Digital Low Level Radio Frequency (system) for reliability-oriented linacs

Christophe Joly

cnrs dépasser les frontières

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Overview

1. Reliability-oriented Linacs : MYRRHA
   - Accelerator design
   - Constraints & recommendations

2. LLRF requirements for reliability (non exhaustive list)
   - Principle
   - Architecture and bus evolution
   - Components and manufacturing generalities
   - Actual LLRF system (PXI architecture)
   - IPN developments around LLRF in progress

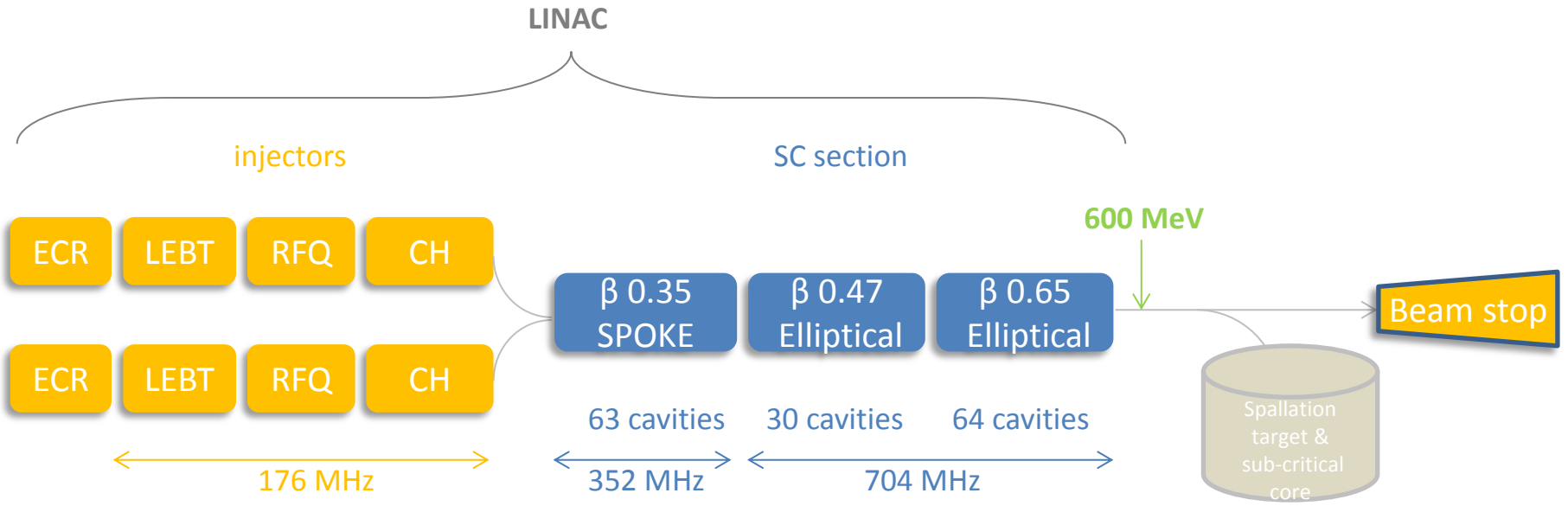
3. Summary

MYRRHA

Linac settings
- Energy : 600 MeV cw
- Beam current : 4mA max
- Field Stability : ±0.2% and ±0.2° rms
- Length : 260m

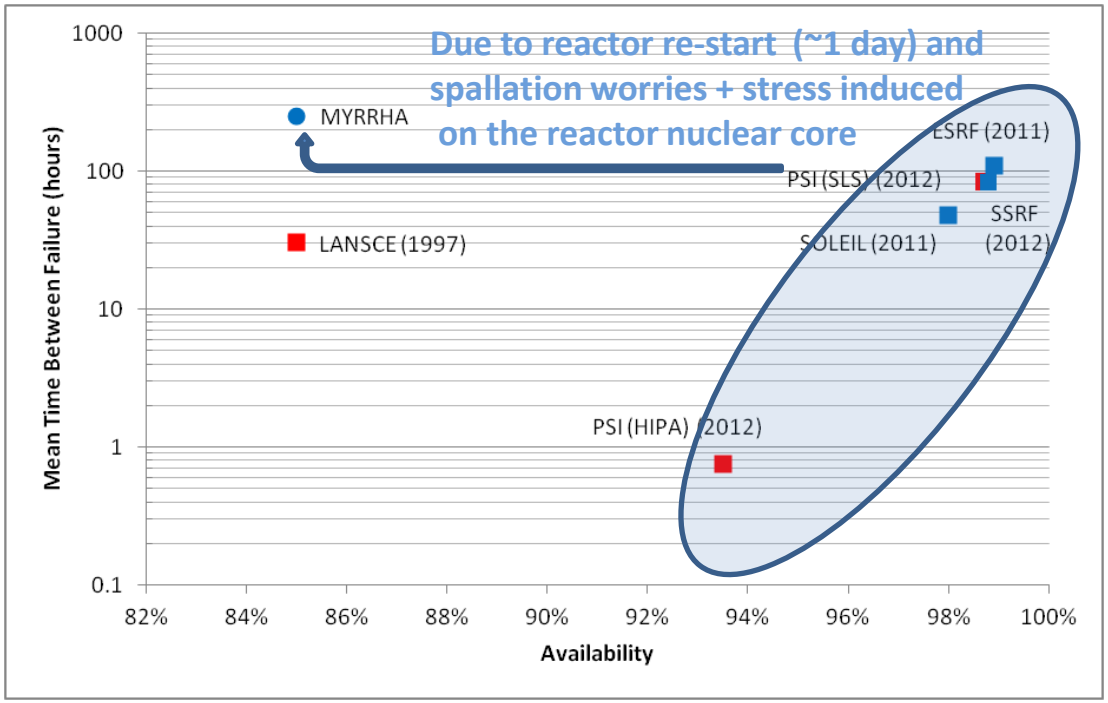
→ Power max 2.4 MW →

Others MW technologies examples
- Cyclotron – PSI
- NC Linac – LANSCE
- SC Linac – SNS



DLLRF for reliability-oriented linacs

Reliability-oriented linacs…What else !



Research and Medical Accelerator

Reliability = Happy users

→ Availability

Several years to obtain these MTBF/ availability

Constraints for MYRRHA :

- Designed for 40 to 60 years
- 10 trips max per 3-month operation period (> 3s) → reactor stop
- 100 trips max per day (> 0.1s)

Conclusions and Recommendations in the framework of MYRRHA :

the most affected Linac parts/systems are:
•SCL, Front-End systems (IS, LEBT, MEBT), Diagnostics & Controls
•RF systems (especially the SCL RF system)
•Power Supplies and PS Controllers

→ The reliability consideration that most needs to be enforced in linac design is redundancy of the most affected systems, subsystems and components
→ There is a need for intelligent fail-over redundancy implementation in controllers, for compensation purposes
→Enough diagnostics have to be implemented to allow reliable functioning of the redundant solutions and to ensure the compensation function.

MAX DELIVERABLE 4.2 "Reliability model of an existing accelerator (SNS Linac)"(2012),
Adrian Eugen PITIGOI and Pedro FERNANDEZ RAMOS (EA)

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Digital Low Level Radio Frequency System

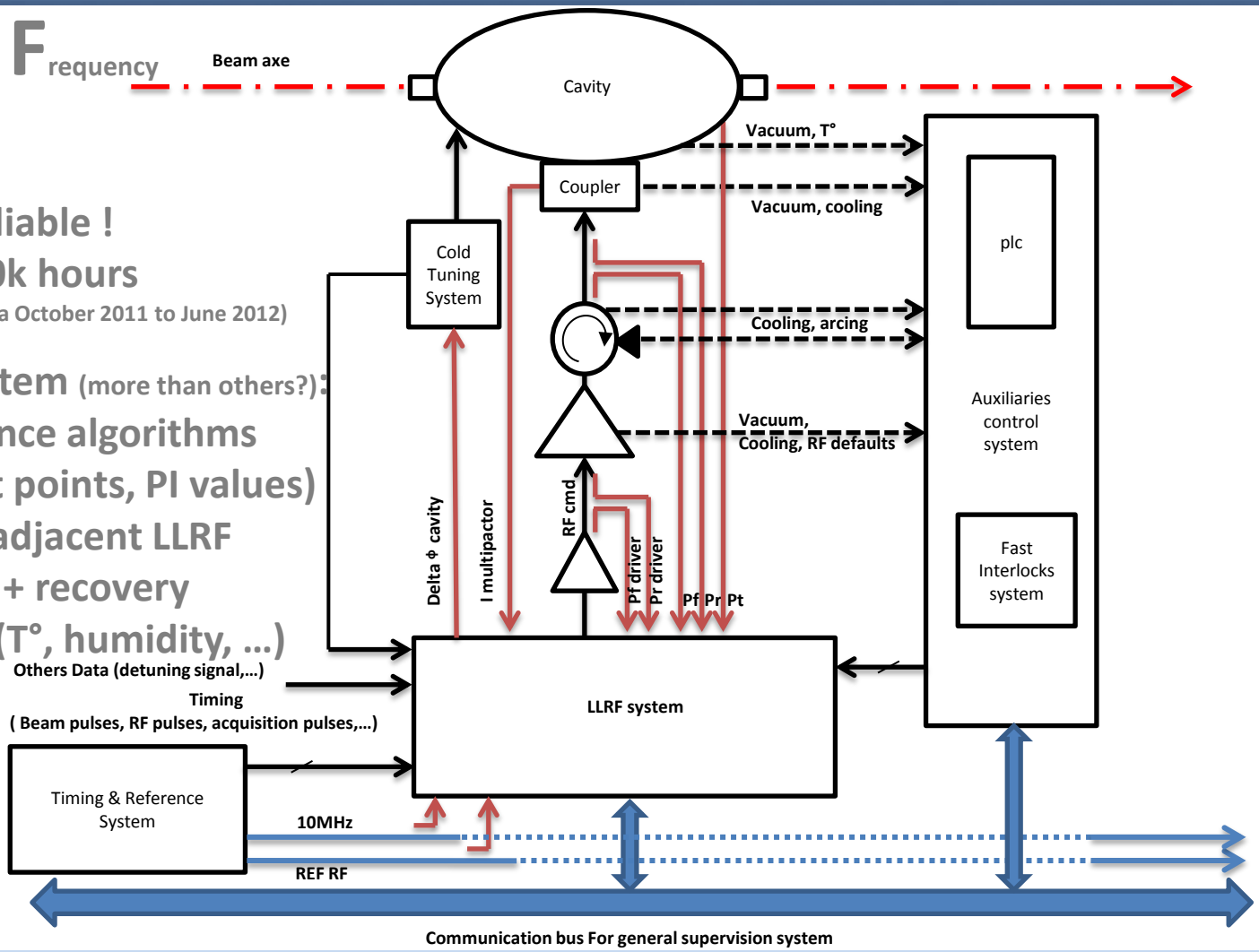
DLLRF needs also to be reliable !

→ MTBF typical : 100k hours

but 38 LLRF defaults (SNS logbook data October 2011 to June 2012)

For ADS it's a complex system (more than others?):

- Robust Fault tolerance algorithms
  - Flexibility (Set points, PI values)
  - Fast link with adjacent LLRF
  - Fast detection + recovery
- Health monitoring (T°, humidity, …)
- Low jitter
- Low latency
- …



DLLRF for reliability-oriented linacs

implies

Choice of architecture allowing :

- Number limited of cables
- Fast data bus
- Scalable board → ≠ functional board, future upgrade,…
- Easy maintenance → hot swap for supplies, fans
- …non exhaustive list

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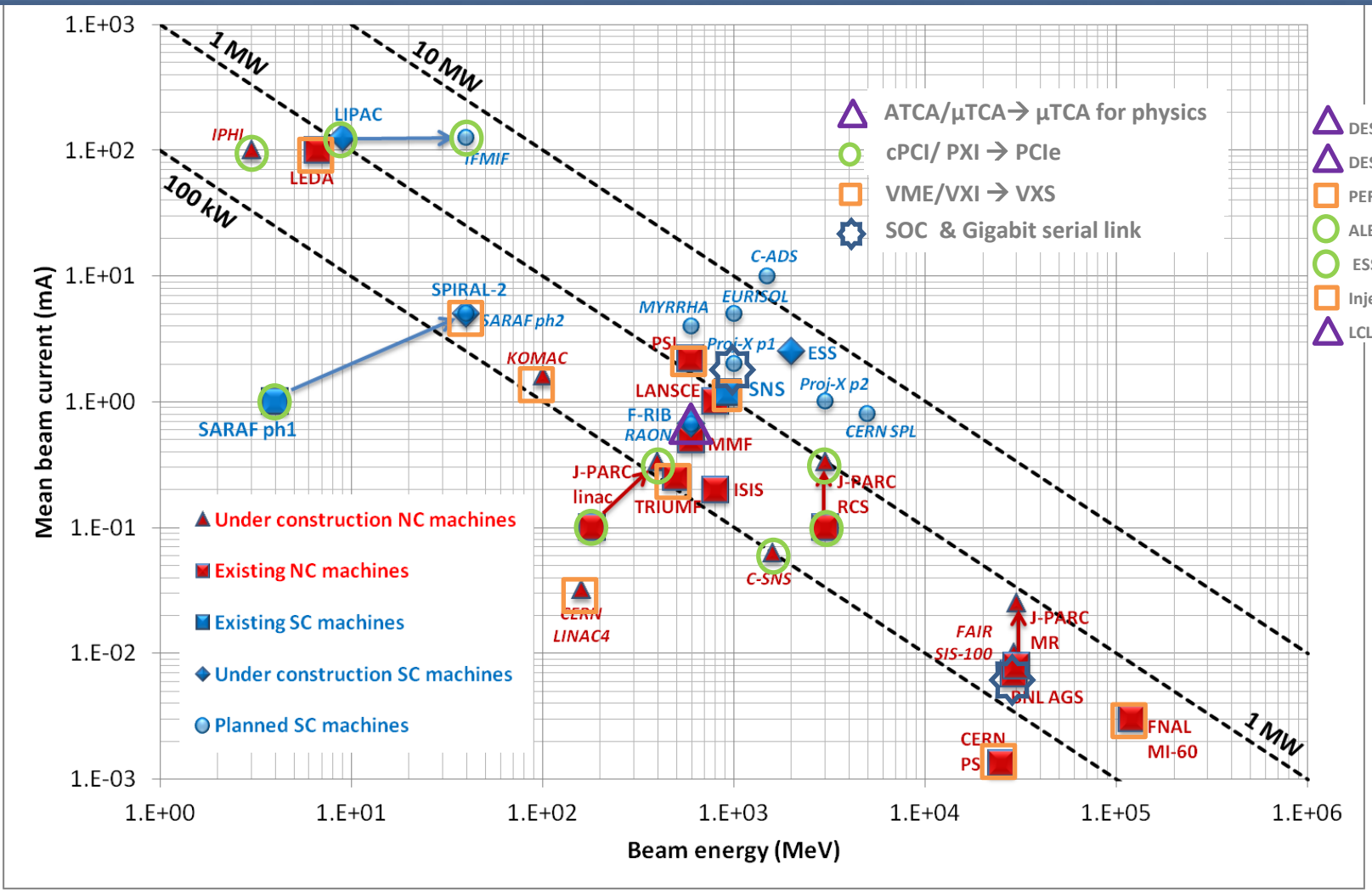

More …

DESY (XFEL)	µTCA/PCIe
DESY (FLASH)	VME/ATCA
PEFP	VME
ALBA storage RING	cPCI
ESS-BILBAO (linac)	cPCI
Injectors CERN)	VXS
LCLS linac (SLAC)	Upgrade µTCA

39% VME/VXI
39% cPCI/PXI

14% xTCA ↗
8% SOC Future?

DLLRF for reliability-oriented linacs

implies

Choice of architecture allowing :

- Number limited of cables
- Fast data bus
- Scalable board
- Easy maintenance

→ **COTS** Commercial Off The Shelf

But also System On Chip (ARM processor)

Traceability of LLRF system

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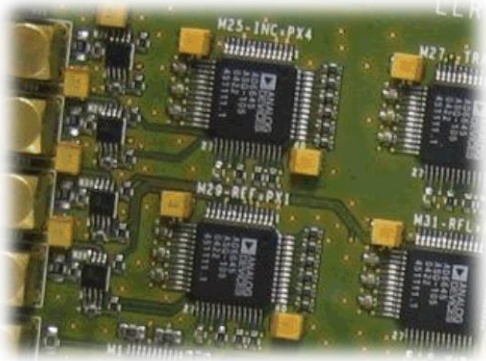
Traceability begins from :



LLRF PXI version 1.0 IPNO & LPNHE labs collaboration

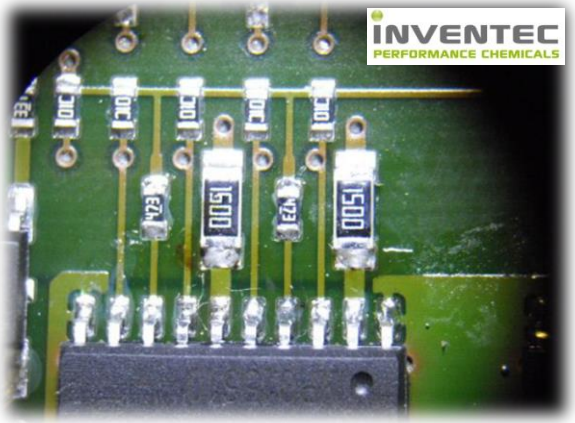
Basic components choice :
- T° stability
- Low dispersion value
- Use range (V, Pw, T°, …) → **Margins**

Be careful to counterfeit electronic component :
See ElectroniqueS-n°46-Feb2014 → Annual risk estimated to 169 Billions $ (IHS source)
- Use Known fabricants & representative sales
- Storage of components (moisture,…)
- Planned obsolescence

→ **Accredited company and database?**

Manufacturing :
- Solder Pastes (storage and use)
- Clean PCB methods adapted
- Tests of validation

→ **Accredited company**



"Cleaning PCBs in Electronics: Understanding today's Needs" data, APAX EXPO IPC [

DLLRF for reliability-oriented linacs

implies

Choice of architecture allowing :

- Number limited of cables
- Fast data bus
- Scalable board
- Easy maintenance

→ Commercial Off The Shelf

Traceability of LLRF system → used in aerospace, automotive and medical domains

- Purchase of components
- Manufacturing
- Documentation (technical docs and operating manual, …)
- Defaults records (logbook SNS example)

→ Collaboration with companies

Testing , conditioning, … → Avoid Youth breakdowns (test stand ?)

Training of the staffs → Although it's a "press button" system, LLRF needs Local experts

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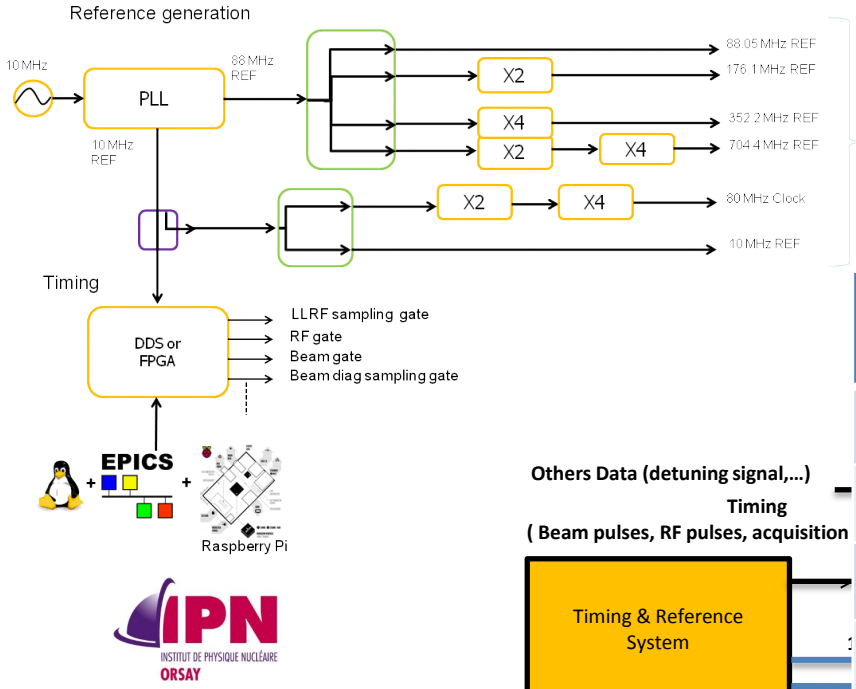
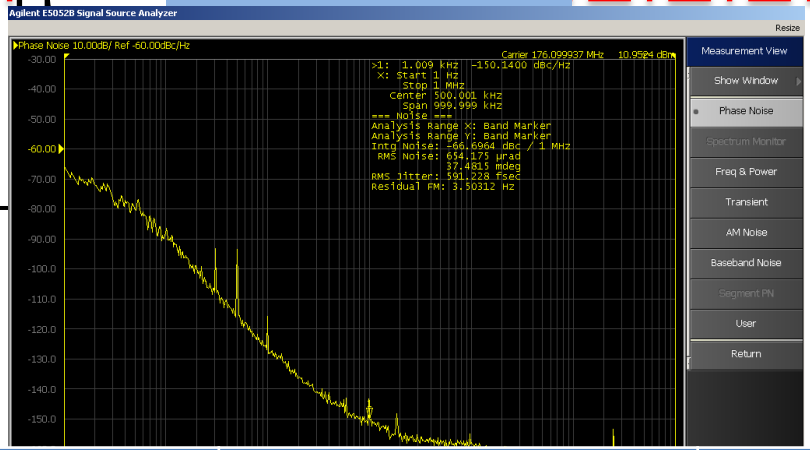
Digital Low Level Radio Frequency System



Preliminary results



Frequency (MHz)	Noise Phase (s) (1Hz-1MHz band)	Jitter (°)
10	~ 107 fs	388µs
88.05	~ 630 fs	~0.020
176.1	~ 591 fs	~0.037
352.2	~ 651 fs	~0.082
704.4	~ 670 fs	~0.170

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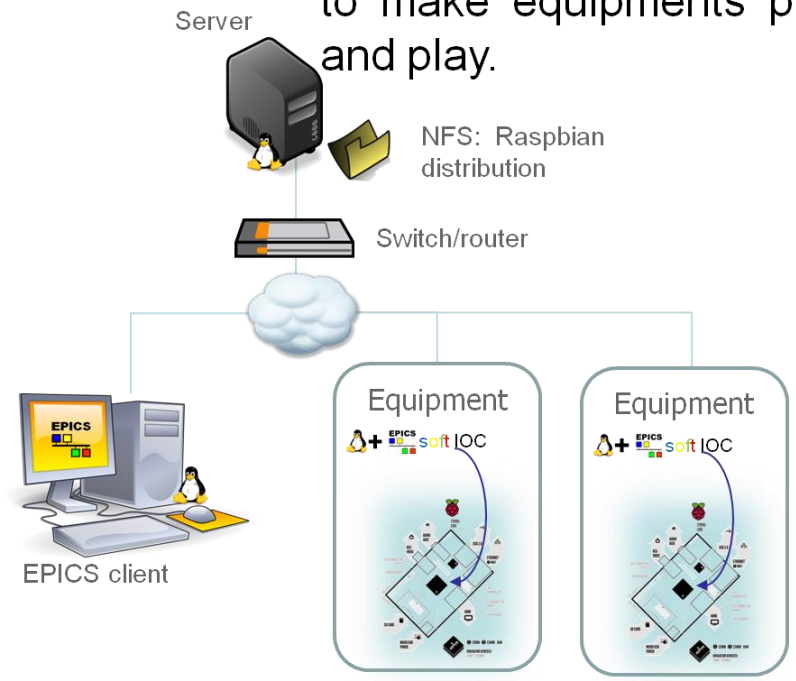
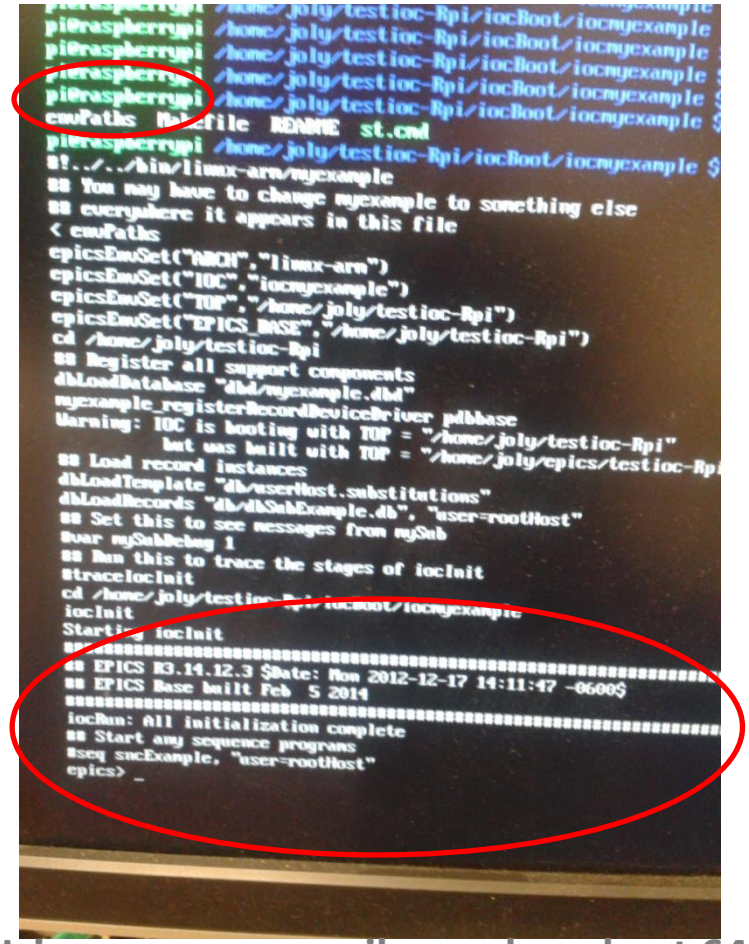
Through Raspberry Pi, the tests of validation of our configuration are in progress. The purpose is to obtain a feasible OS via NFS incorporating a IOC to make equipments plug and play.





Using a cross-compiler under a host 64bits With Debian7

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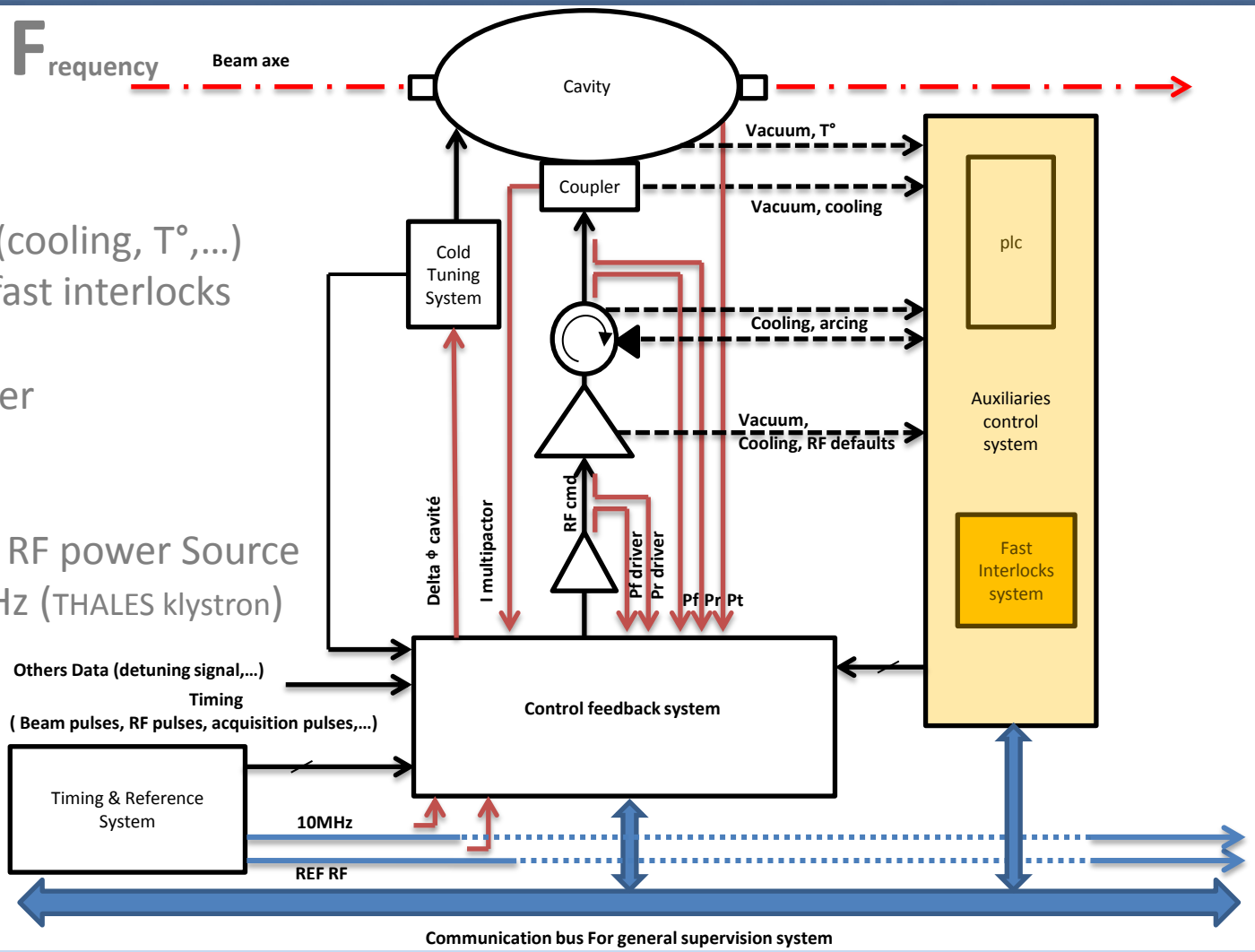
Digital Low Level Radio Frequency System

- PLC for low interlocks (cooling, T°,…)
- Specific hardware for fast interlocks
  - Multipactor
  - Reflected RF power
  - Vacuum
  - Arc

In progress for our new RF power Source
2.8MW pulsed @352MHz (THALES klystron)

Pulse width: 3ms /1.5ms
Repetition rate : 14Hz/50Hz

2015



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Digital Low Level Radio Frequency System

- Down converters (Pf, Pr , Pt and Ref)
- IQ modulator (actuator), RF switch,…

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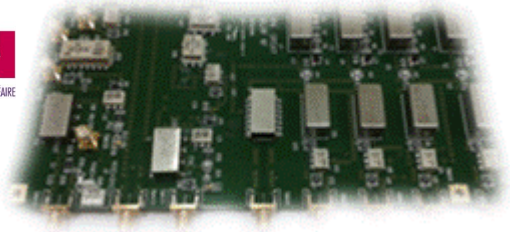

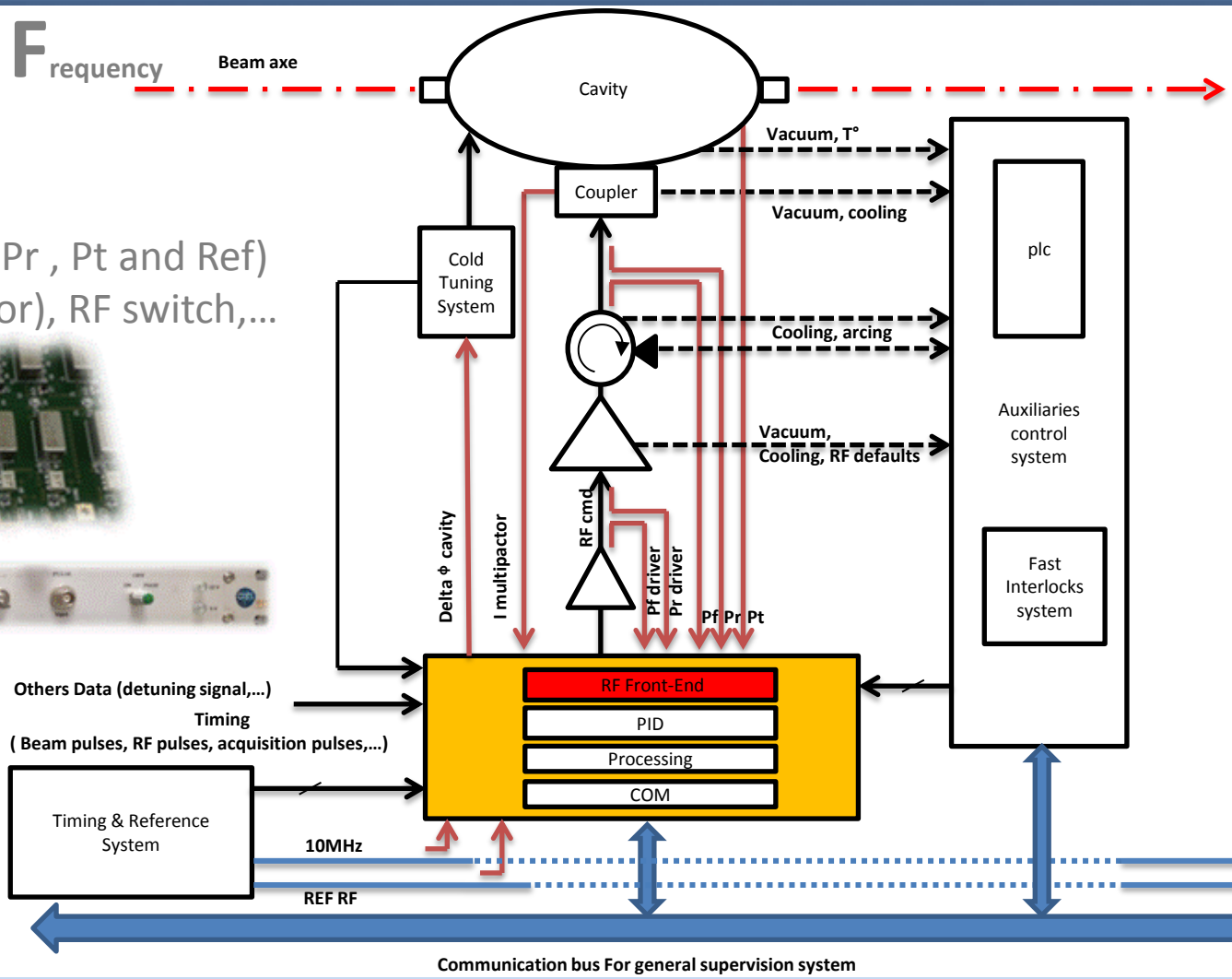

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Digital Low Level Radio Frequency System

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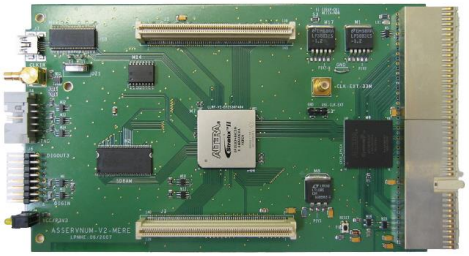
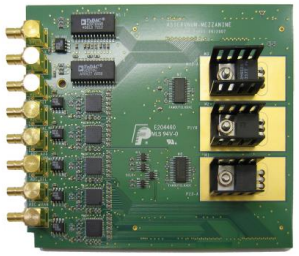
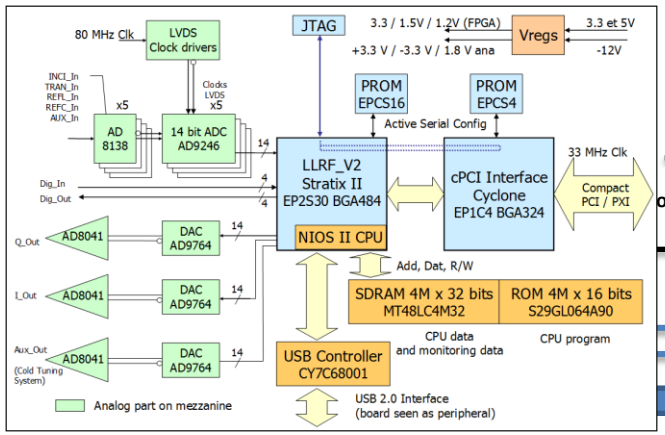
Actual LLRF system used (collaboration with LPNE Lab)







See talk of M. El Yakoubi
Commissioning of MAX 700MHz Test stand

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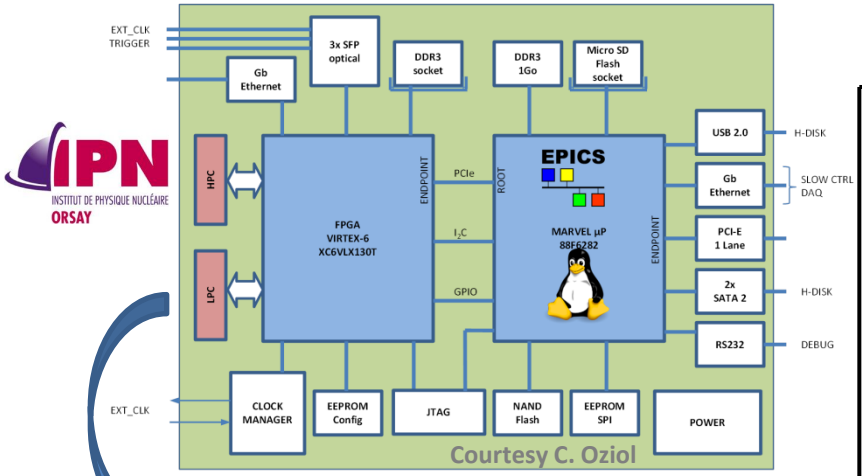
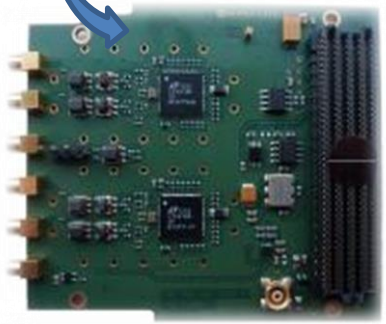
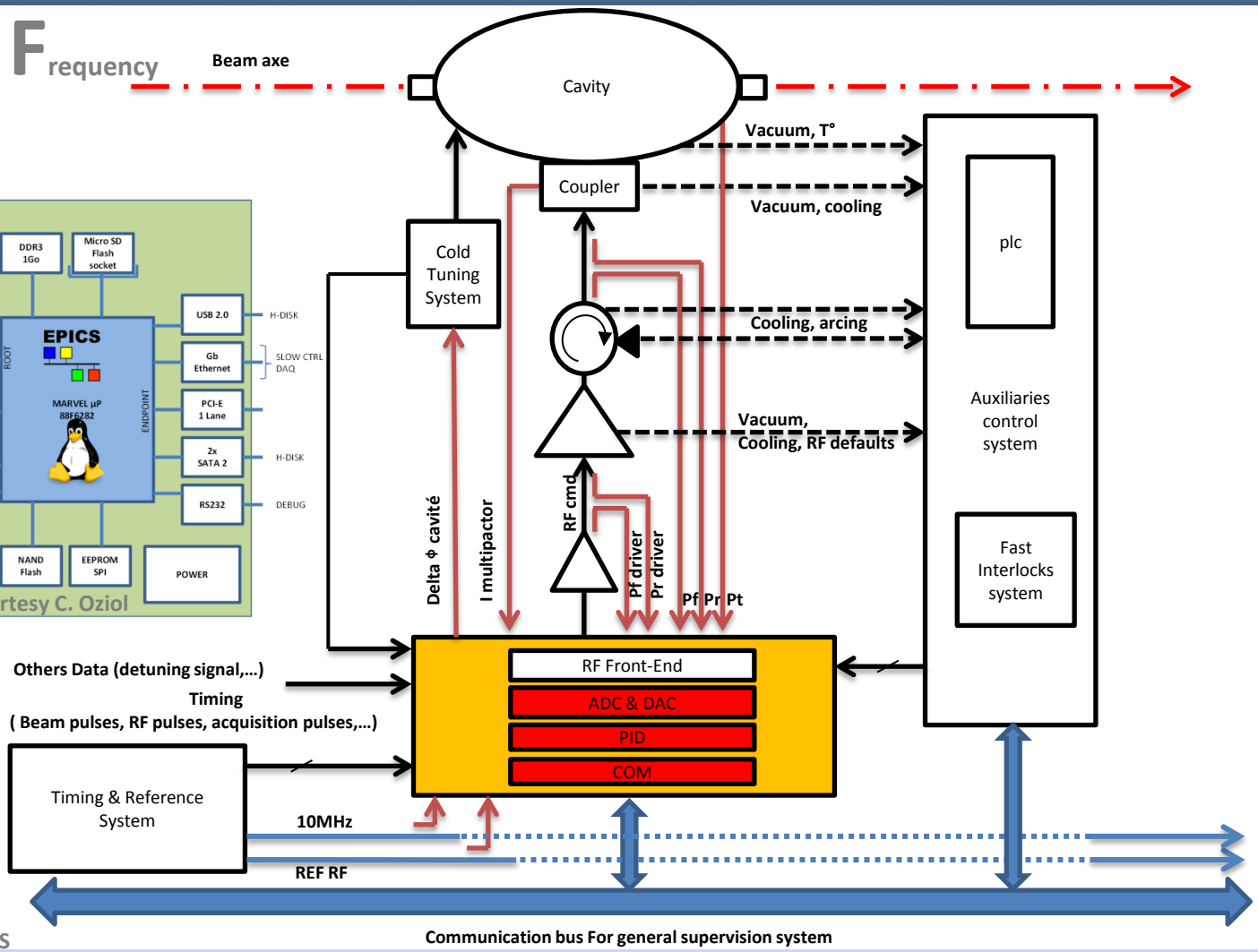




FMC ADC FMC 4 16bits channels@125 MSPS



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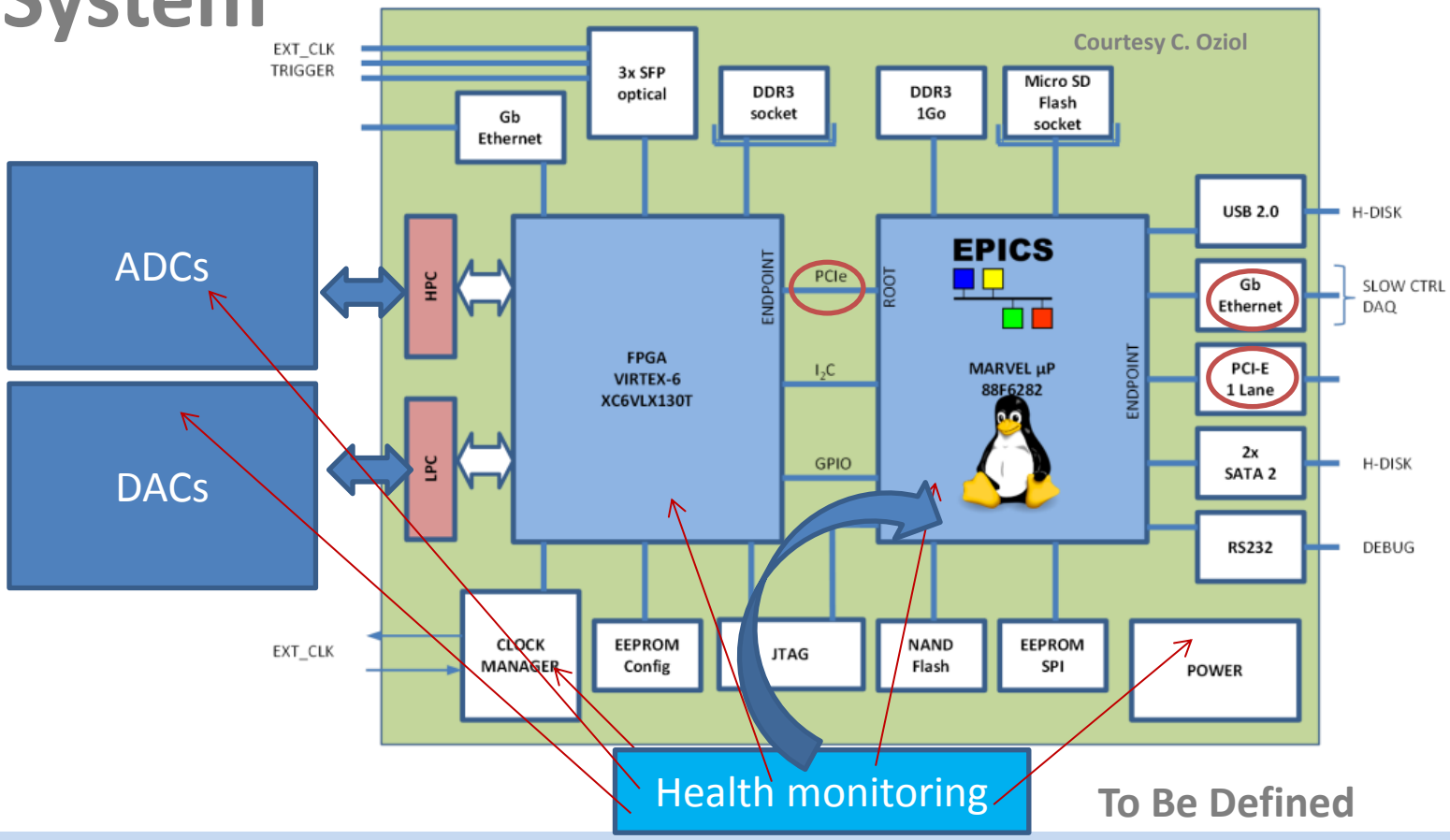

Summary

Collaborations for reliability-oriented design studies with
→ LLRF community of accelerator complex
→ Companies (with aircraft or aerospace experience if it's possible)

Use of quality and traceability process
→ Documentation, production monitoring,… → database (?)
→ Use of mature technology (prototype now → reliable or obsolete system tomorrow ?)
→ Test stand to avoid Youth breakdowns before ramp up

Strong interaction with the software community (EPICS, …)

Request of a LLRF topic
in the framework of the next PCRD "horizon 2020"

Thank You for your Attention

And

Sorry for all possible mistakes & omissions …

Warm thanks for their help to
J-L. Biarrotte (IPNO)
and
S. Meyroneinc
(Curie Institute ORSAY – Proton therapy Center).

without forgetting my IPNO colleagues for their participation in our LLRF project