

Real-time controls and data acquisition

First ET-France workshop
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III Interferometer

III.1 Observatory design
and noise budgets

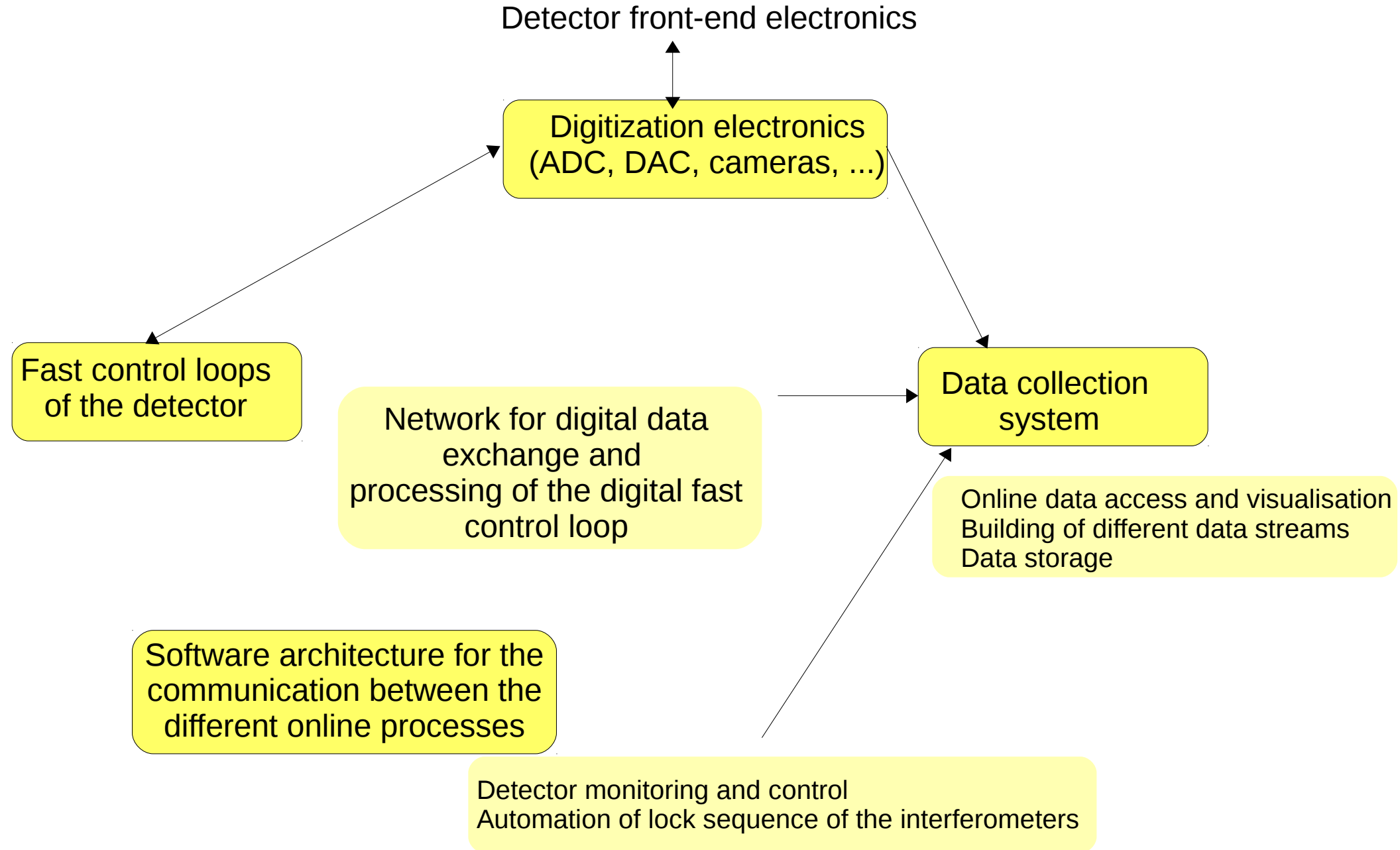
III.2 Optical layout,
sensing and control
scheme LF

III.3 Optical layout,
sensing and control
scheme HF

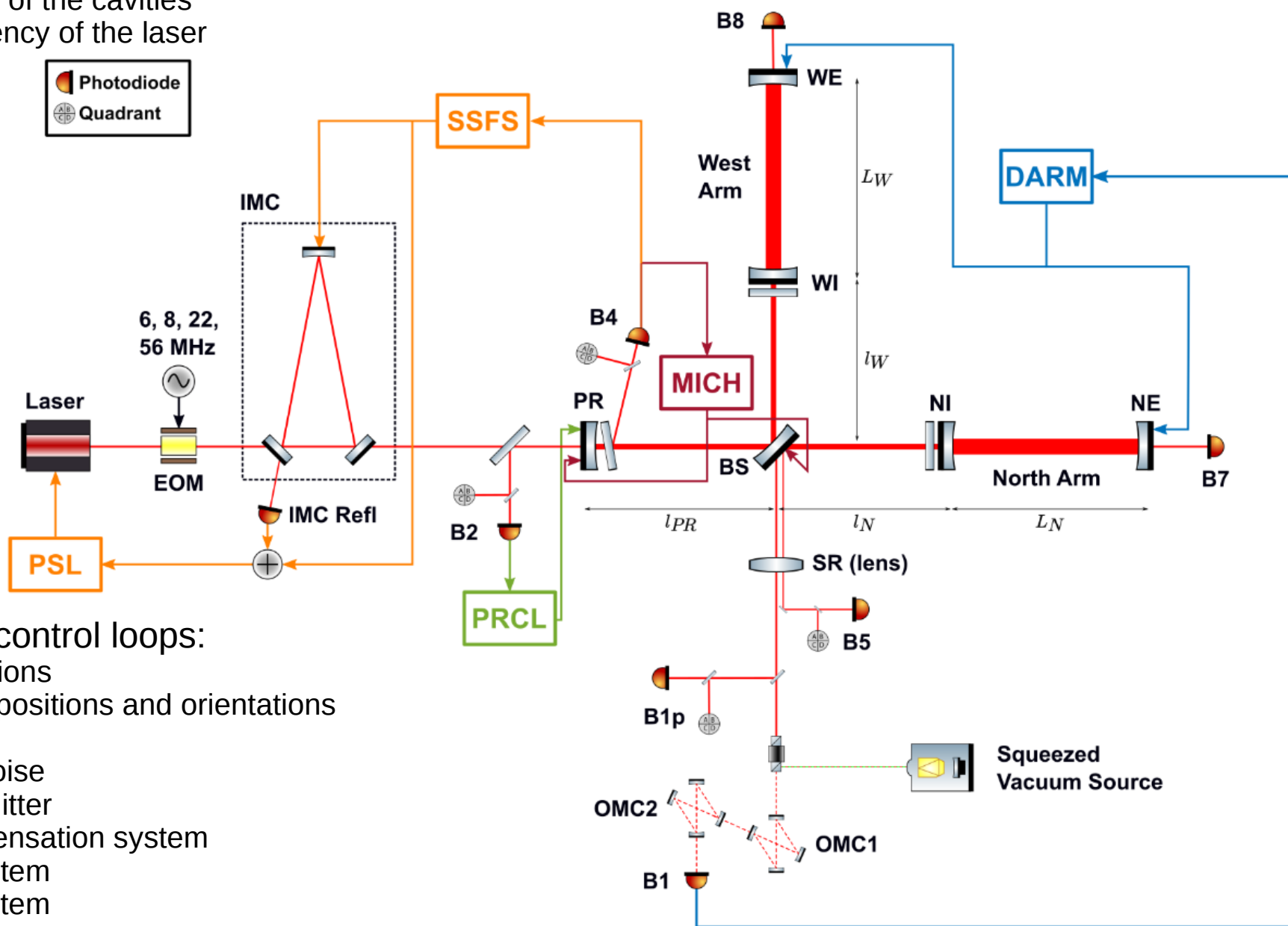
III.5 Data acquisition and
real time controls

III. 6 Detector
characterisation
& calibration

Sub-division content overview (preliminary)



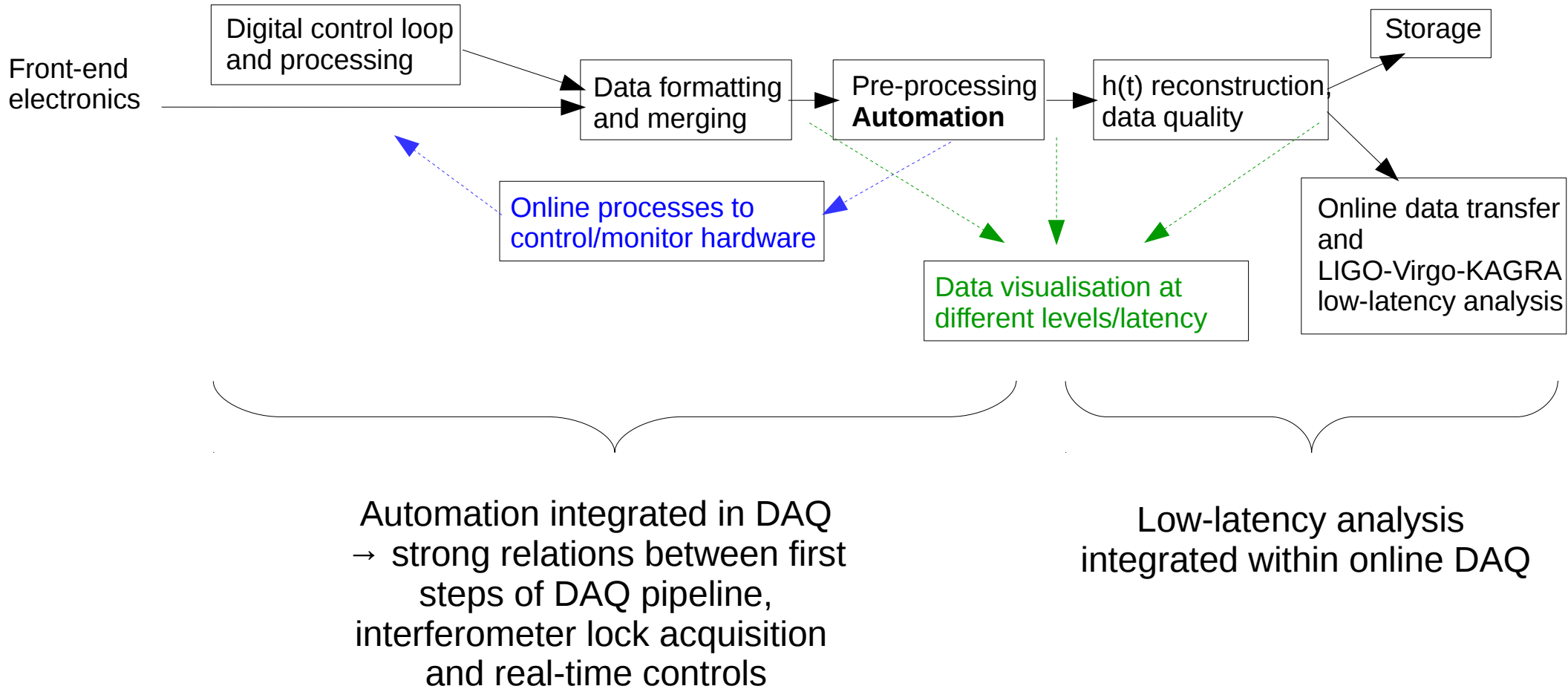
- control the length of the cavities
- control the frequency of the laser



- + a lot of other control loops:
 - mirror orientations
 - optical bench positions and orientations
 - suspensions
 - laser power noise
 - laser position jitter
 - thermal compensation system
 - squeezing system
 - calibration system

■ ■ ■

Overview of data acquisition pipeline in Virgo

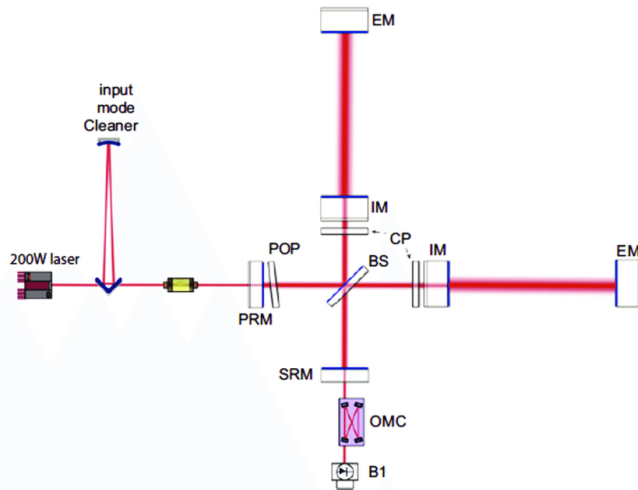


From Virgo to E.T.

1 Virgo interferometer



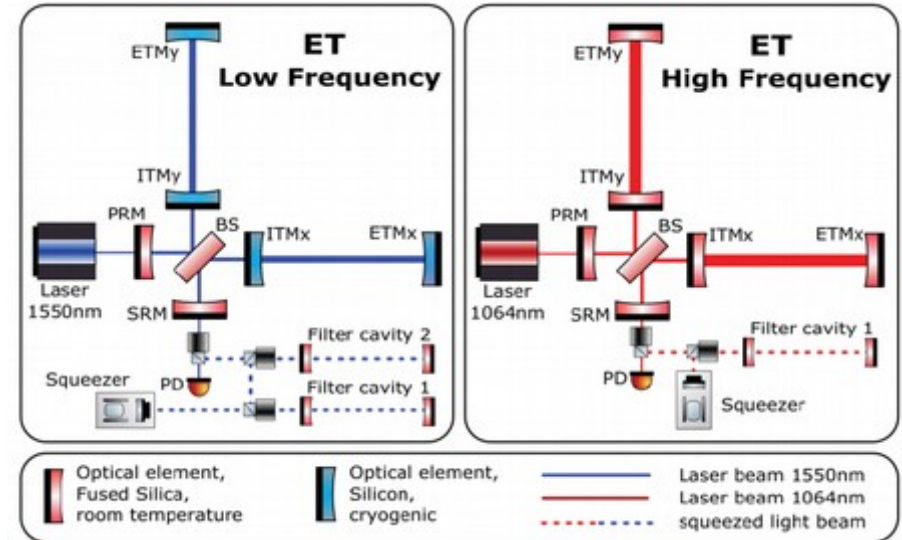
6 E.T. interferometers



Arm length 3 km (transmission delay $\sim 15 \mu\text{s}$)
 Longitudinal control loops running at 10 kHz
 Angular control loops running at 2 kHz
 Some loops running at 400 MHz

+ many local controls (suspensions, mirrors, optical benches, lasers, cavities, ...)

Data flow at storage level $\sim 50 \text{ MB/s}$ for AdV+



Arm length 10 km (transmission delay $\sim 50 \mu\text{s}$)
 → to be taken into account in E.T. control strategy
 Speed of loops: same? faster ? slower?

More sub-systems (suspensions and mirrors if folded cavities, ...)

Data flow at storage level: few 1 GB/s ?

(In)Dependence of colocated interferometers?
 (for both real-time controls and DAQ pipelines)

Some of the requirements to be defined

Data flow (front-end and data acquisition levels)

Number of channels, sampling frequencies, ...
 Front-end camera flows
 Uncompressed/compressed data flows
 Number of data flows and online/offline accessibility

Some numbers from Virgo

~50 MB/s at the storage level

Real-time fast controls

Maximum delay from electronics and digital control (from loops)
 Unity Gain Frequencies (UGF) of the loops
 Transfer of small data packets but w/ deterministic and low latency

*UGF of 100 Hz in general
 Few loops with UGF few kHz*

Timing system

Absolute timing (for data analysis)
 Relative timing over whole detector (for loops)
 Local timing jitter on digital devices

*~10 μ s absolute timestamp
 Local clock jitter ~10 ps on ADCs
 Local clock jitter ~100 fs on fast ADCs*

Automation

State machine to acquire the detector working point (lock)

Data access with latency ~1 s

Data visualisation

Online data access with latency few seconds

Some other general constraints

System easy to reconfigure, easy to test on test benches in labs
 Reliability and maintainability

Some of the interfaces

all the front-end hardware of E.T.

all systems with digital loops

(digital) demodulation of photodiode signals

overall monitoring/control of the detector

overall computing infrastructure

data format

data storage

user data access and visualisation needs

...

Some possible evolutions of real-time networks

Timing distribution

- keep **centralized timing** source distributed all over the detector
- reduce timing **jitter/phase noise** in the distribution
- reduce local timing jitter/deterministic local timing
- control **deterministic phase** between all the synchronised parts?

→ test of WhiteRabbit to distribute lower phase noise clocks over 10 km lengths

Digital data network and digital loop processing

- keep centralized computing processing for loops with Unity Gain Frequencies of few 100 Hz?
- for loops with UGF of few kHz, separate processing on different parts?

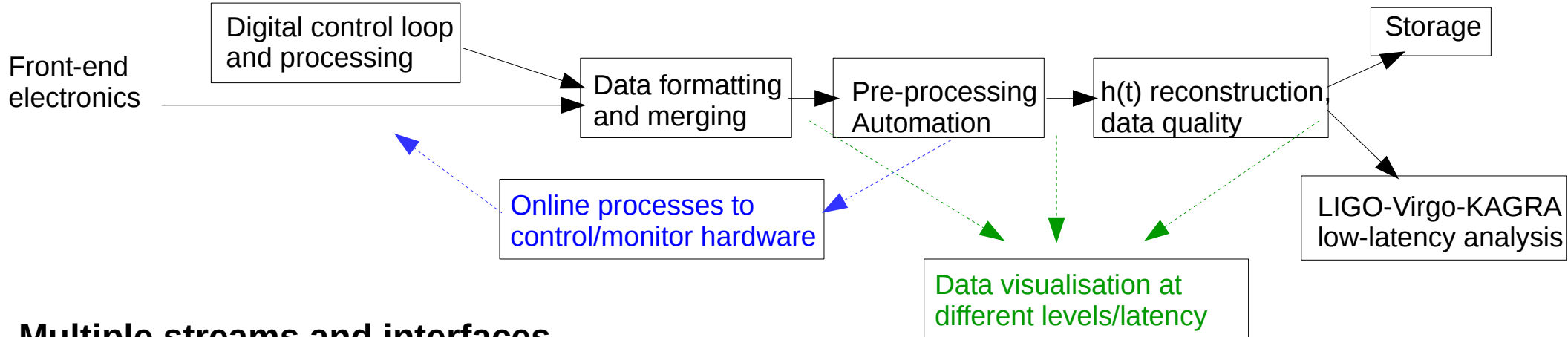
- **fast links with deterministic and very low latency, exchanging small packets** (~100 32- or 64-bit words)
- real-time processing on PC, DSP, FPGA, ... with “flexible” configurations/updates
- evolution of Virgo network? Ethernet-based network, WhiteRabbit? Other?

A few fast loops running on dedicated processing units (DSP/FPGA?)

- UGF of few kHz
- loop speed of ~1 MHz

....

Some possible evolutions of data acquisition



Multiple streams and interfaces

- Multiple interferometers
- Multiple data stream per interferometer
- Integrated with automation for interferometer lock acquisition and control
- Integrated with low-latency $h(t)$ reconstruction, data quality and data analysis

New architecture/tool to be defined

- new architecture/software to be studied
- same solution for all E.T. or different solutions in parallel for different detectors?

Data visualisation tool to be defined

- very low latency for online commissioning
- offline for offline commissioning, detector characterization, noise hunting, calibration, ...

Data format(s)

- online and offline

....

Concluding remarks

A lot of evolutions from Virgo to E.T.

Interferometers control loop strategy to be defined and impact on real-time electronics

Data flux, number of channels, ... probably larger by more than a factor 20

Computing, ...

A lot of interfaces with most other interferometer sub-systems

a work package that gives a general view of the overall detector design (+ construction/commissioning)

LAPP has expertise in most of these topics in Virgo,

but **new ideas and more/new teams are needed to go on towards the big E.T.!**

Some developments will probably be validated on Virgo interferometer in the period 2026-2036, and/or on the ET Pathfinder prototype in Maastricht, without waiting for E.T. installation.

Participating to the E.T. Technical Design Report is a good opportunity to start with

→ if you want to participate in future discussions, feel free to contact me!

Working group formation just starting...

Principle of timing/data networks in Virgo

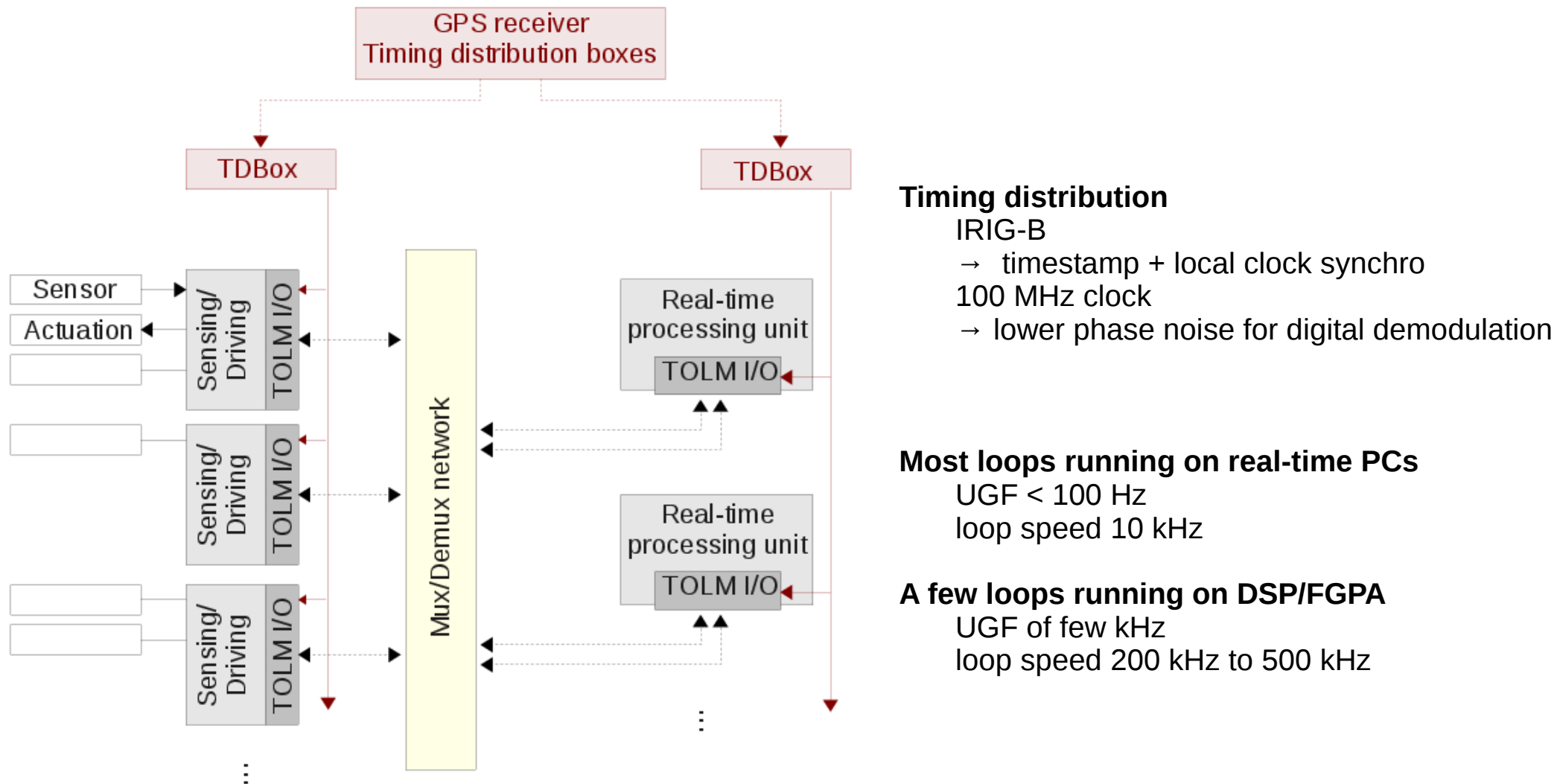
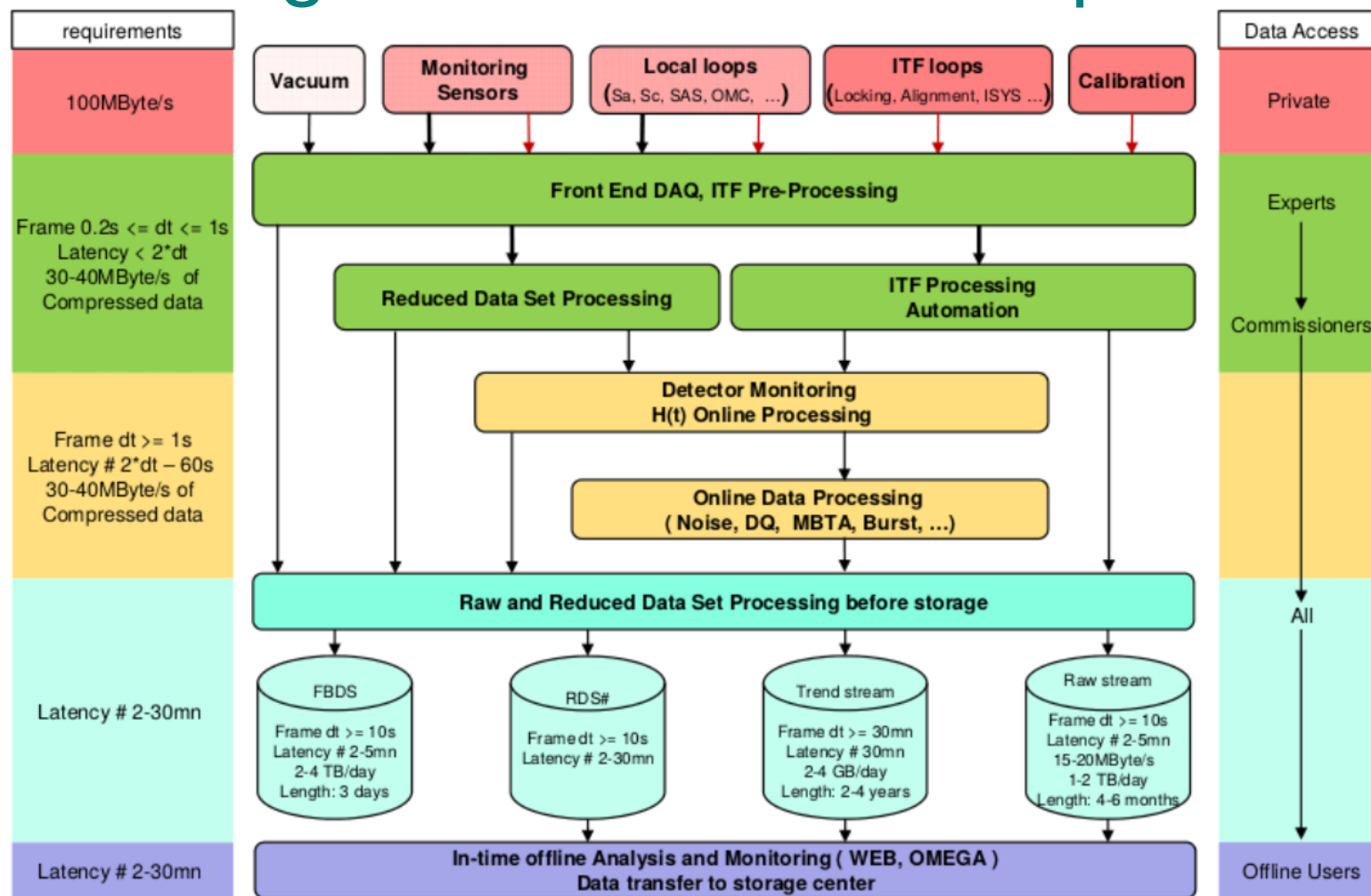


Diagram of AdV data acquisition pipeline



Warning: Estimations from 2012 for Advanced Virgo (sketch extracted from AdVirgo TDR)
 Data flow have been a bit higher in practice
 Data flow x2 with the addition of the squeezing for AdV+