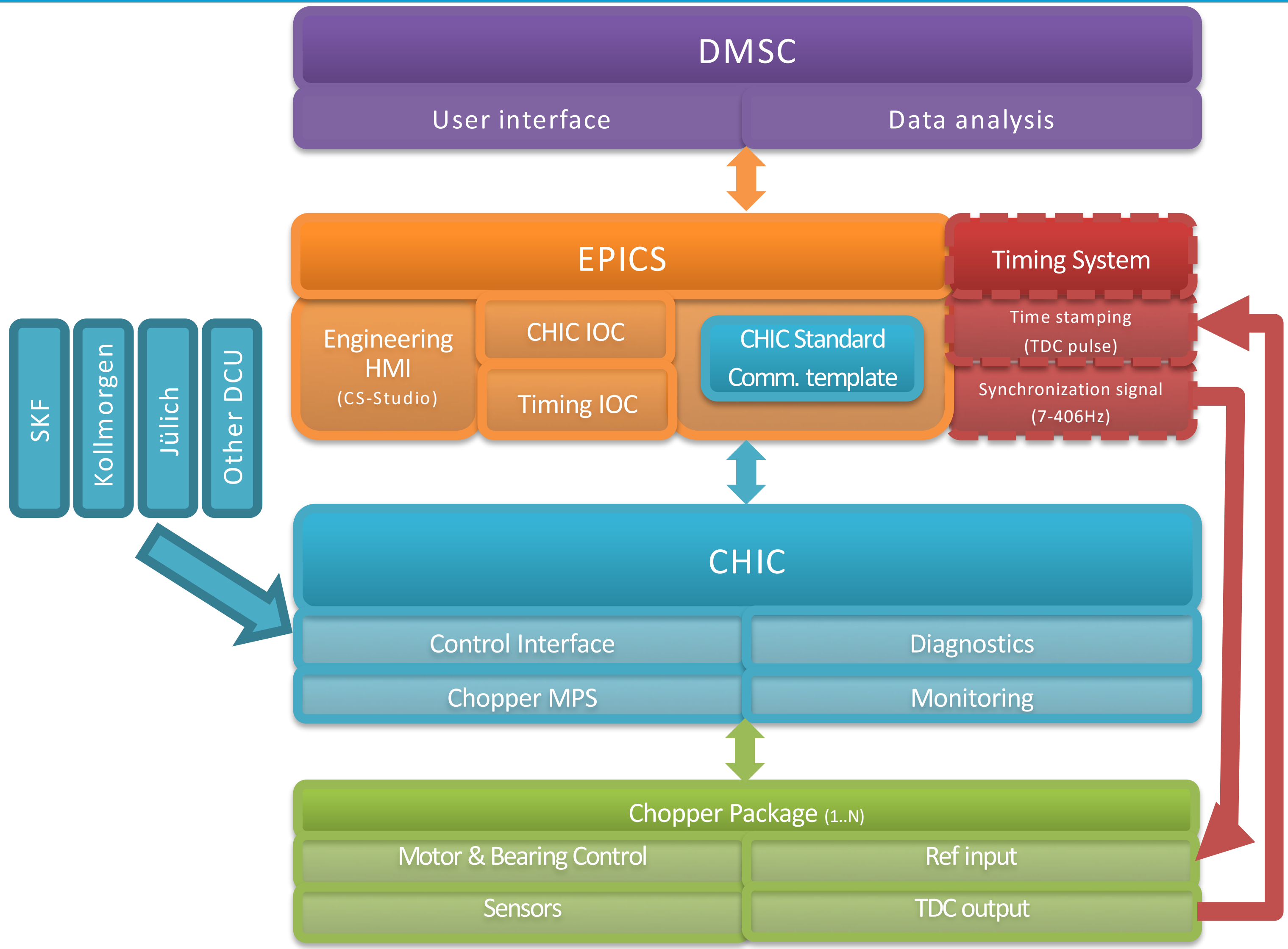
1. System Overview
2. CHIC software architecture
3. Hardware design (Crate / Rack)
4. Chopper timing
5. General discussion

Choppers

Chopper control challenges purpose

- We need a way to standardise the communication between the chopper drives from different manufacturers and EPICS.
- We need to standardise the monitoring of all choppers from different manufacturers.
- Reduce the maintenance delays during operations
- Allow the instruments to concentrate on their core business.

Chopper control concept



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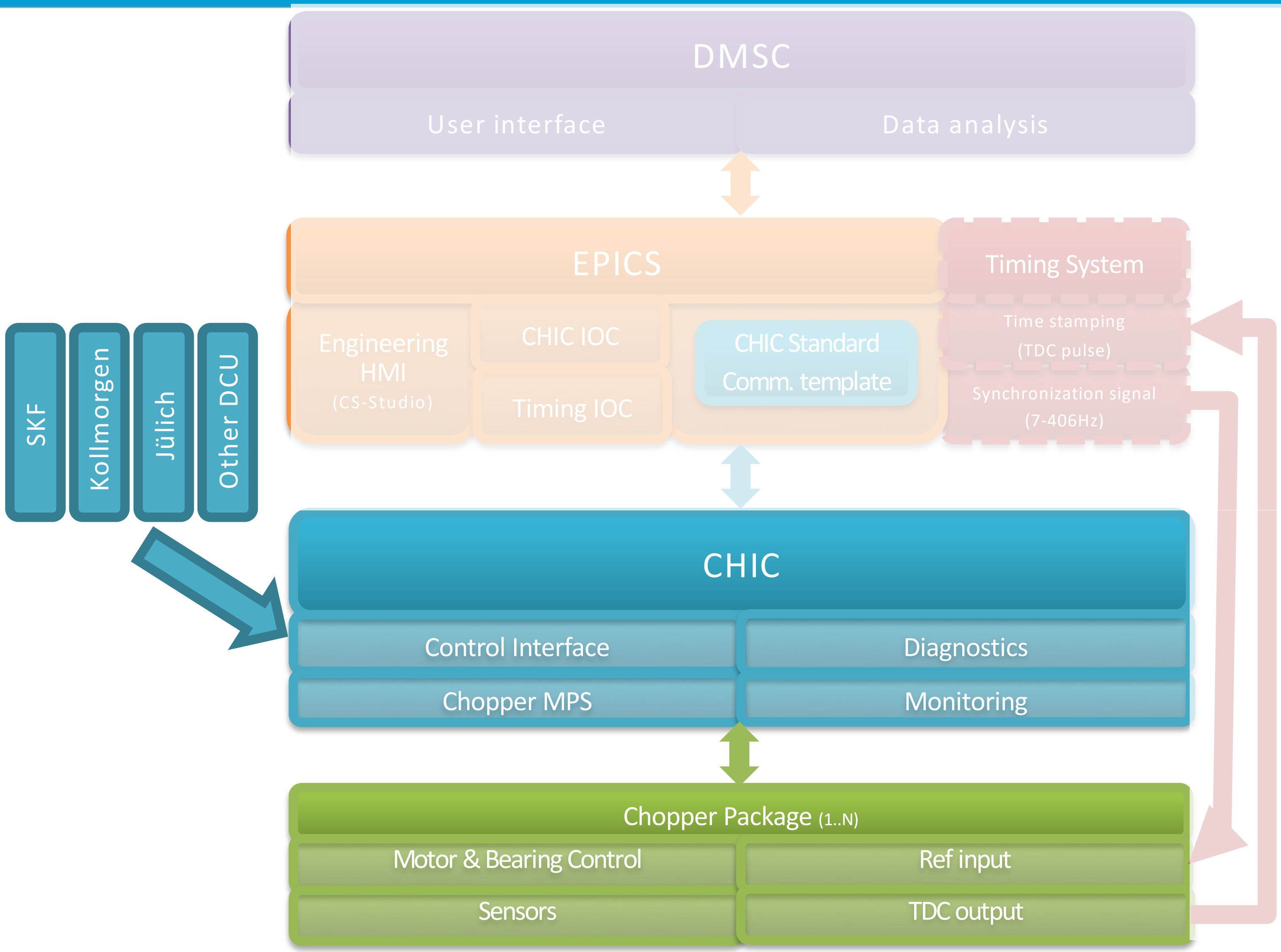
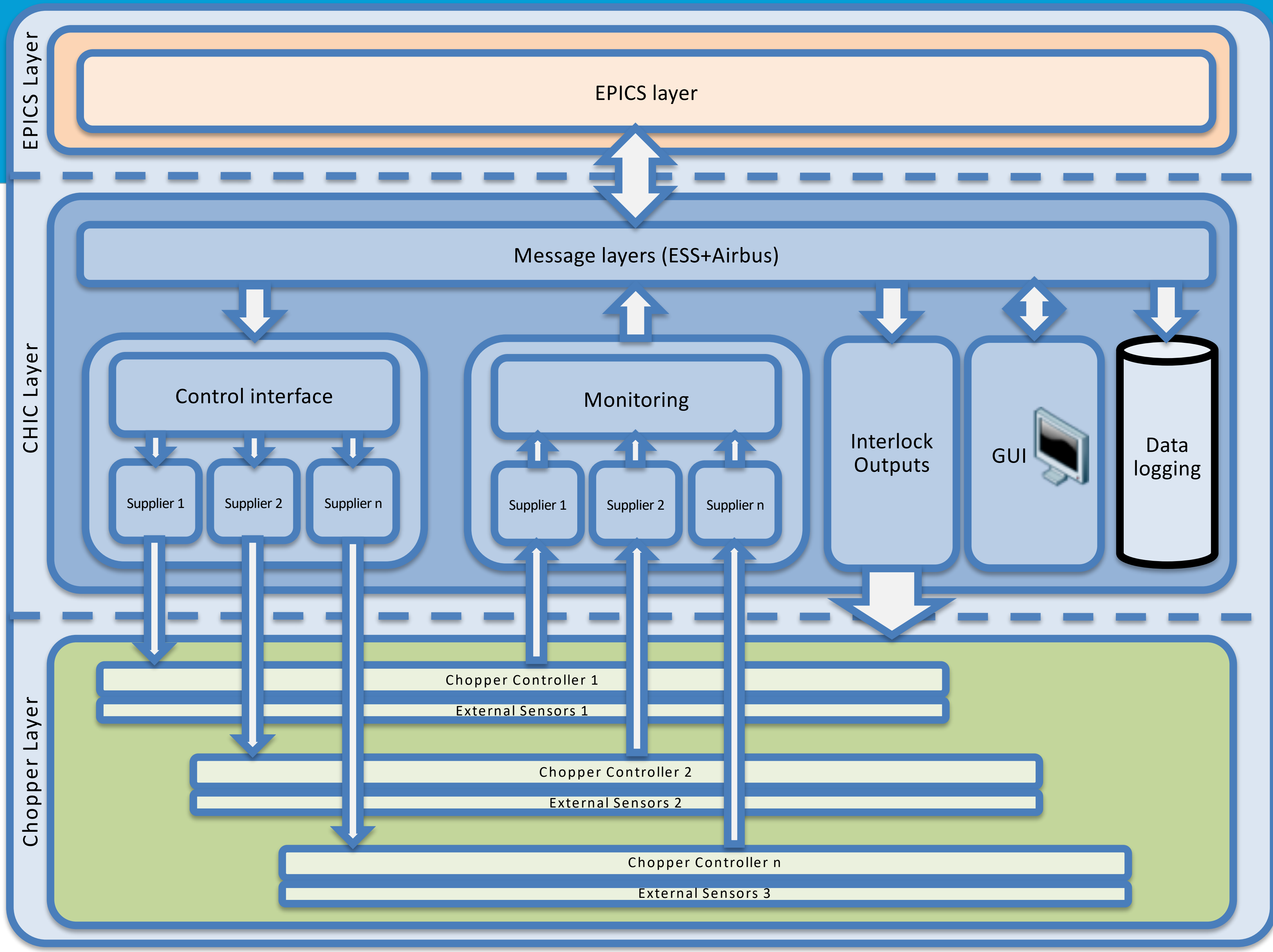


What is the CHIC?

- It is a PLC that works as a ”translator” for commands between EPICS and the chopper drives.
- It is a monitoring system for external measurements such as vibration, cooling, vacuum and disk temp.
- The monitoring system gives the ability to implement predictive maintenance.
- It will act as a local machine protection system (MPS) to set the choppers into safe state if any value exceeds a predefined threshold.
- One CHIC can control and monitor up to four drives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CHIC Layer
Message layers (ESS+Airbus)
Control interface
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Supplier 2
Supplier n
Monitoring
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Supplier 2
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GUI
Data logging
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External Sensors 1
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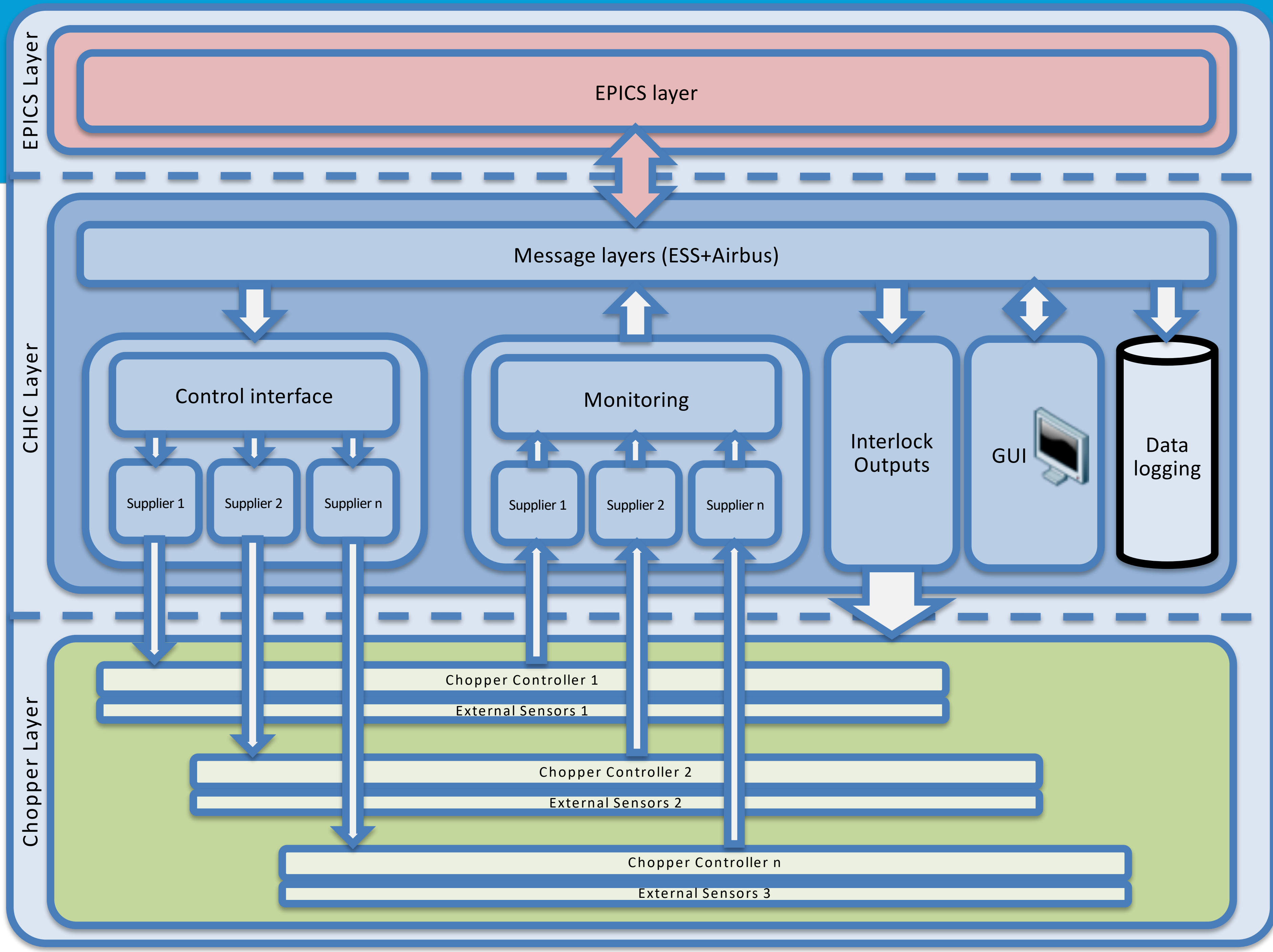
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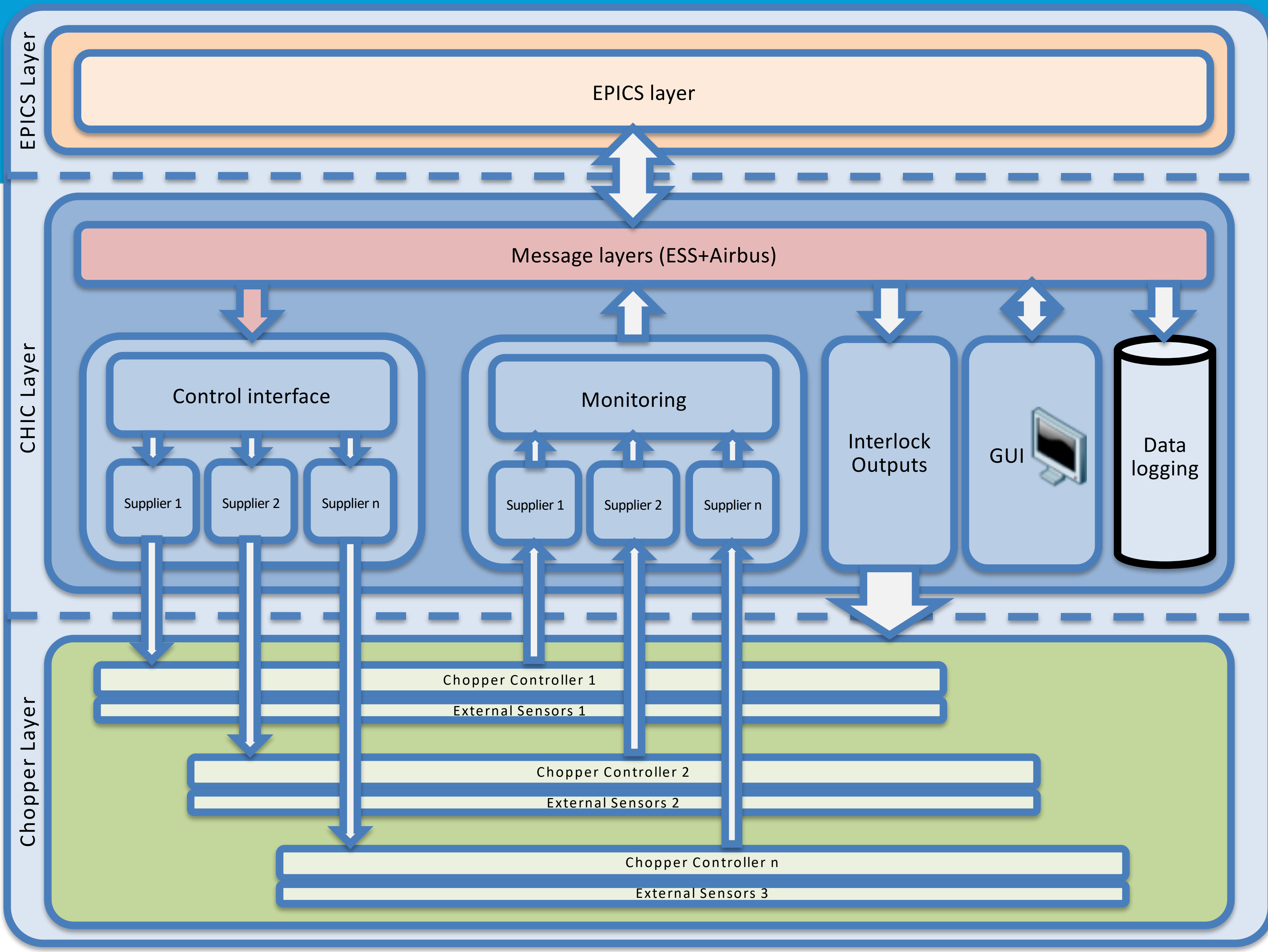
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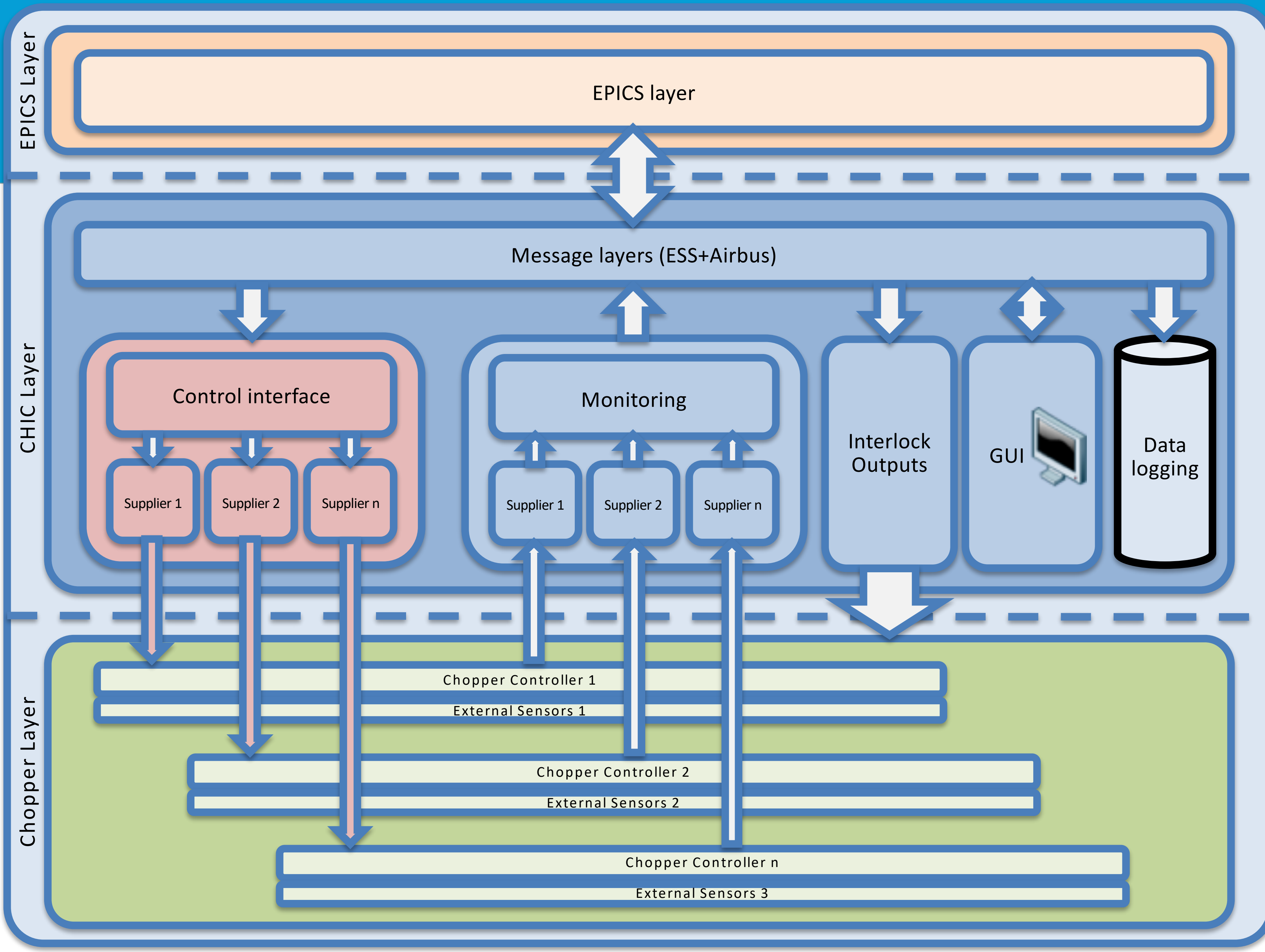

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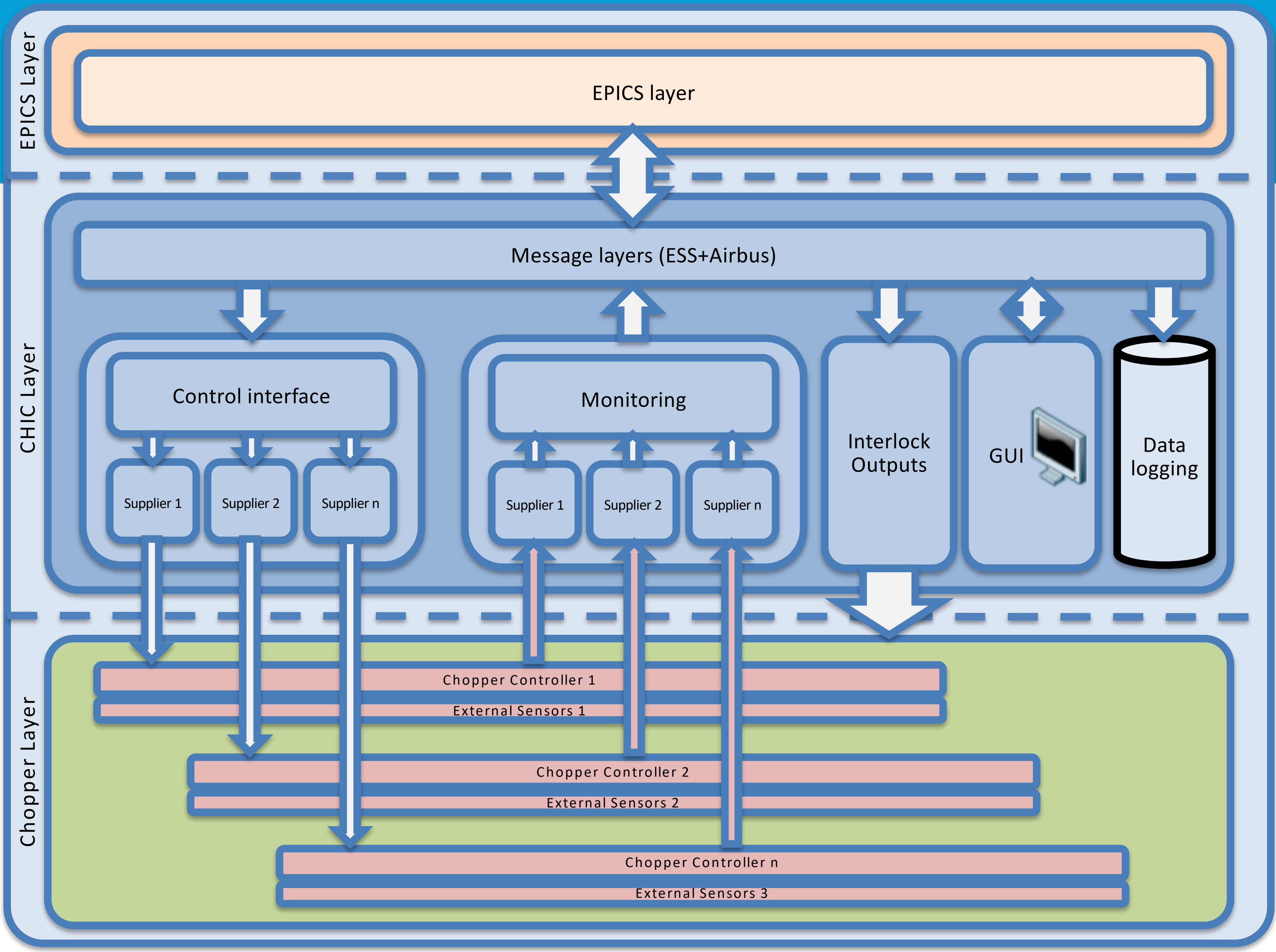
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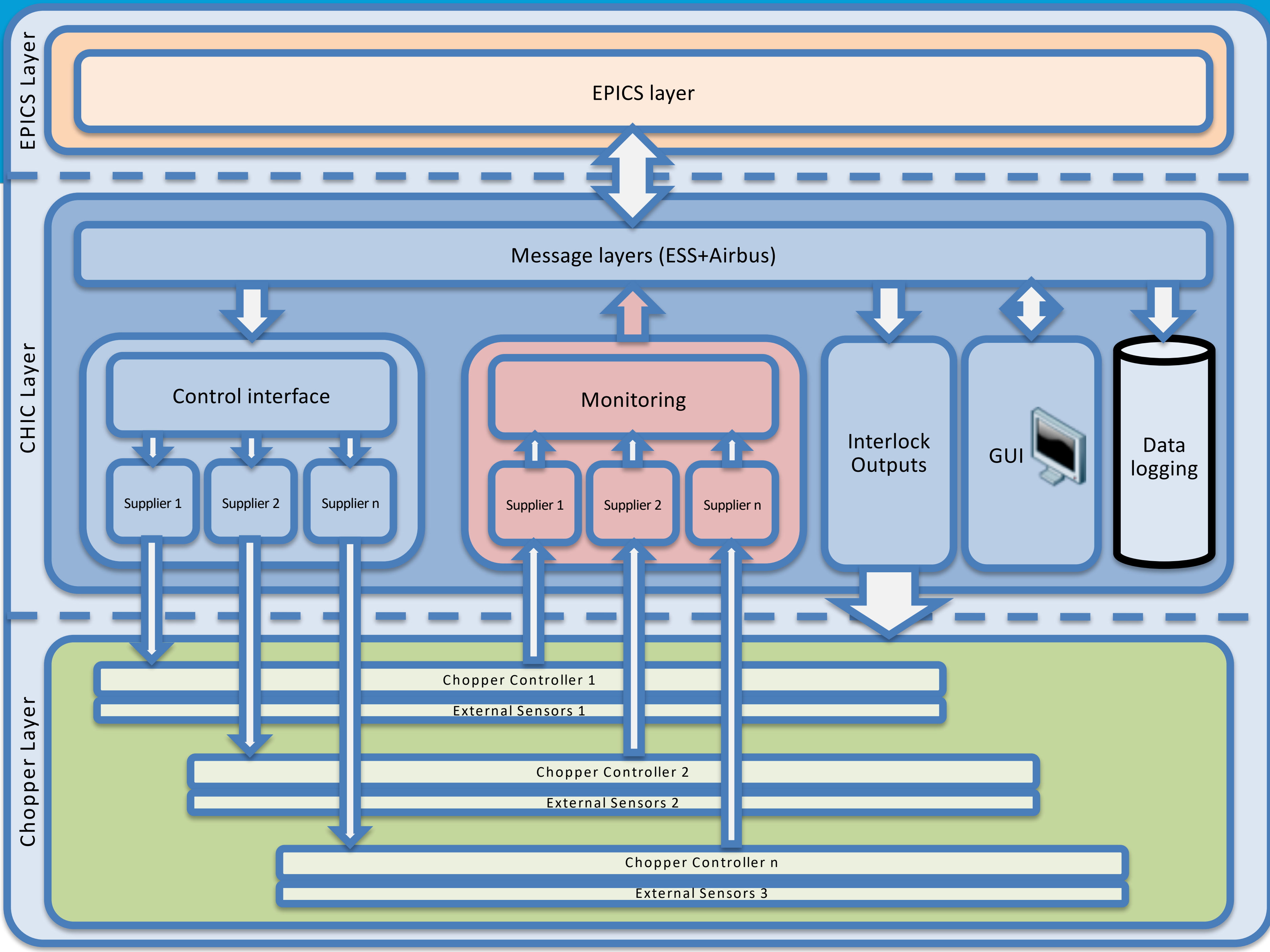
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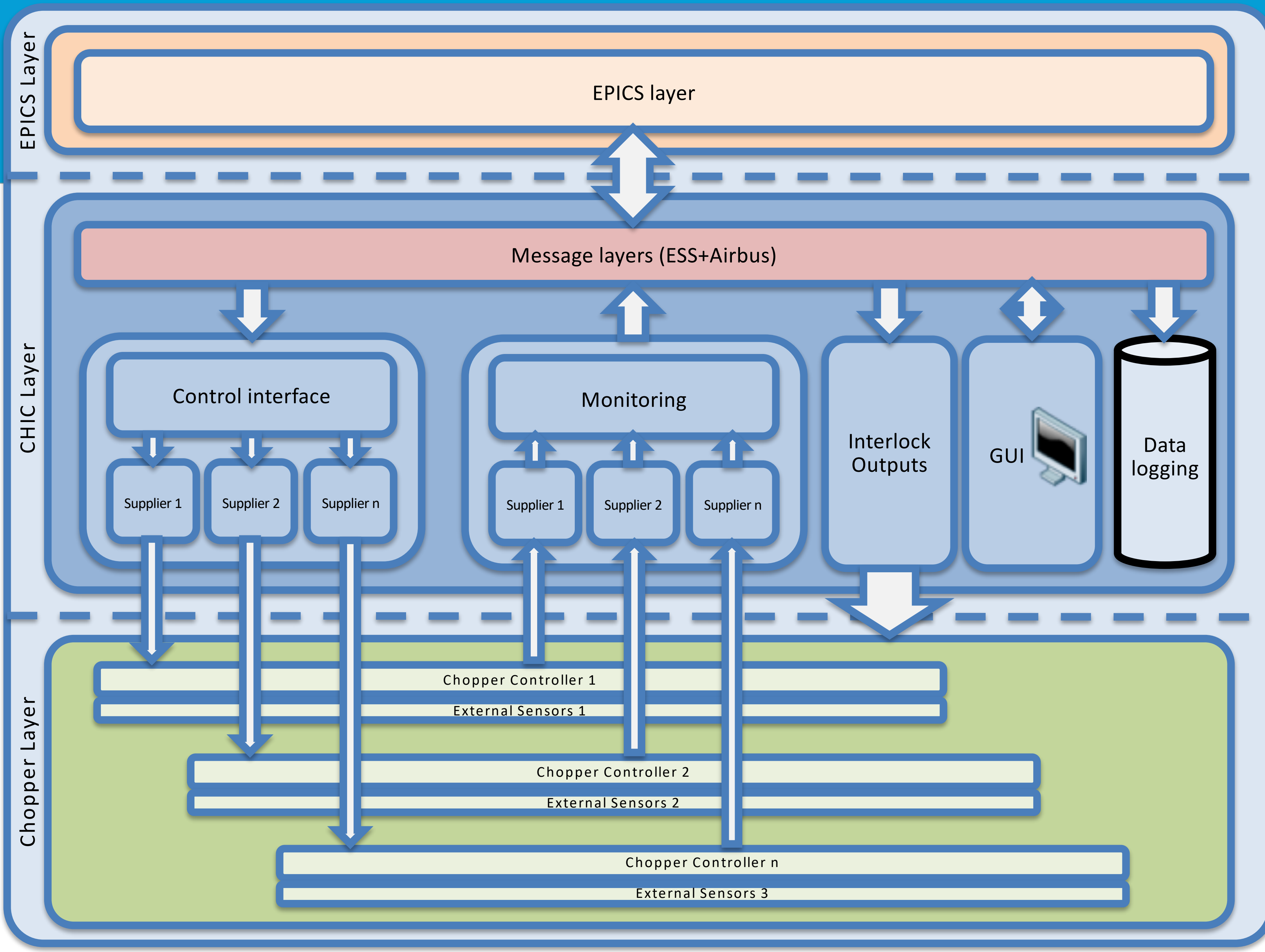
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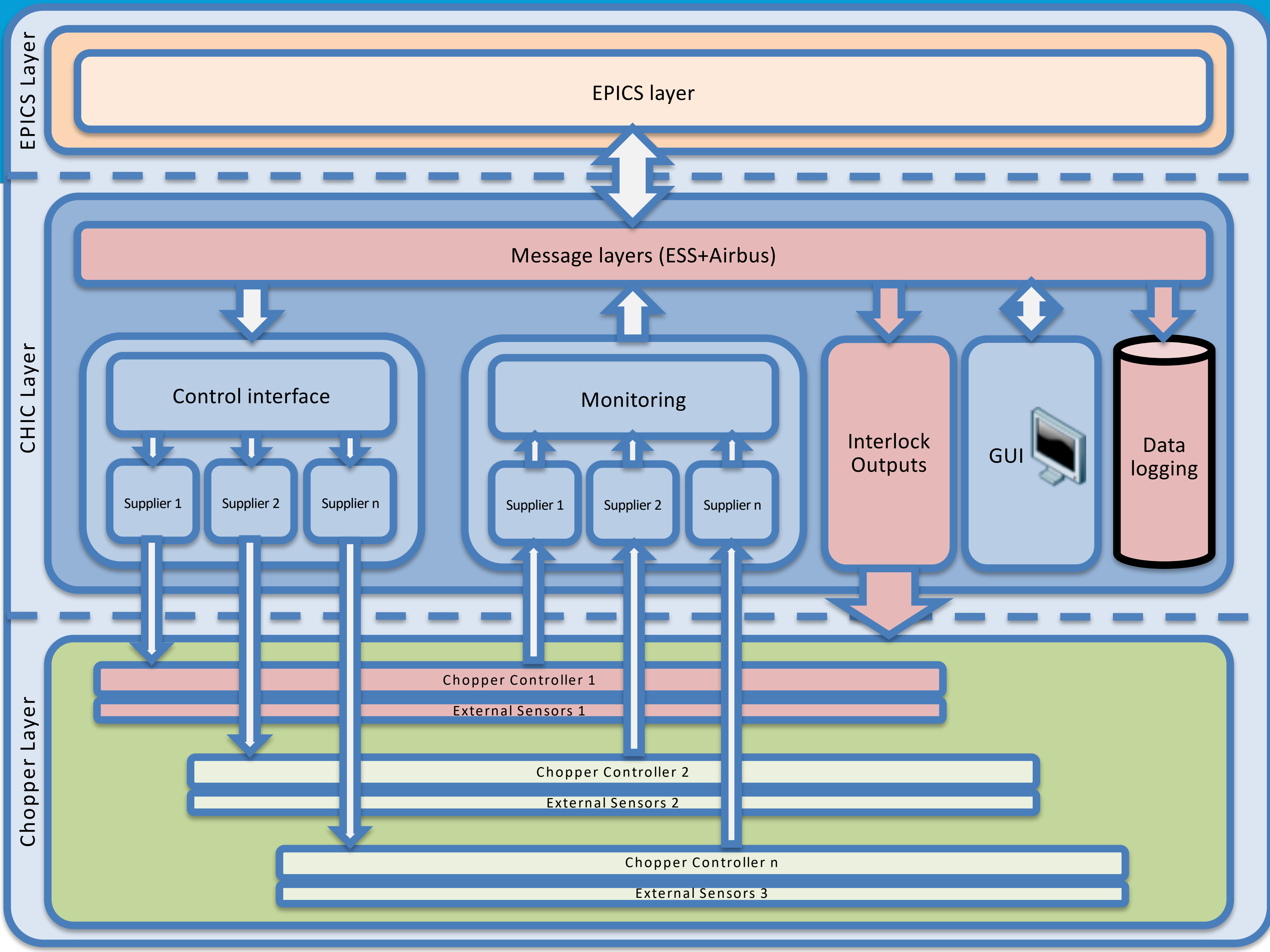

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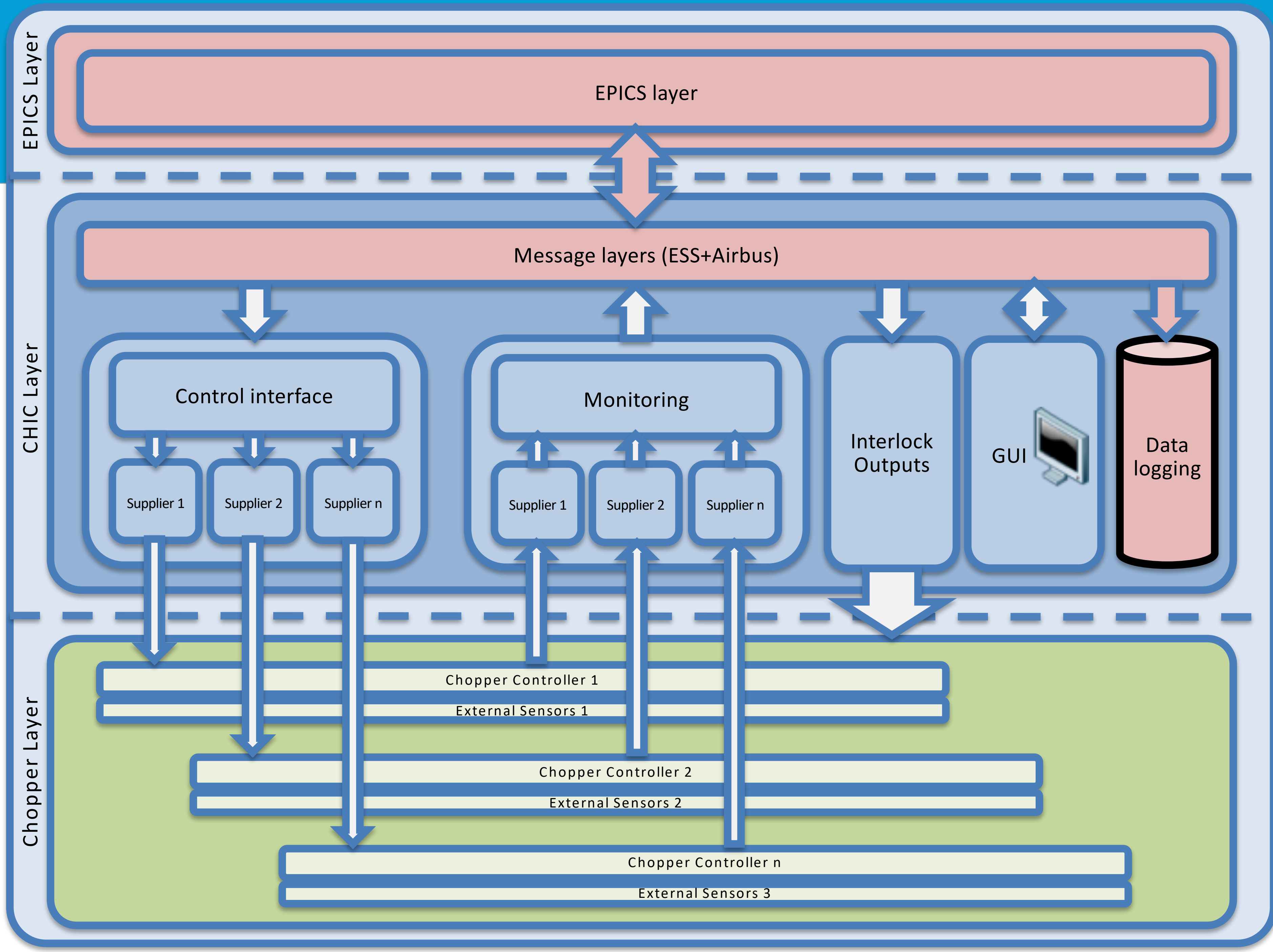

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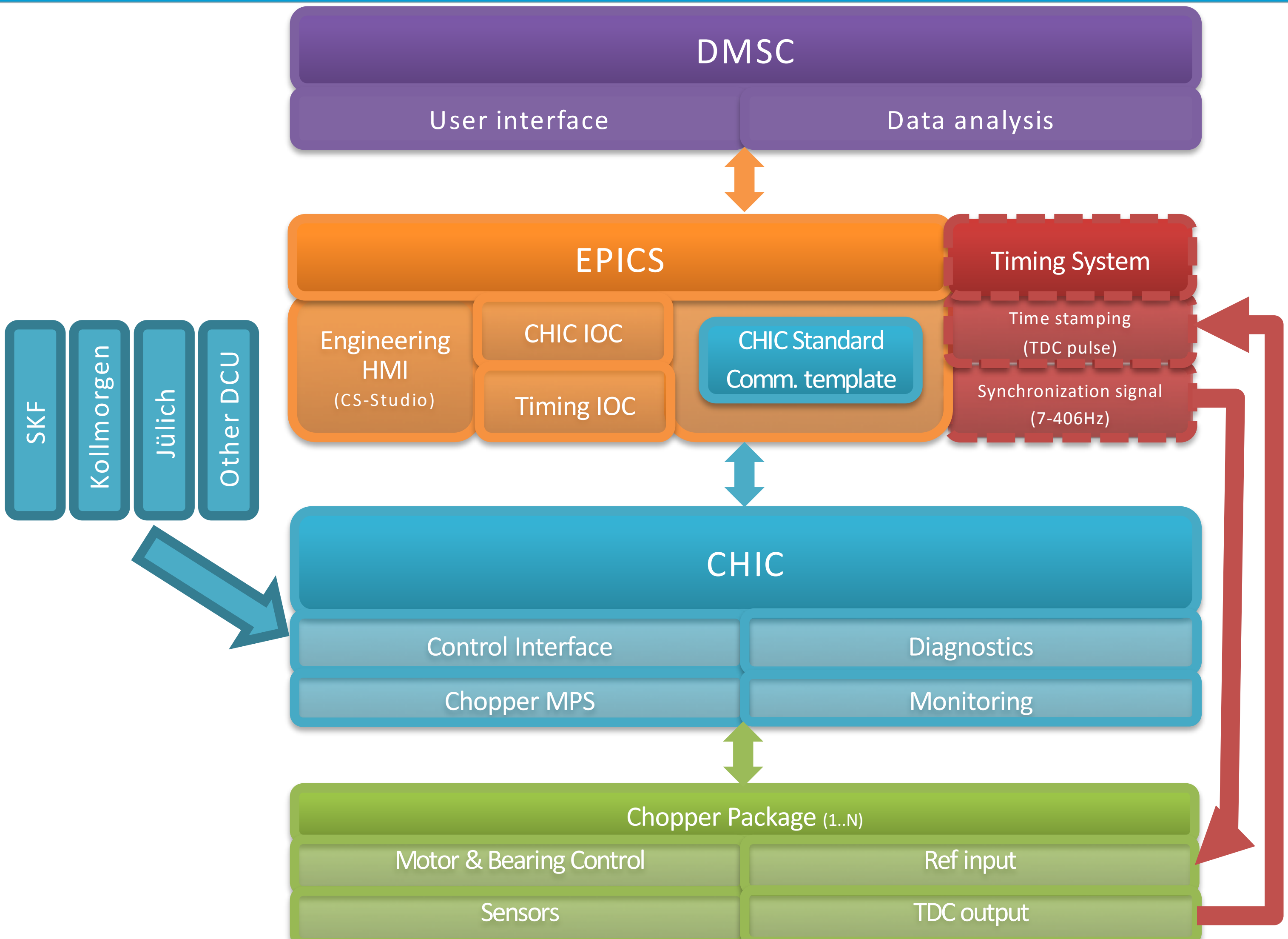

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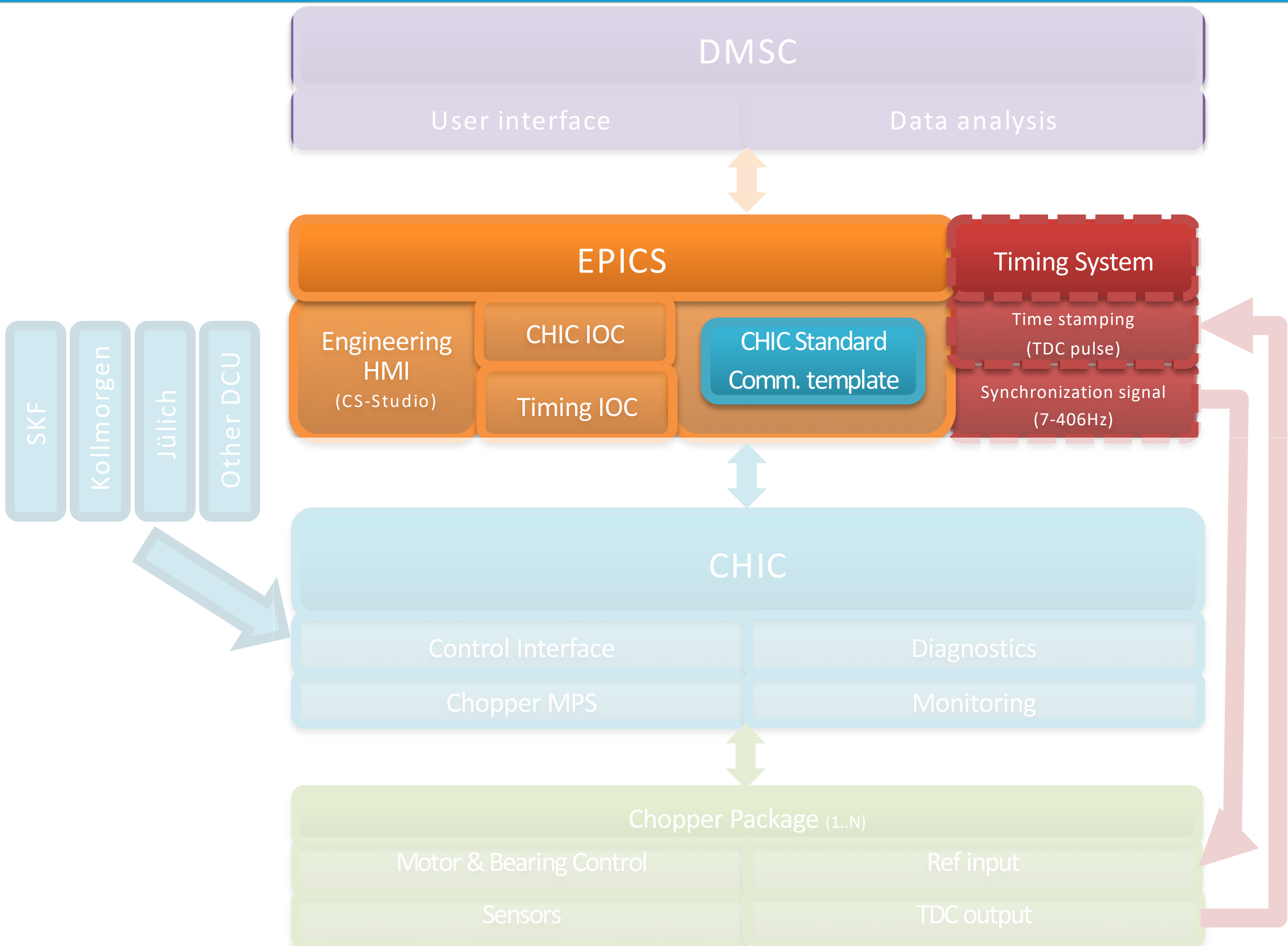
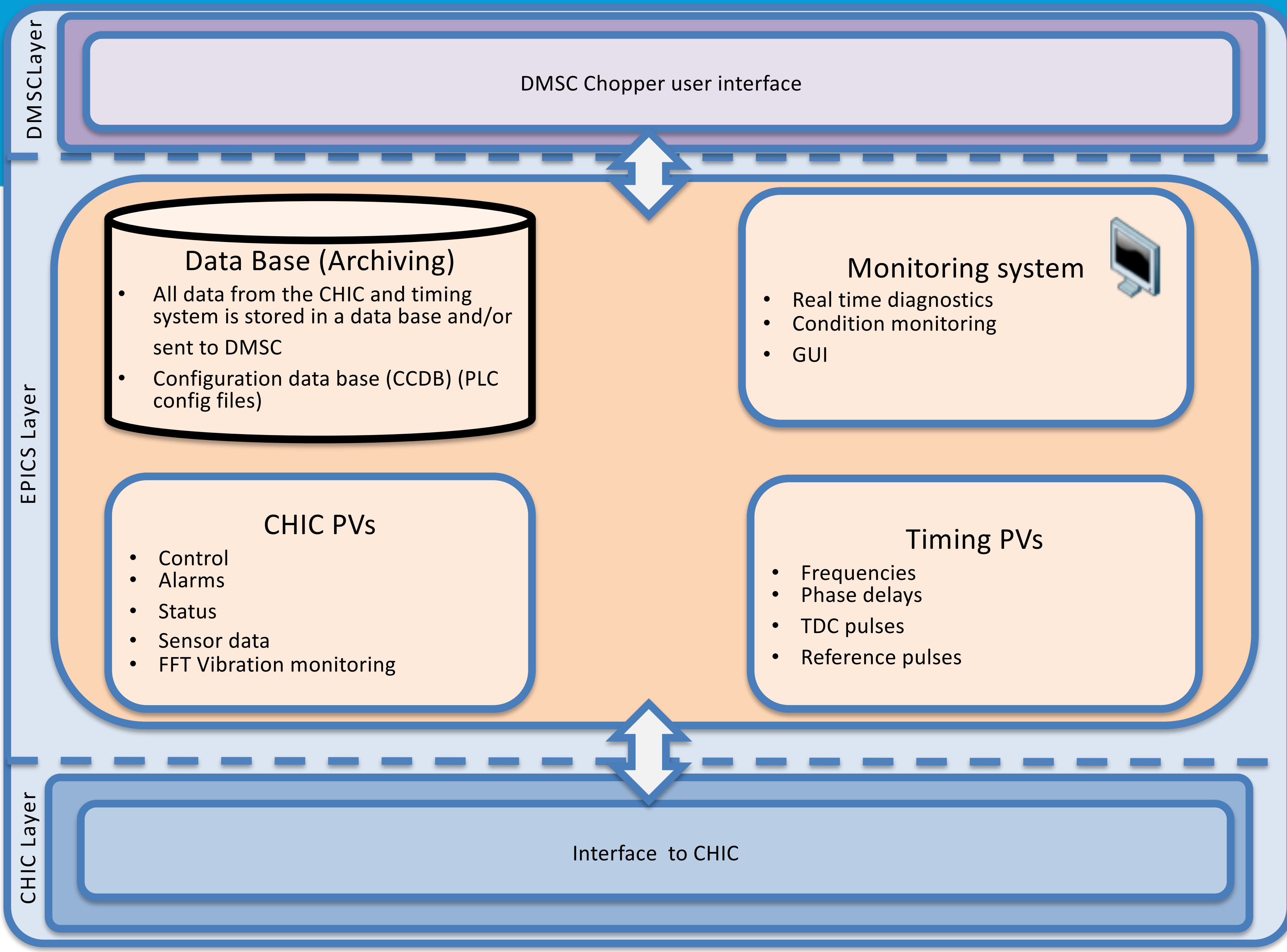
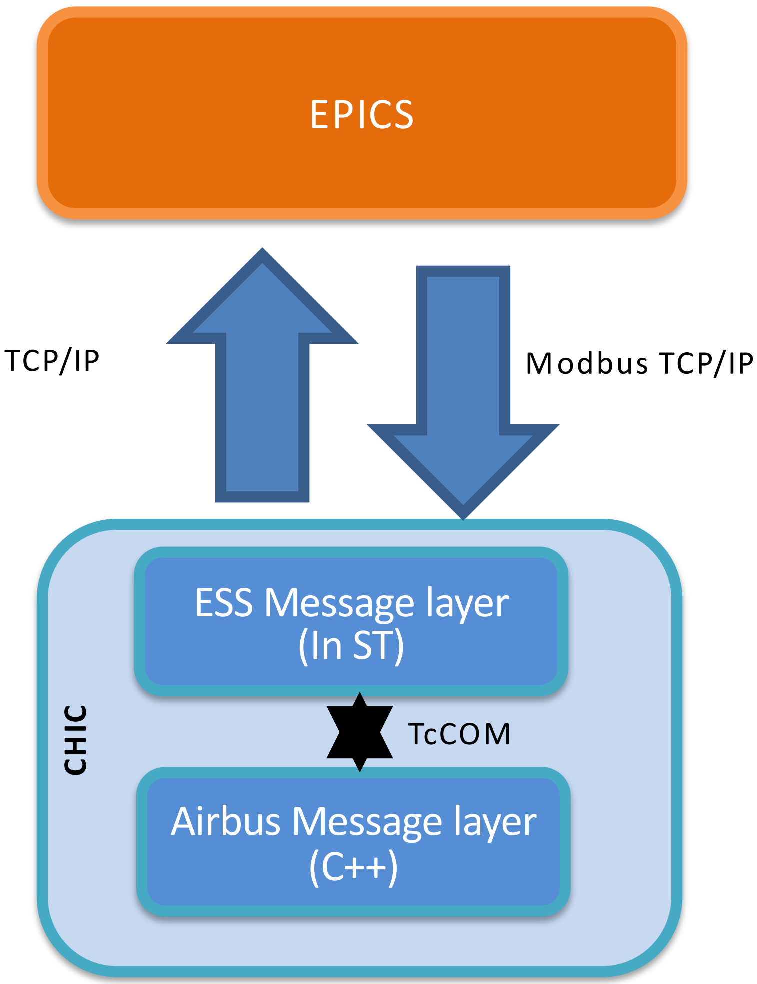



DMSCLayer
DMSC Chopper user interface
EPICS Layer
Data Base (Archiving)
• All data from the CHIC and timing system is stored in a data base and/or sent to DMSC
• Configuration data base (CCDB) (PLC config files)
Monitoring system
• Real time diagnostics
• Condition monitoring
• GUI
CHIC PVs
• Control
• Alarms
• Status
• Sensor data
• FFT Vibration monitoring
Timing PVs
• Frequencies
• Phase delays
• TDC pulses
• Reference pulses
CHIC Layer
Interface to CHIC

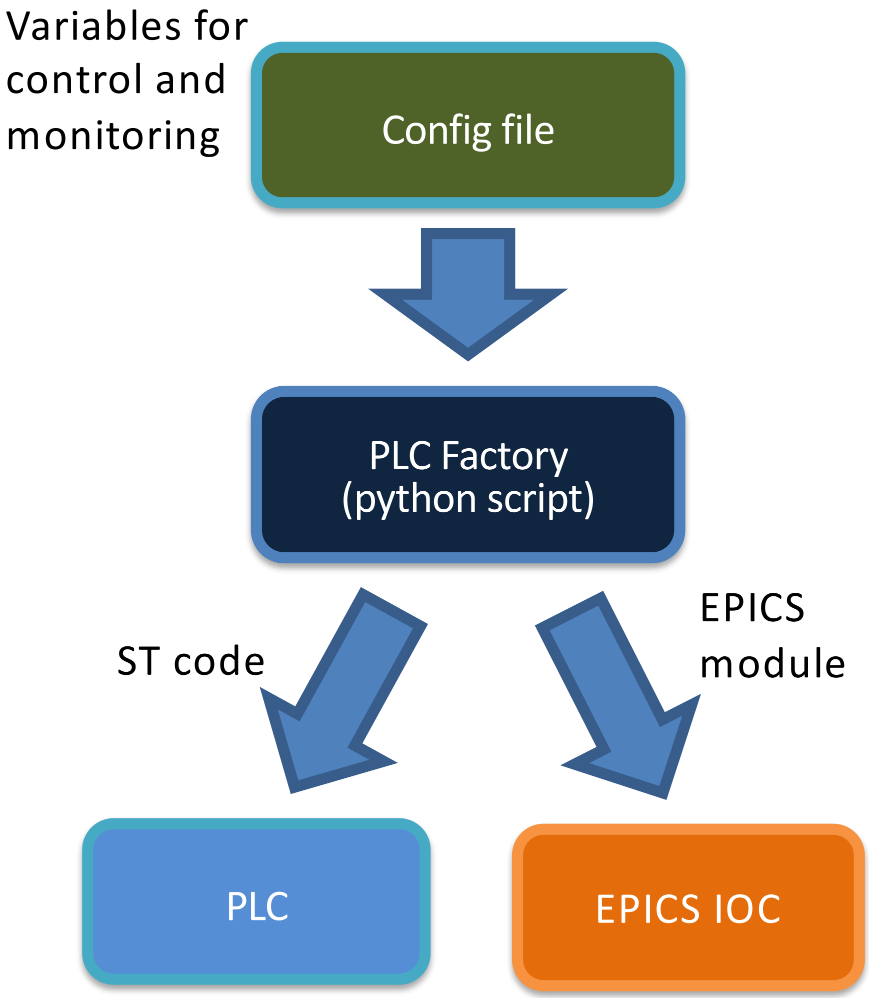
EPICS – CHIC interface

- Modbus TCP/IP to PLC
- TCP/IP to EPICS
- Two "message layers" one in ST (ESS) one in C++ (Airbus).
- Full implementation of all layers scheduled to fall 2018.



Automated script – PLC Factory

- Developed by Miklós Boros and Andrés Quintanilla
- Config file with variables for control and monitoring.
- The script will create two sets of code, one to PLC and one to an EPICS module
- Will save a lot of time and reduce the risk of human errors.



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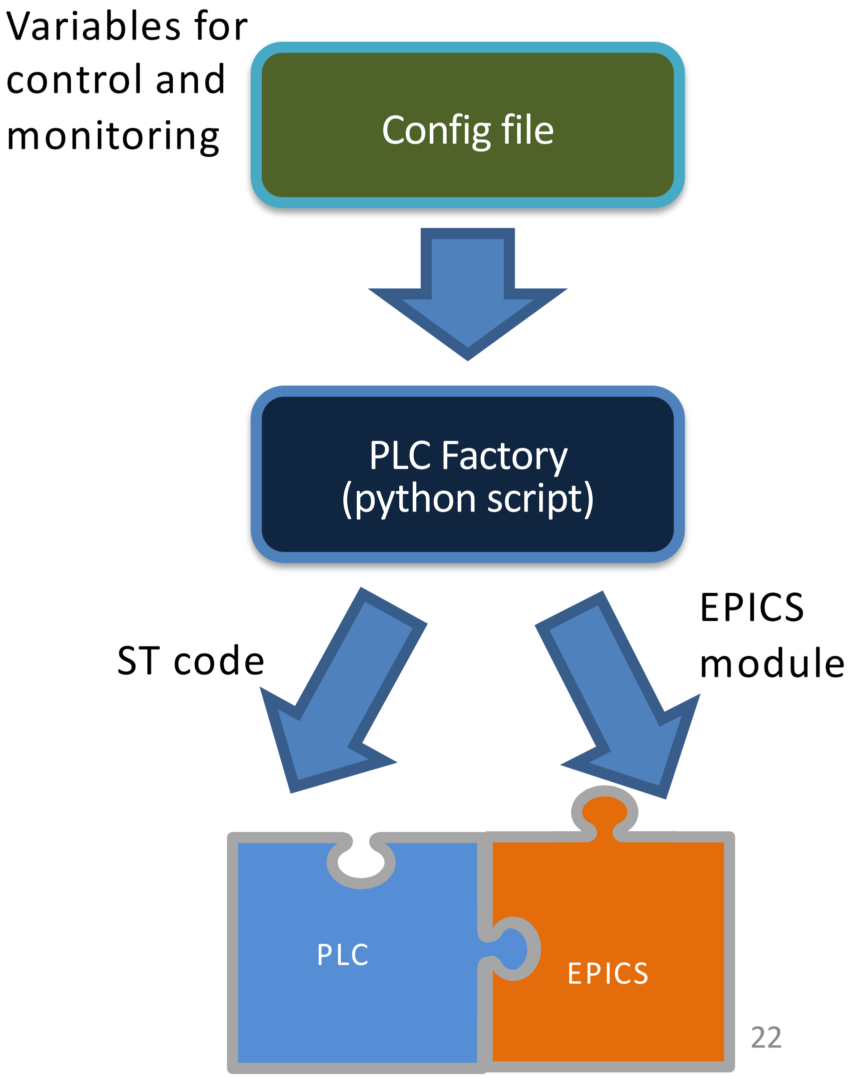
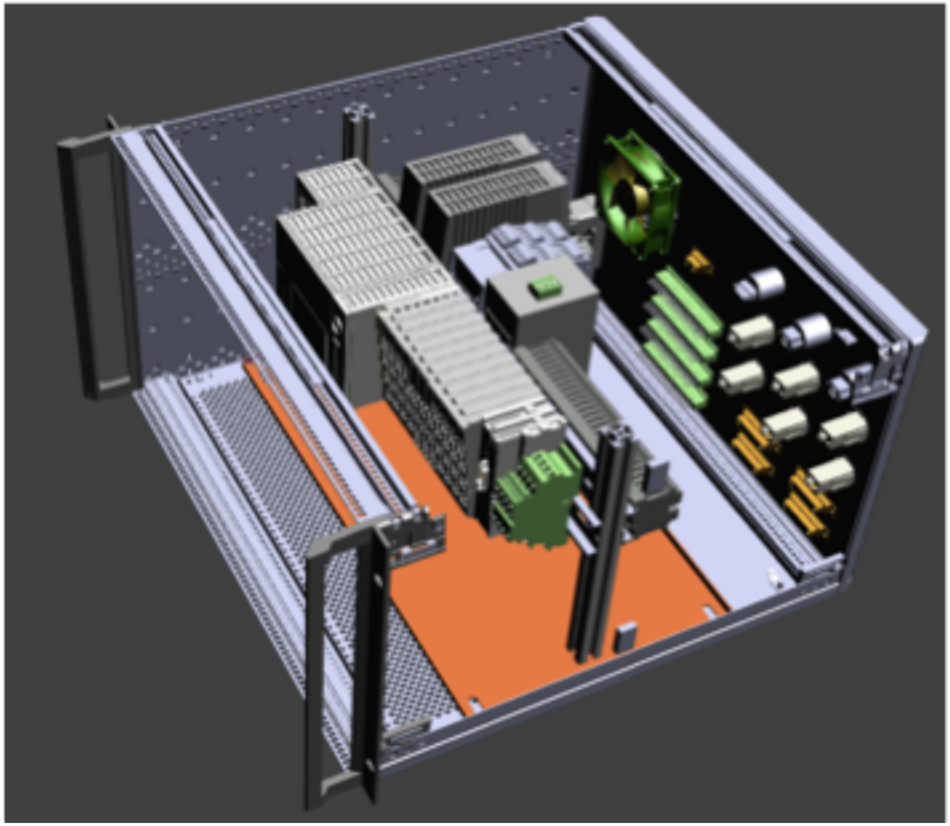


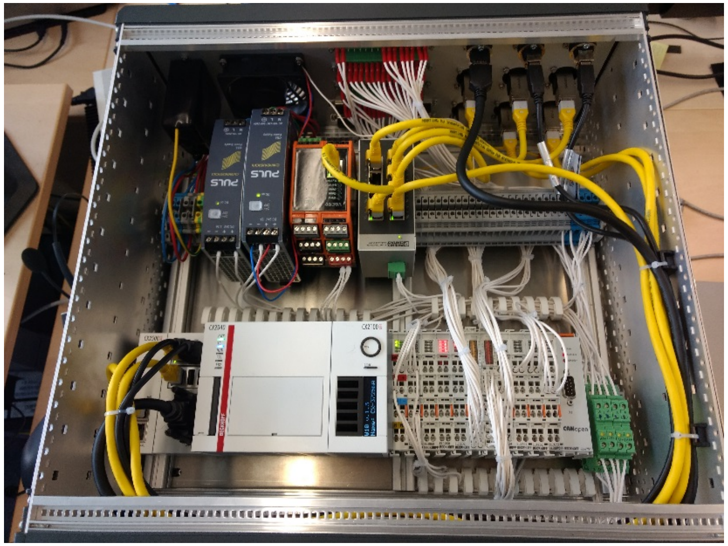
CHIC Hardware design

1. Crate 4U high
2. PLC (Beckhoff)
3. Vibration Monitoring
4. 2 x Power supply
5. Remote controlled Switch
6. Analog I/Os
7. Digital I/Os
8. Fieldbuses (Ethernet ports)
9. External hard drive



CHIC crate (In-kind with Jülich)

- First prototype crate made by Airbus spring 2018
- Second prototype in design stage. To be built fall 2018.
- Third version delivered spring 2019
- Drawings finalised Q2 2019.

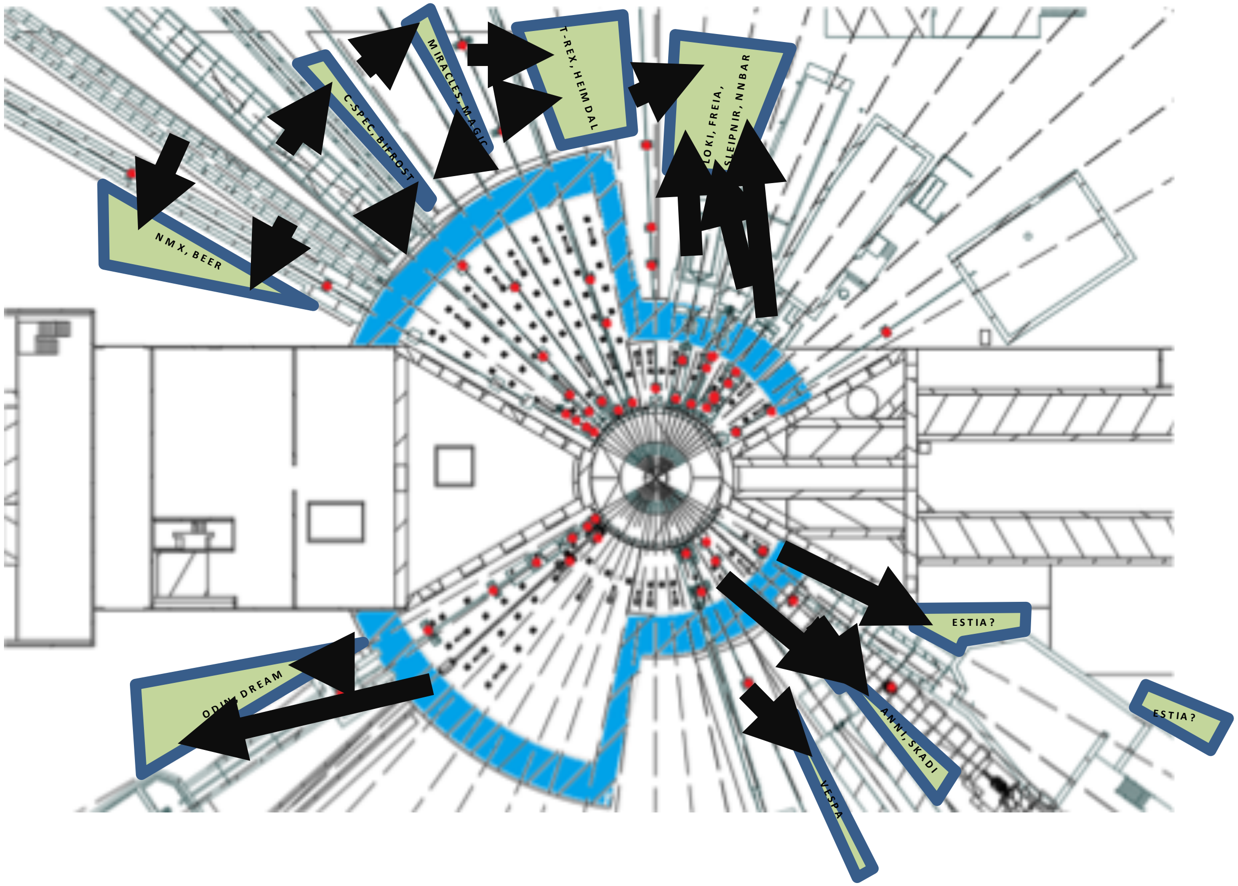


Chopper control rack

- Variant of the ESS standard instrument rack
  - Designed according to ESS standards and SE legislation.
- The rack is discussed together with suppliers
- Part of the control system in-kind with Jülich.
- Prototype delivered spring 2019
- Possible rack layouts for all instruments on confluence

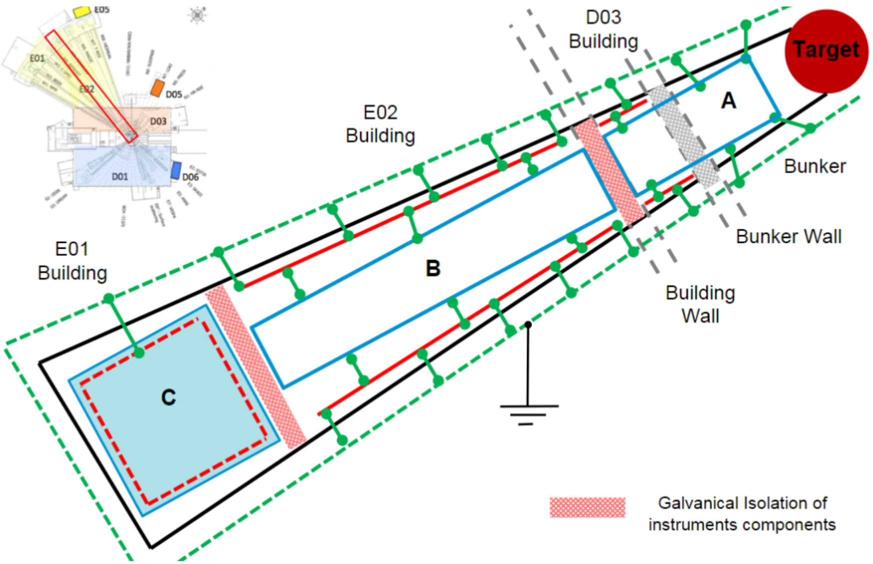
Prototype chopper control rack

Rack locations (for choppers in bunker)



Simple grounding rules for chopper racks

1. The chopper control rack shall always be in the same grounding zone as the chopper.
   - Mixing grounding zones can cause damage on equipment or introduce noise into the system
2. A rack shall never be shared between instruments.
   - To ensure the reliability of the instrument



Chopper timing
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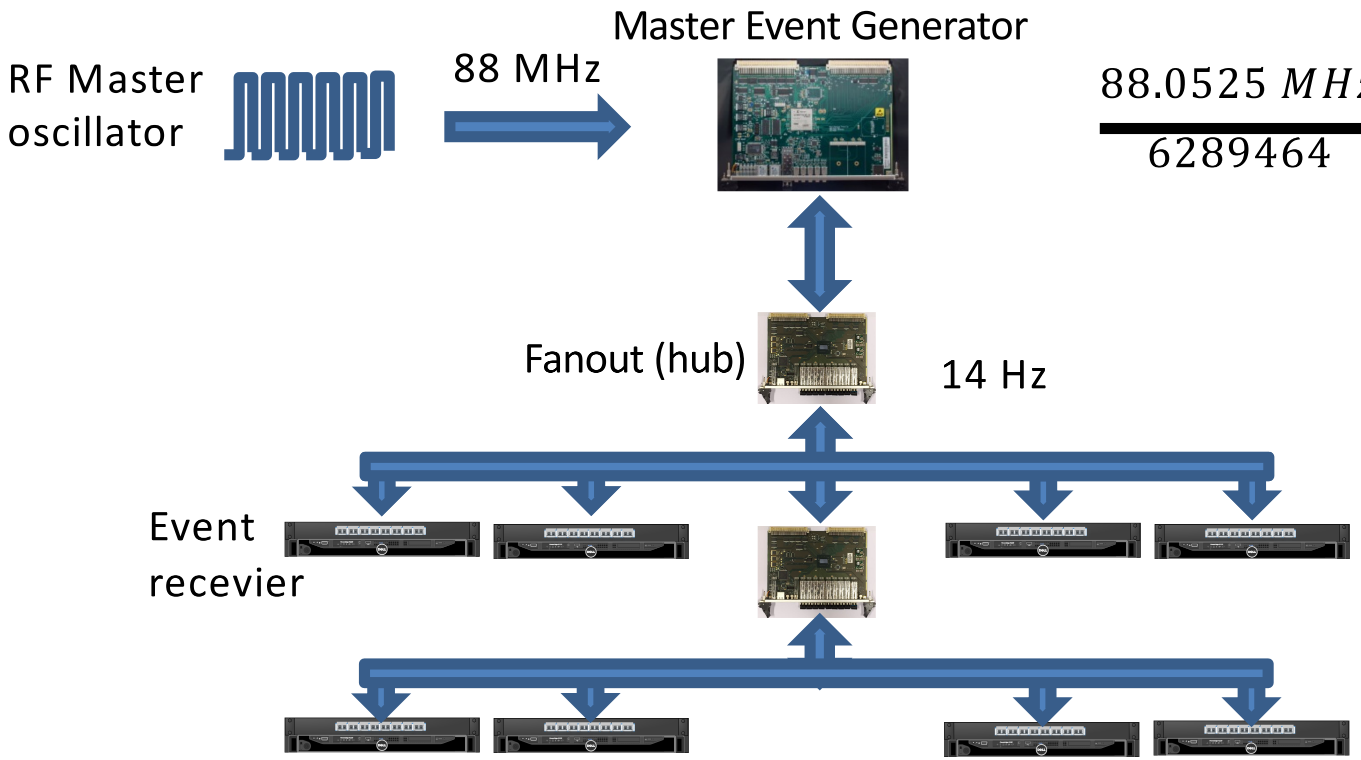
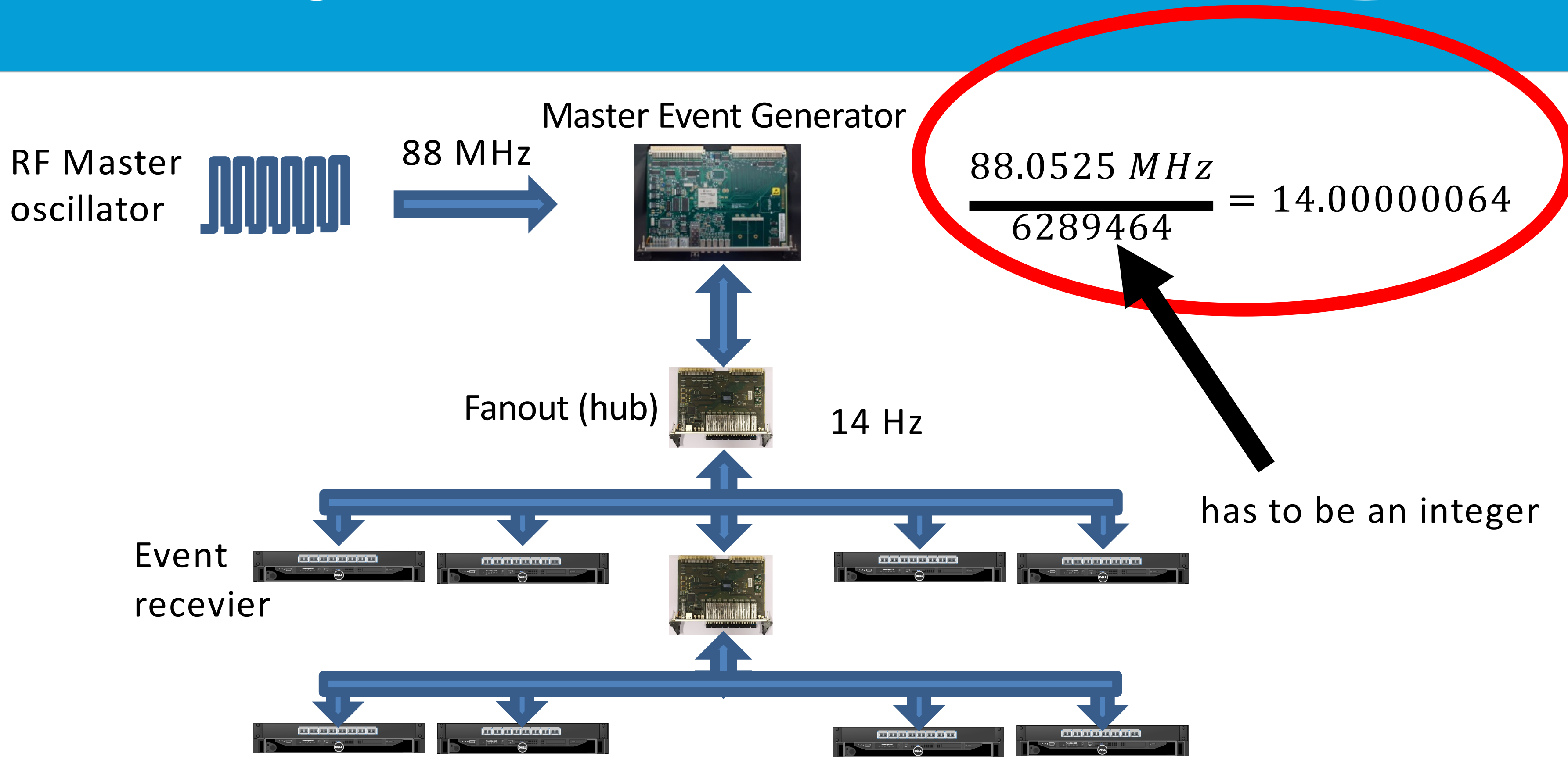
ESS Timing



$$\frac{88.0525\ MHz}{6289464} = 14.00000064$$

- The 14 Hz operating frequency will be generated by down conversion from RF in the event generator (divide 88.0525 MHz by 6289464 to get 14.00000064 Hz)
- All timing sequences, events, etc., generated in hardware
- One event generator for ESS

ESS Timing



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Creation of higher frequencies

- Normally it would make sense to use a different prescaler (divider) to produce higher frequencies
- Bifrost requires 210,0000095 Hz with the closest integer I will get 209,9998092 Hz

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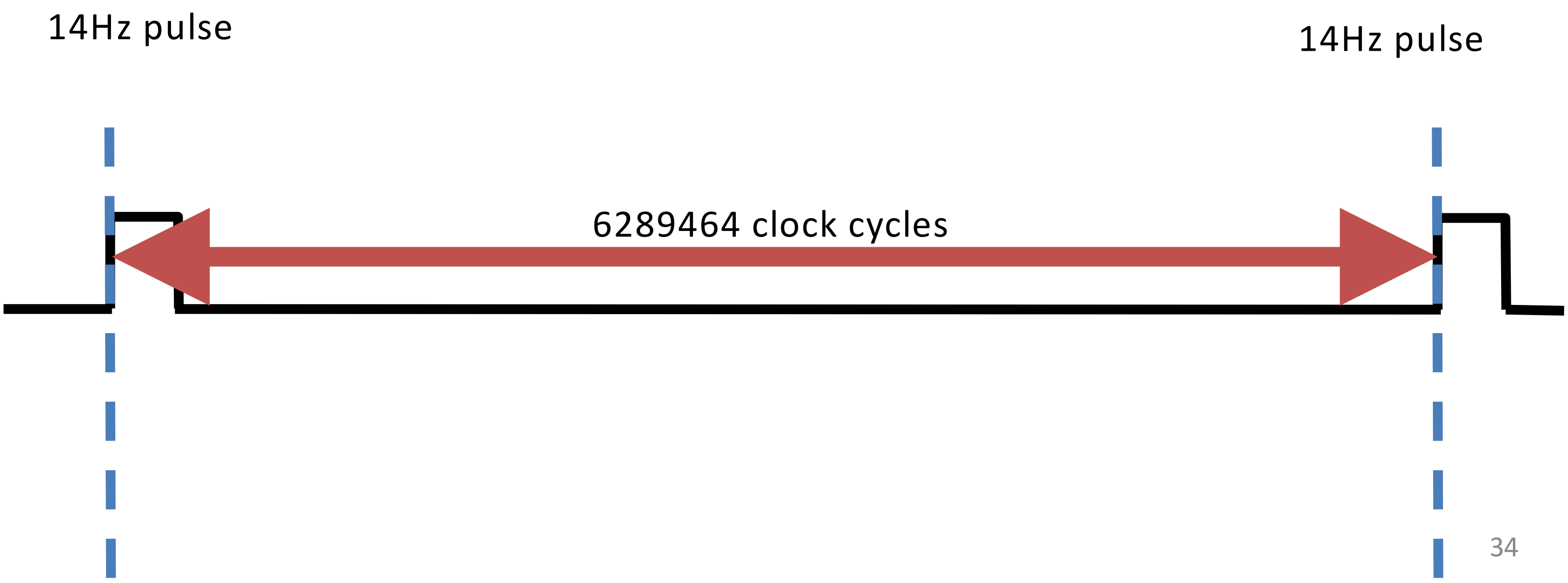
There is a solution

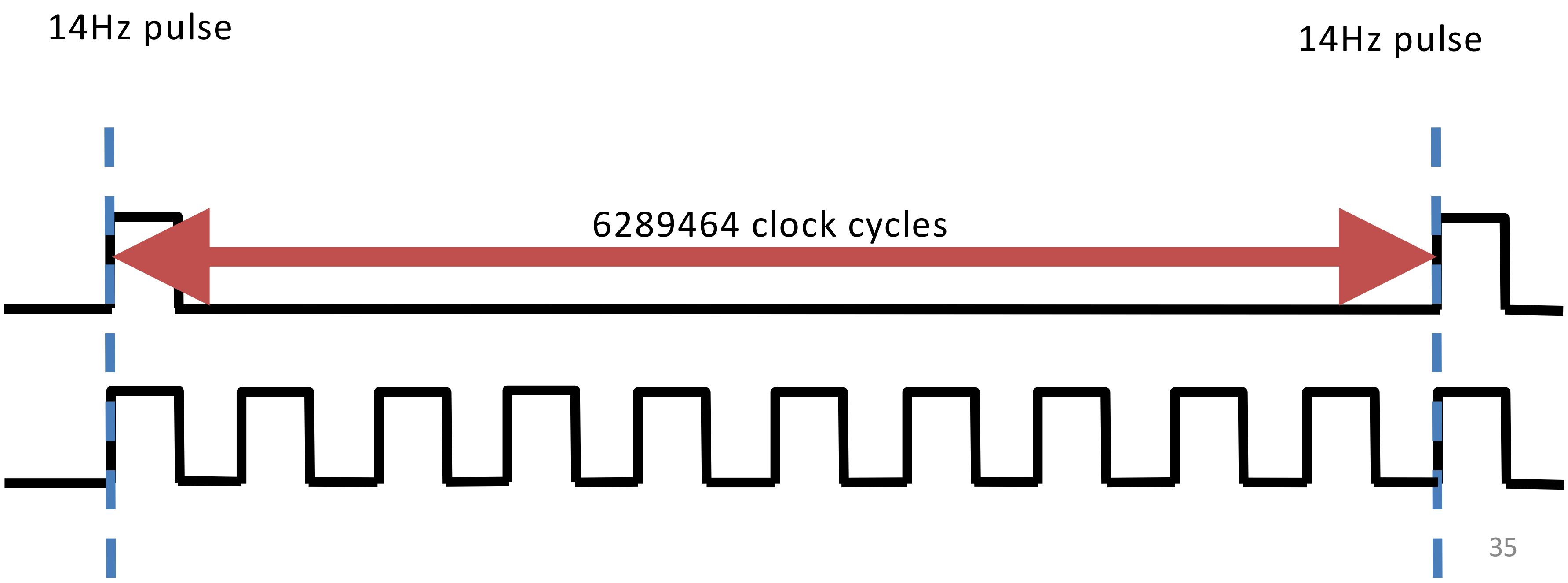
Creation of higher frequencies

- Solution is to create pulse trains



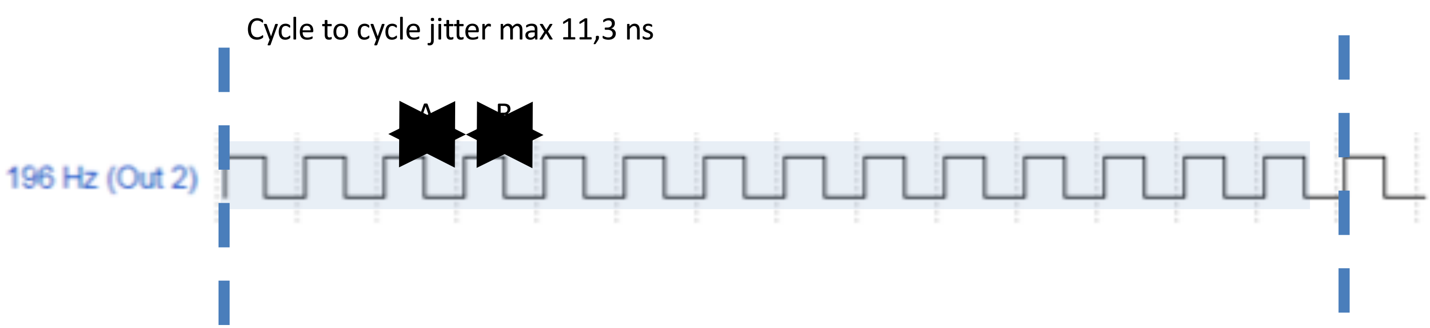
Creation of higher frequencies

- Pulse train consists of pulses generated at specific clock cycles
- The predefined ”pulse train” is triggered by the 14Hz event
- The “pulse train” is regenerated at every 14 Hz pulse
- Every pulse in the pulse train can be adjusted back and forth in time with a resolution of 11,3 ns.



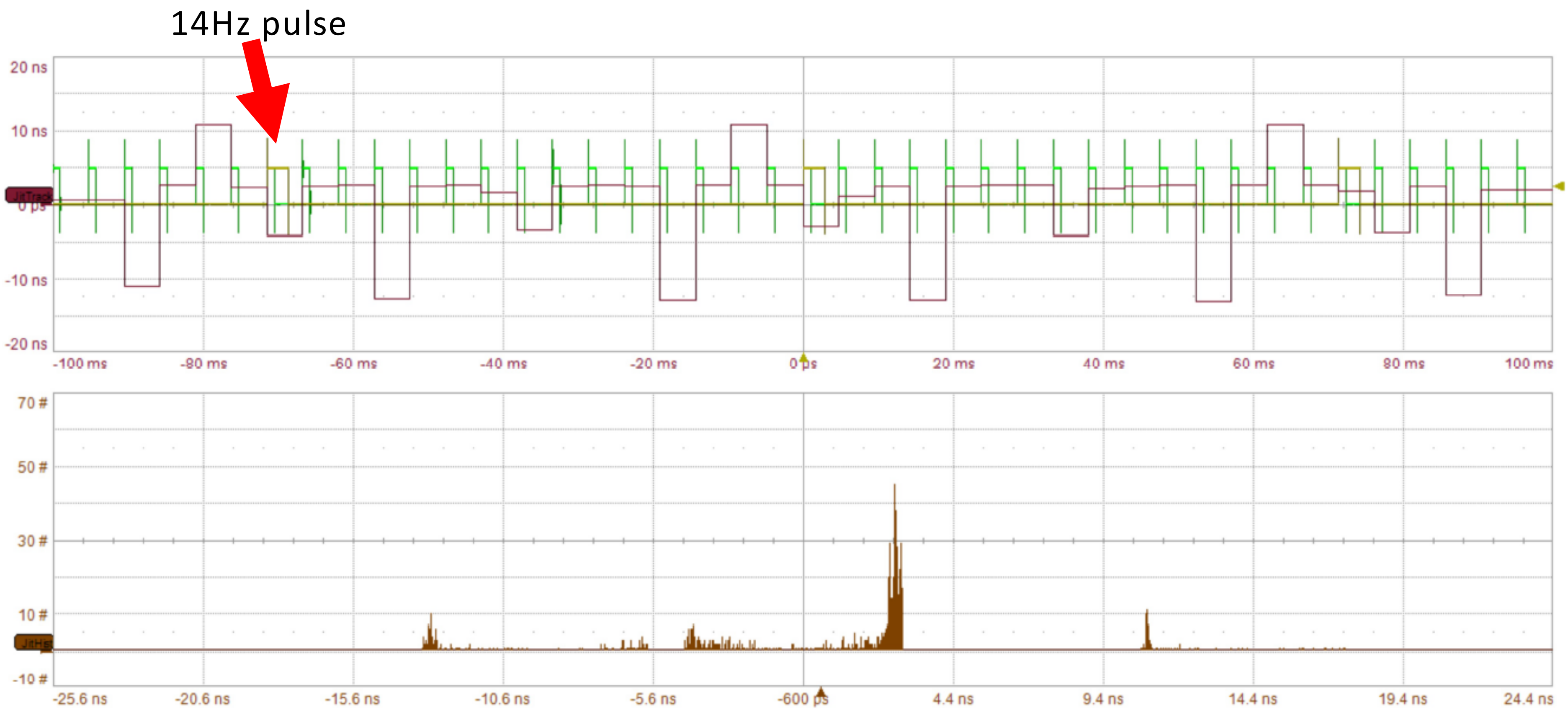
Chopper timing

- For 196 Hz we have 14 pulses in the pulse train
- The pulses are evenly spread out for any frequency, in some cases a rounding error occurs which means that the maximum cycle to cycle jitter will be 11.3 ns for any frequency.



$$Jitter_{ctc} = B_{period} - A_{period}$$

Experiment 210Hz



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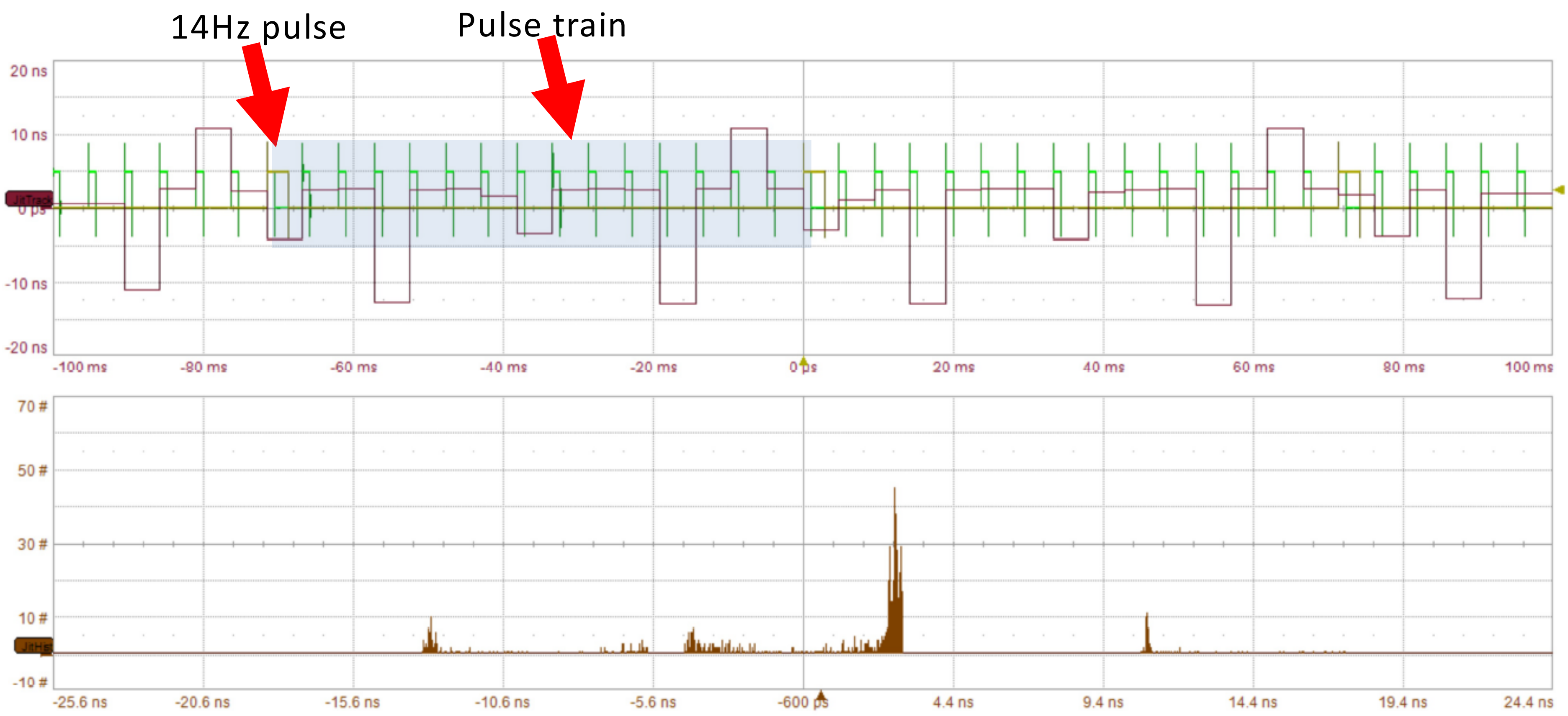

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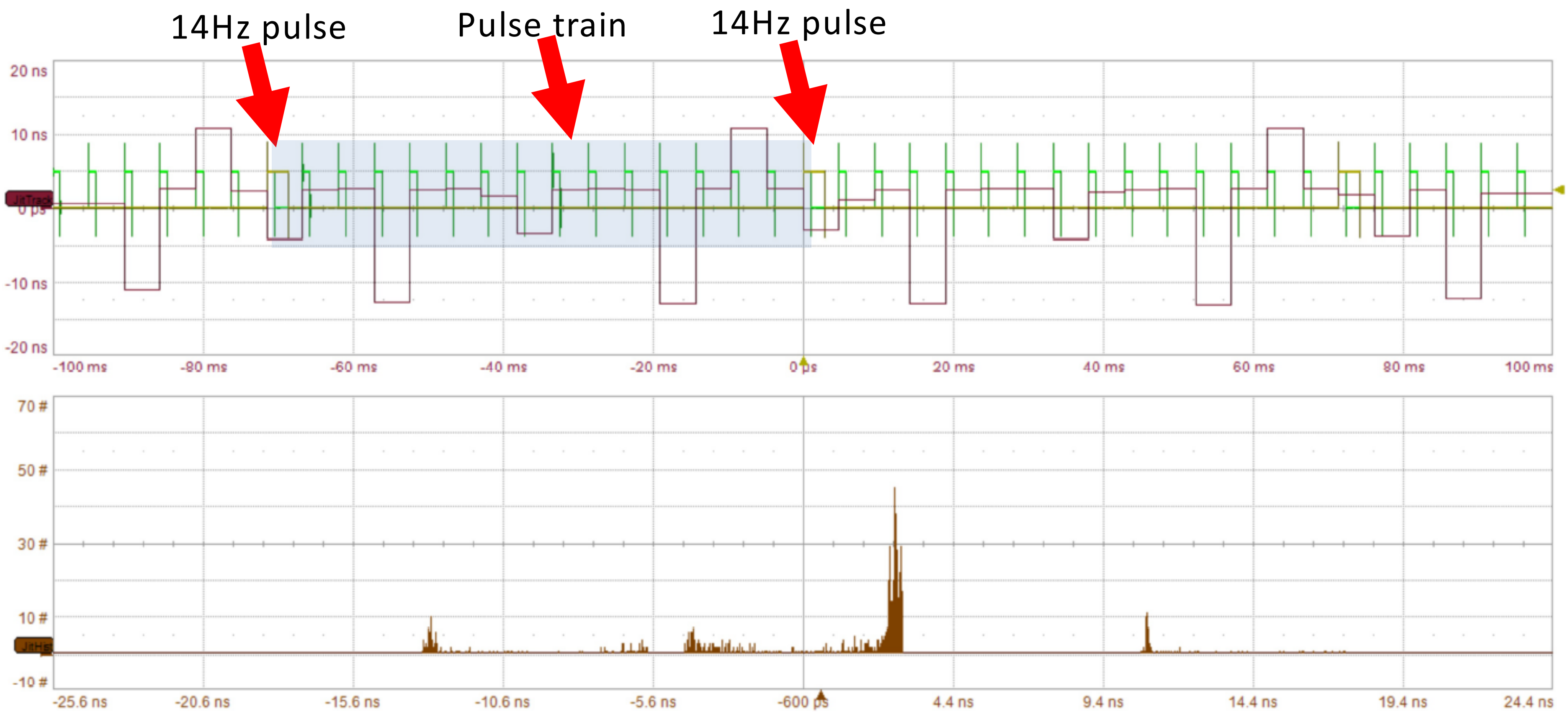

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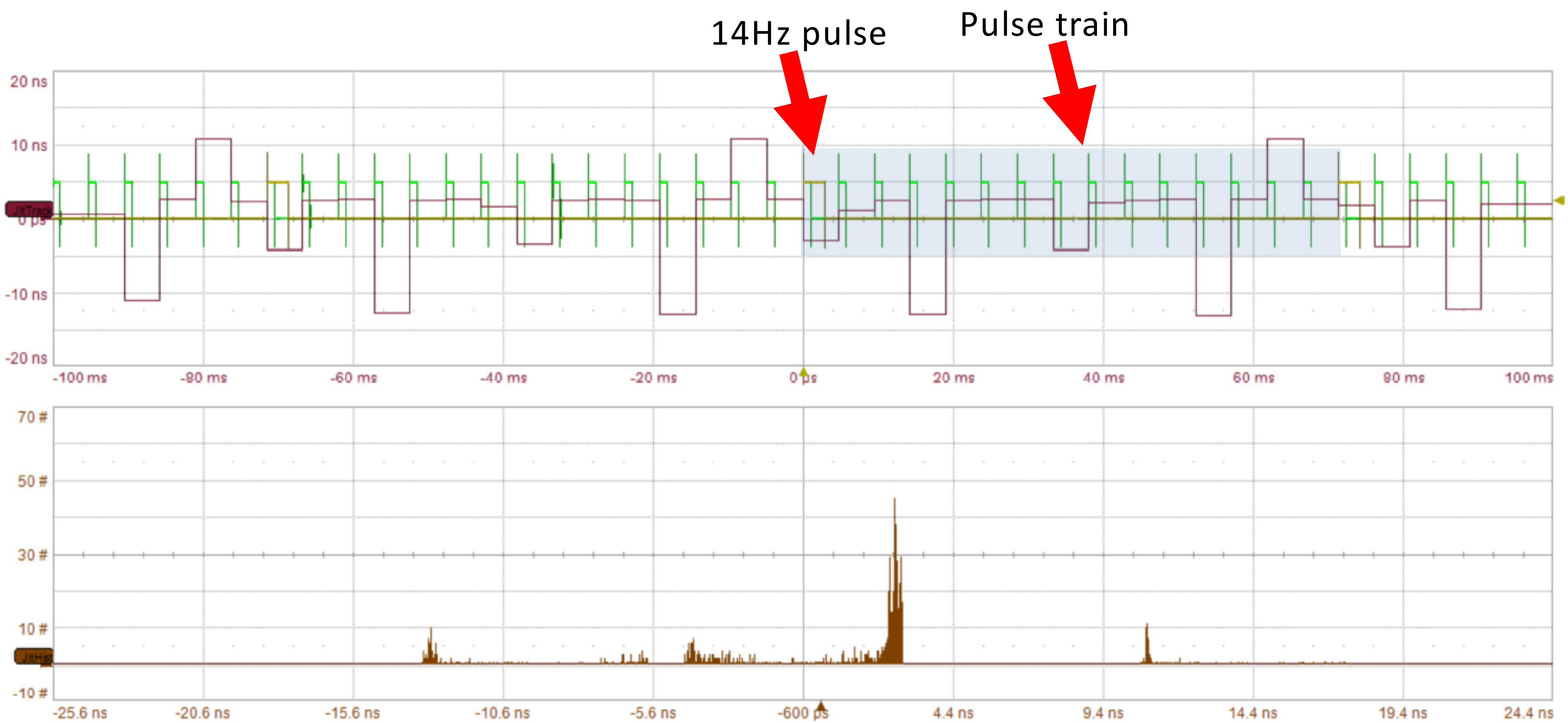

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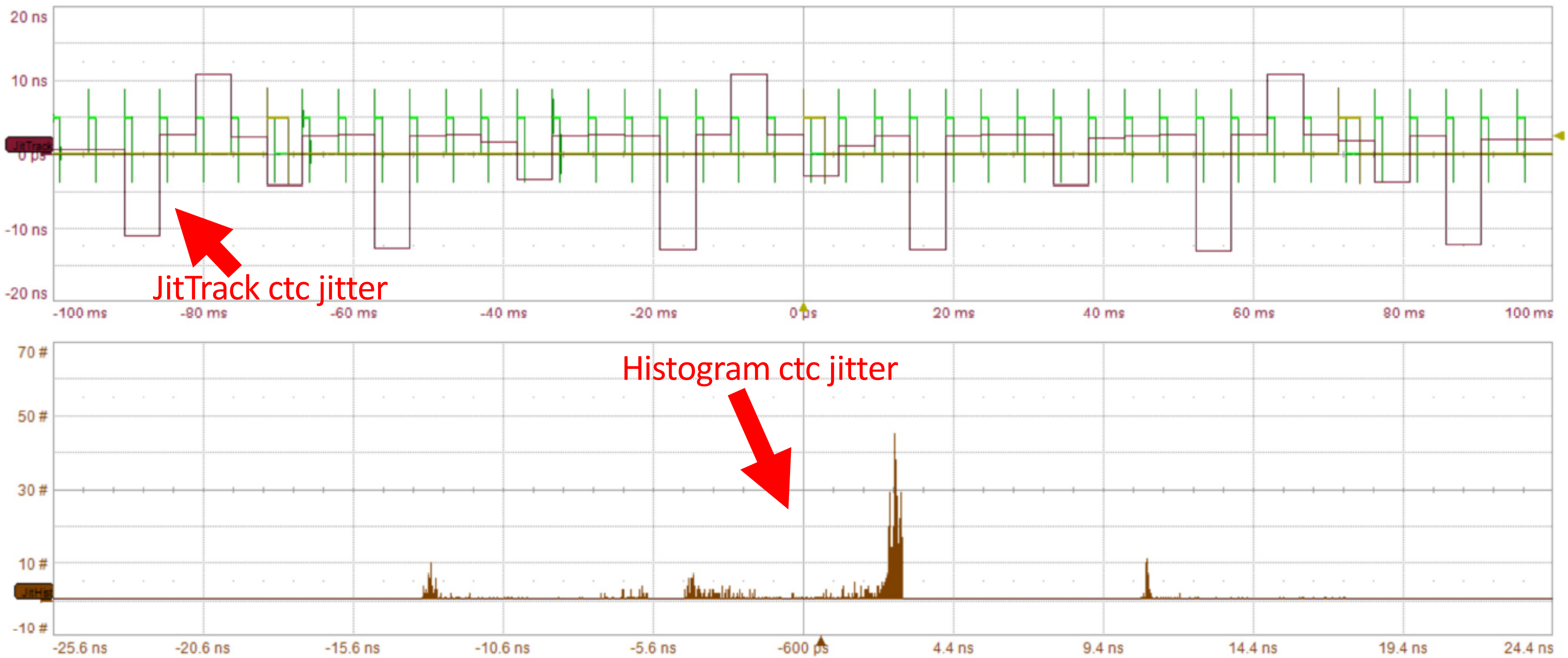
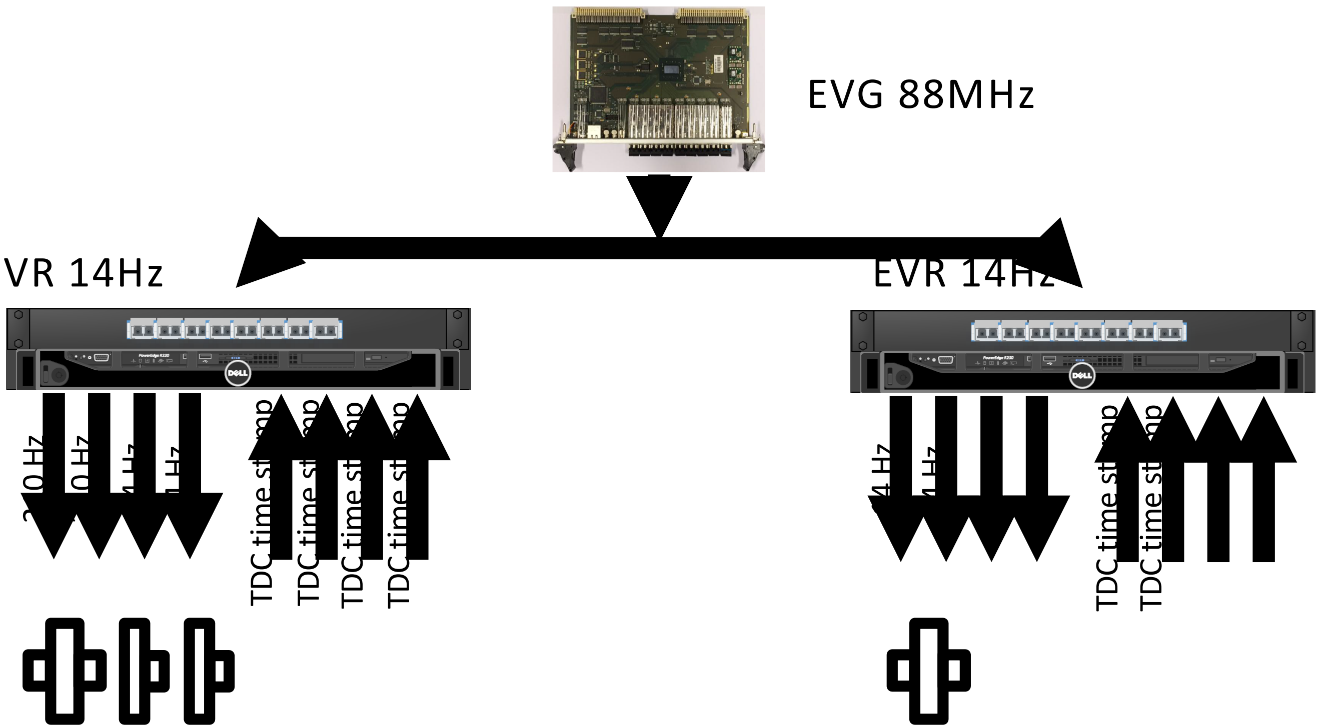


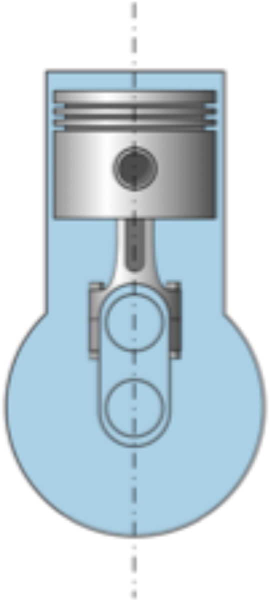
Timing

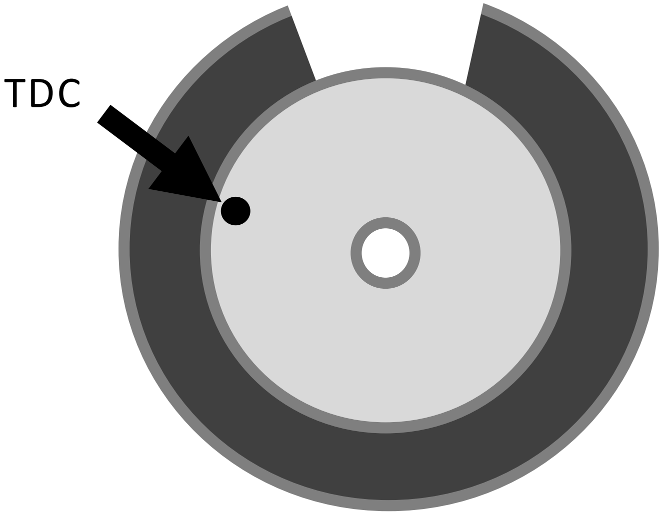
- Every rack will have an event receiver (EVR) that will provide reference frequencies to the choppers.
- Frequencies from 3.5Hz to at least 336 Hz will be created. (14Hz-350Hz tested)



TDC definition

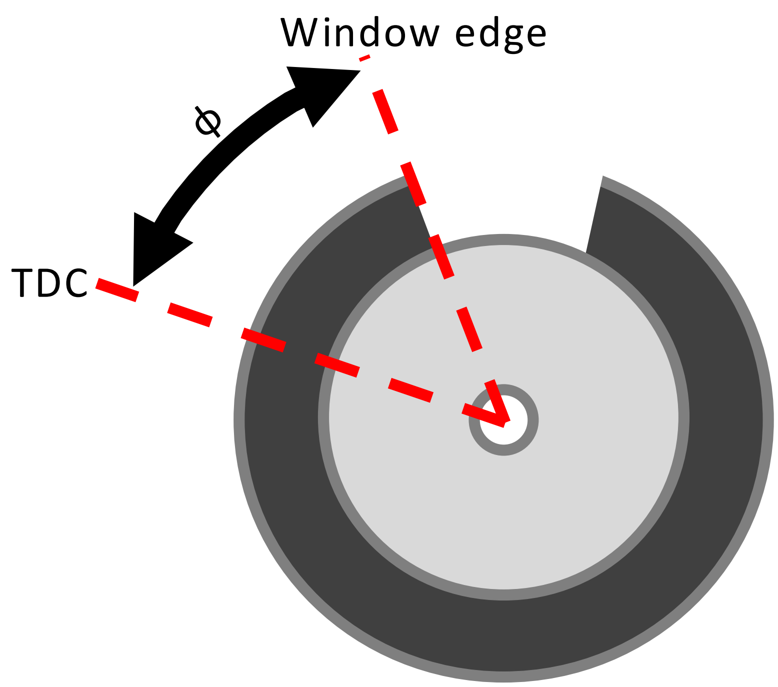
- Top Dead Centre (TDC) comes from the top position of a piston in an engine
- In chopper world it is a reference point on the disk
- The TDC can be a magnet on the disc or
  a position on the shaft





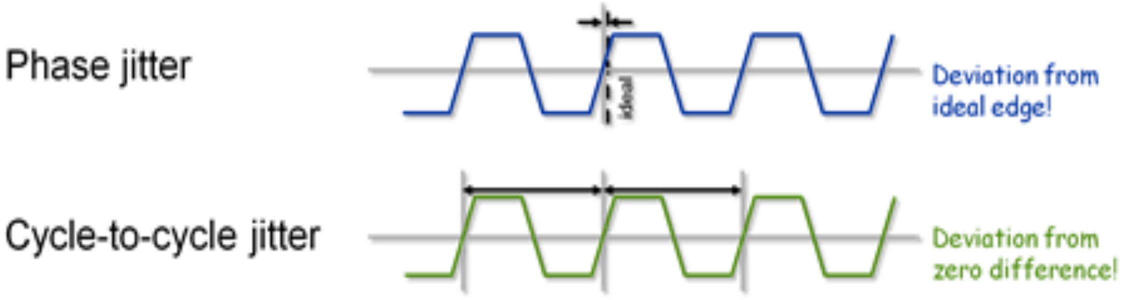
TDC offset determination

- The TDC can be a magnet on the disc or a position on the shaft
- The offset angle is predetermined with laser
- Verified with neutrons once installed in beam



Chopper phase error (phase jitter)

- Talking directly to suppliers (Airbus, Jülich, SKF, Mirrotron)
- During fall we will continue to talk to instrument scientists.
- Phase error = rising edge TDC – rising edge Reference
- Can be measured easily with an oscilloscope (persistence on)
- Max phase error requirement for each instrument and chopper should be communicated by the instrument to NCG.



Phase error and error propagation

- Reference signal jitter
- Control loop error (PID)
- Chopper mechanical error
- TDC sensor error
- Time stamping error

- $BW1\ Error = \sqrt{Ref^2 + Mech^2 + Ctrl^2 + TDC^2 + Tstamp^2}$

- $Chopper\ total\ error = \sqrt{BW1^2 + BW2^2 + \ldots^2}$

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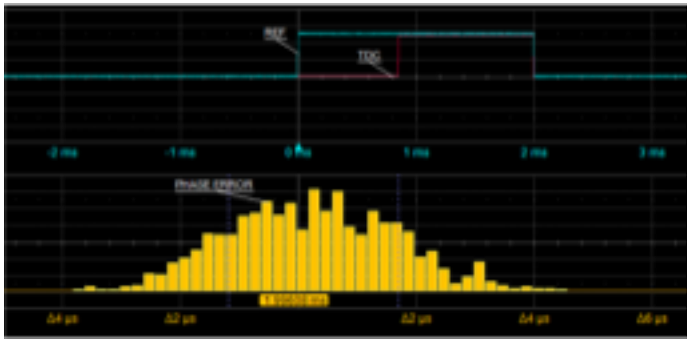
Determined with neutrons (beam monitors/detectors)

Sent to DMSC

- $Chopper\ total\ error = \sqrt{BW1^2 + BW2^2 + \ldots^2}$

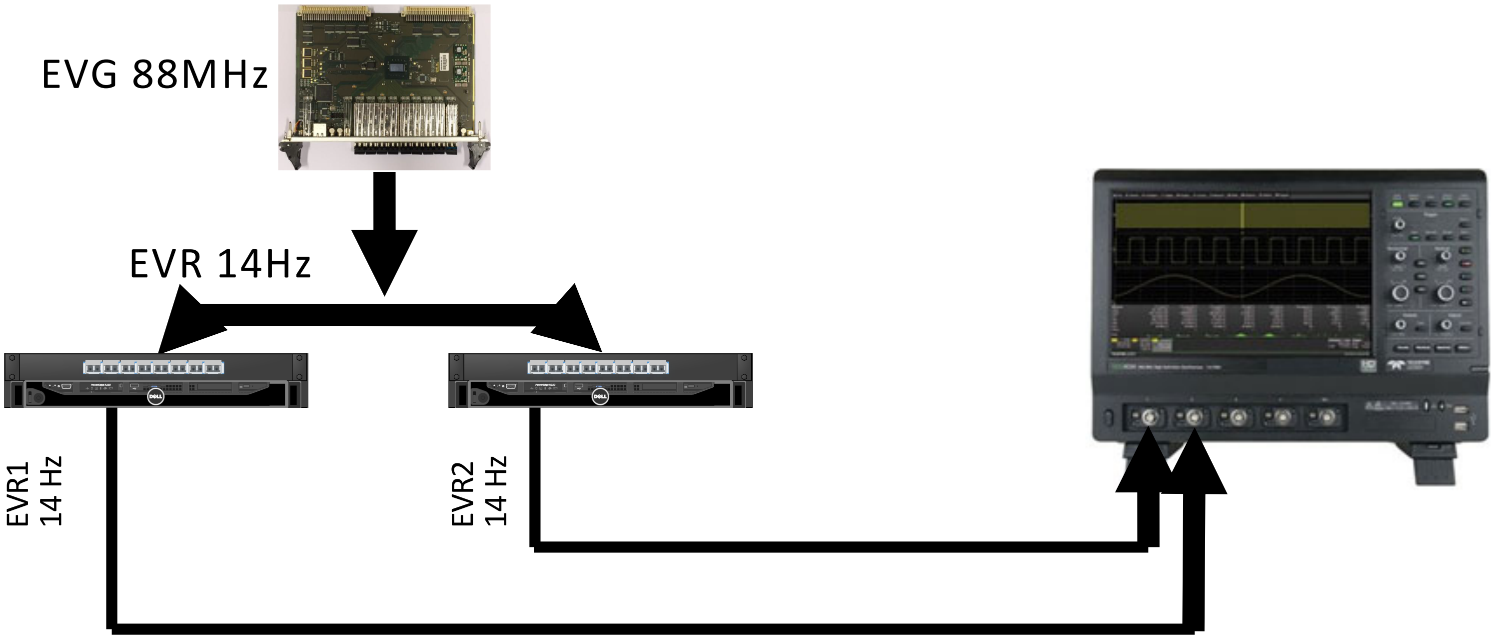
Verification and validation

- 300 MHz oscilloscope for verification of timing and chopper accuracy
- Jitter and chopper phase error can be plotted directly in a histogram with a few ns resolution
- Possible to connect accelerometers for additional vibration analysis.



Timing update

- Frequencies 14-350Hz generated with the EVR
- Two EVRs connected to one EVG
  - Tested at utgård August 2018.
  - Histogram shows EVR1 – EVR2 (rising edges)
  - 440 ps jitter, resolution limited by our oscilloscope



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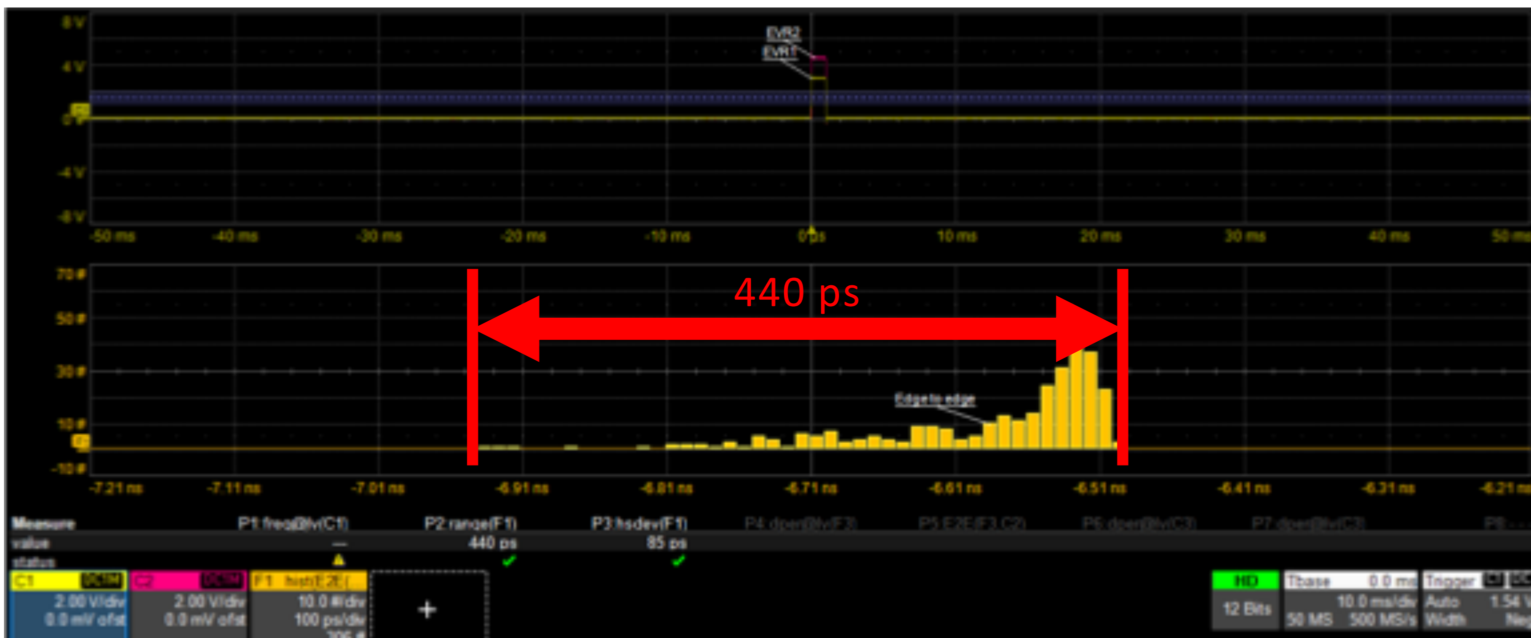
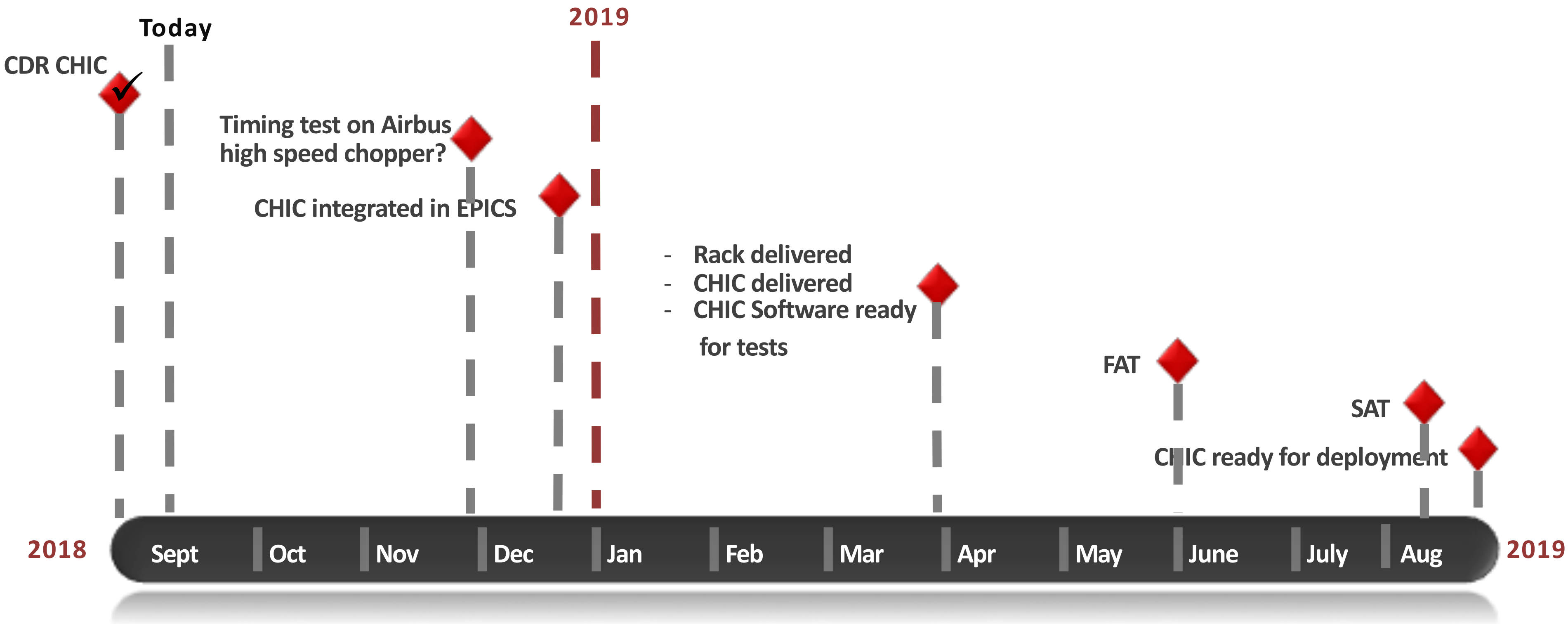


Planned tests - fall 2018

- Atomic clock ordered to improve time stamping in the EVR (for test purposes)
- Test with laser to determine the angular offset between the TDC and a specific window in the disk.
- Test timing system with high speed chopper in-kind project (pre FAT)


CHIC timeline 2018/2019



Thanks to

- Andrés Quintanilla (NSS/ESS)
- Nikolaos Tsapatsaris (NSS/ESS)
- Florian Engler (Airbus)
- Philip Seif (Airbus)
- Marko Leyendecker (Jülich)
- Javier Cereijo García (ICS/ESS)
- Nicklas Holmberg (ICS/ESS)
- Miklós Boros (ICS/ESS)
- Jonas Nilsson (DMSC/ESS)
- Neutron chopper STAP members

Thank you

Questions?

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12 September, 2018

Chopper Group/Instruments

- What drives will be used? SKF communication module will be implemented into the CHIC fall 2018.
- What communication protocol will be used between CHIC and drives. (Modbus preferred)
- We need to know the maximum allowed phase error for each chopper.

Example of a timestamp

	Absolute time us precision	EPICS epoch since Jan 1st 1990 11,3 ns resolution
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:00.820983	879522180.82098281
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:00.892302	879522180.89230168
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:00.892411	879522180.89241135
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:00.963725	879522180.96372509
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:00.963840	879522180.96383989
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:01.035168	879522181.03516793
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:01.035288	879522181.03528833
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:01.106586	879522181.10658598
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:01.106717	879522181.10671699
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:01.178034	879522181.17803359
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:01.178146	879522181.17814553
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:01.249463	879522181.24946344
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:01.249574	879522181.24957407
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:01.320885	879522181.32088518
HZB-V20:Chop-Drv-01:Ref	2017-11-14 16:43:01.321003	879522181.32100260
HZB-V20:Chop-Drv-01:TDC	2017-11-14 16:43:01.392310	879522181.39230955

Chopper timing

- Different "pulse trains" are triggered by the rising edge of the 14 Hz event.