Phase Stability Testing of the

# White Rabbit based LHC RF Dependant Timing Distribution Backbone Upgrade

**Philippa Hazell, CERN EP-ESE-BE**

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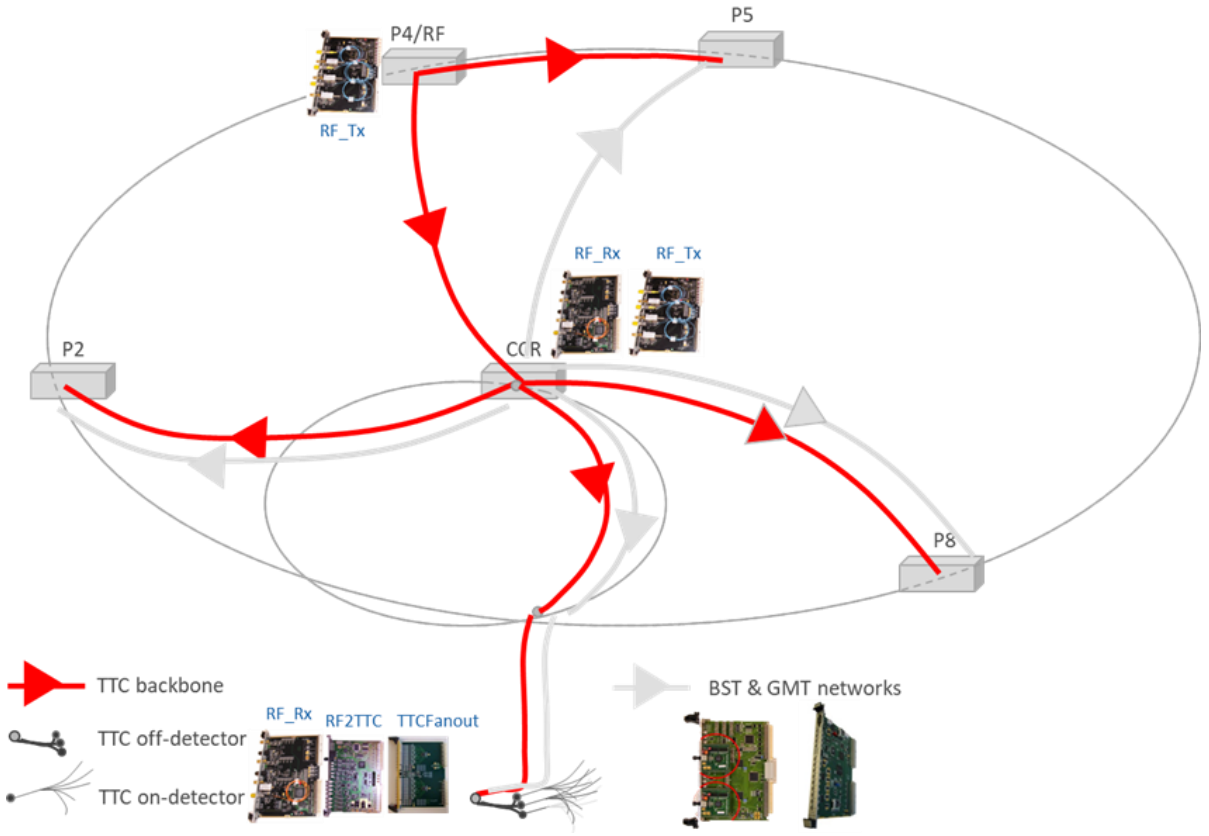
A (**very simplified**) overview of the current timing, trigger and control backbone.




**Simplified example of current system**

Backbone is **unidirectional.**

**400 MHz RF** generated at Point 4.

**40 MHz bunch clocks** and **11 kHz Orbit Clocks** are also transmitted from **P4** to the **Experiments.**

# Why is upgrading the backbone necessary?

## Aging Hardware and obsolesce of components

- Design ~ 20 years ago and has obsolete components

## Good opportunity to address a few other things..

# Why is upgrading the backbone necessary?

## Aging Hardware and obsolesce of components

## Good opportunity to address a few other things..

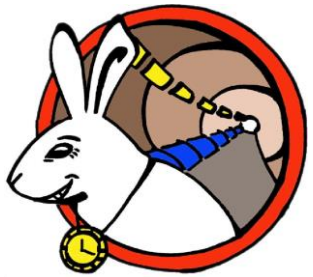
- HL-LHC’s RF-dependant timing signals need good phase stability
- Also need to replay RF signal for ATLAS and CMS crab cavities
- On paper – White Rabbit (WR) based technology/system should provide this
- How far though? Needed to do thorough testing to find this out…

# White Rabbit (WR Technology)

## What is White Rabbit?

- Technology developed at **CERN** (in collaboration with other companies and institutes).
- Part of the 1588 IEEE ethernet standard.
- Uses Ethernet to interconnect WR compliant switches and nodes - **synchronised** using **precision time protocol** (PTP)
- Used in a variety of industries and applications (telecommunications, finance, quantum computing …)

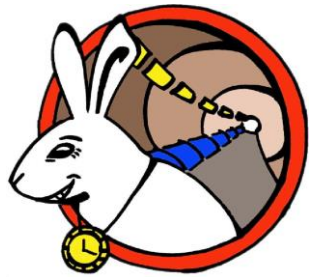
## Why use White Rabbit for upgrade?



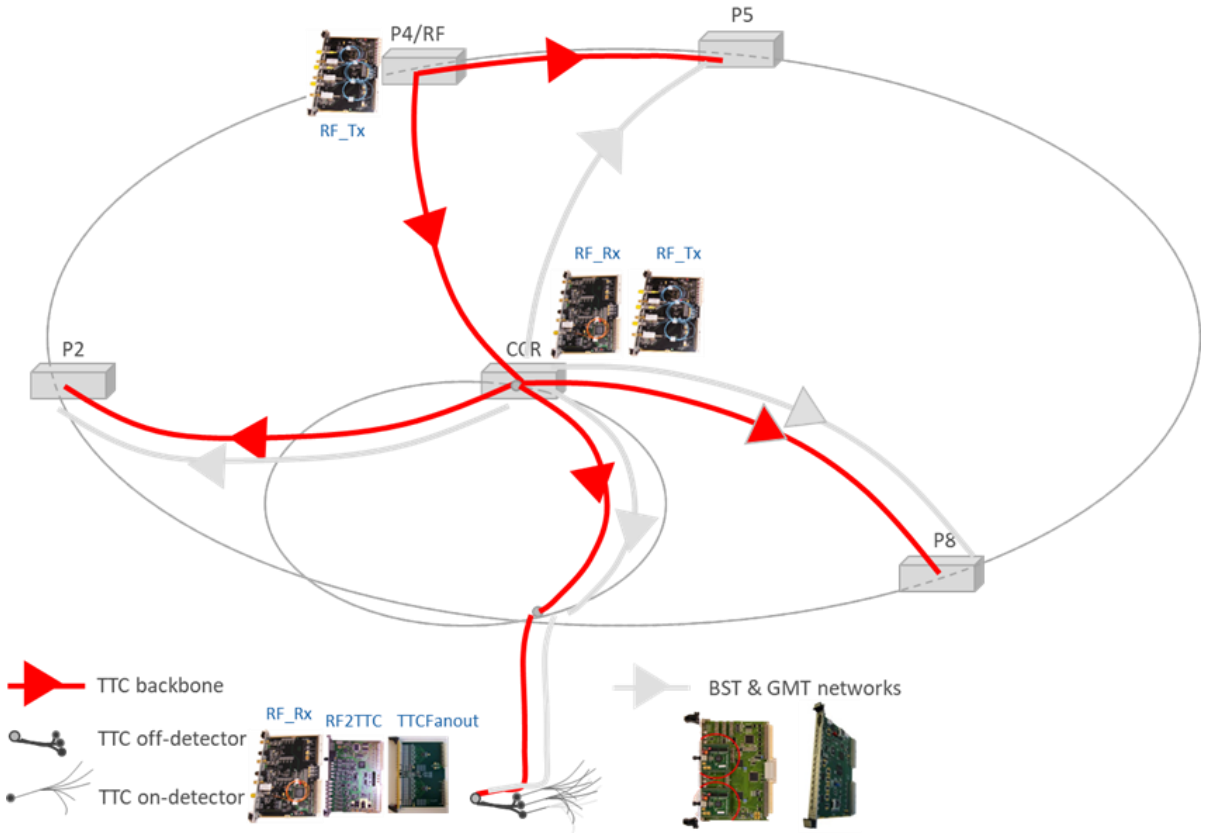
# White Rabbit (WR Technology)

## What is White Rabbit?

## Why use White Rabbit for upgrade?



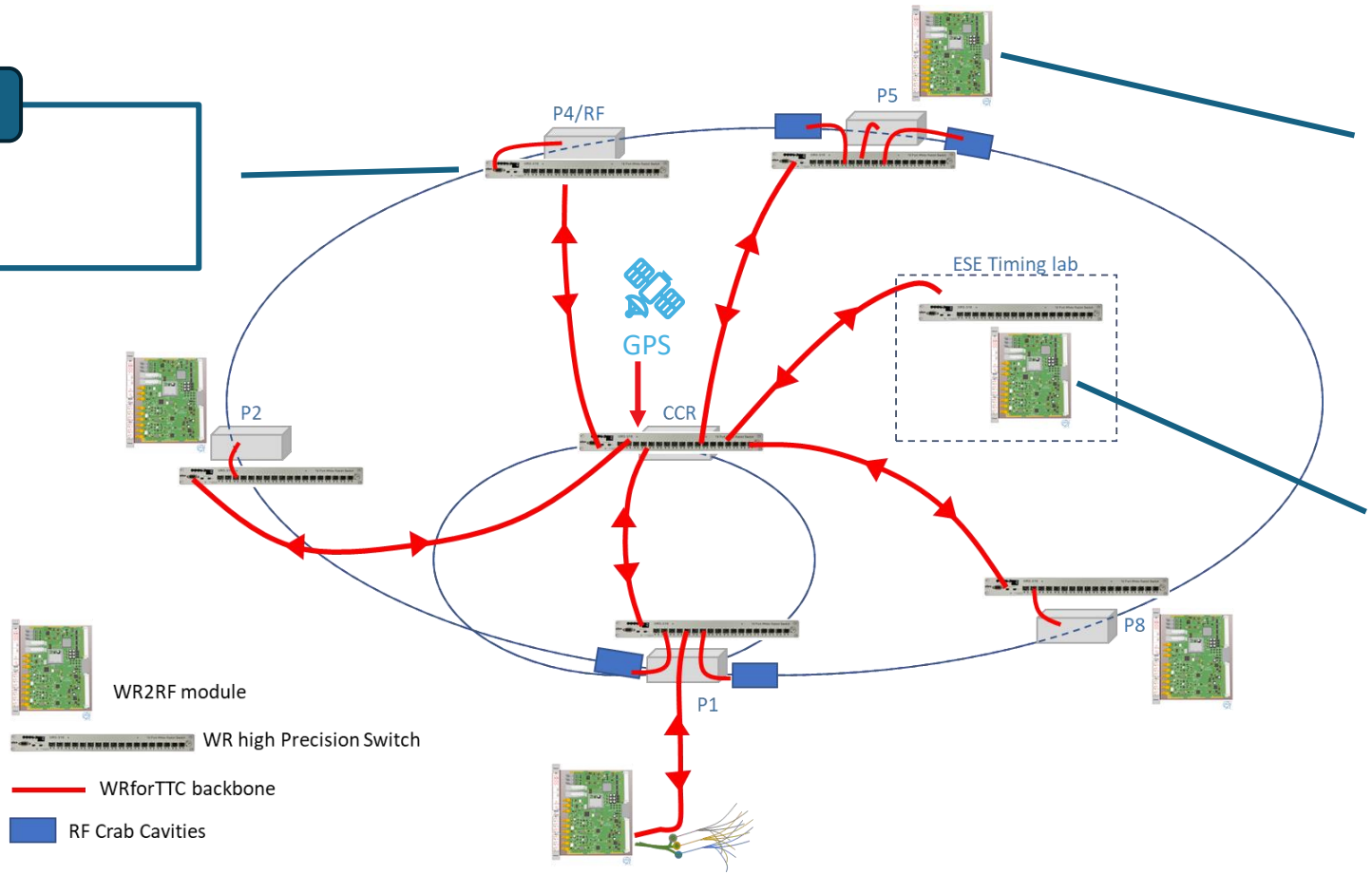
- WR switches and WR nodes routinely **compensate for phase shift**
- **Proven technology** - used in SPS for the same purpose.
- **Scalable** solution, currently **developed** and **maintained**
- Will become the **official solution** for **accelerator** (machine) **timing distribution** at CERN




**Simplified example of current system**

WR Switches

WR2RF boards




Proof of Concept System

**Simplified example of proposed system**

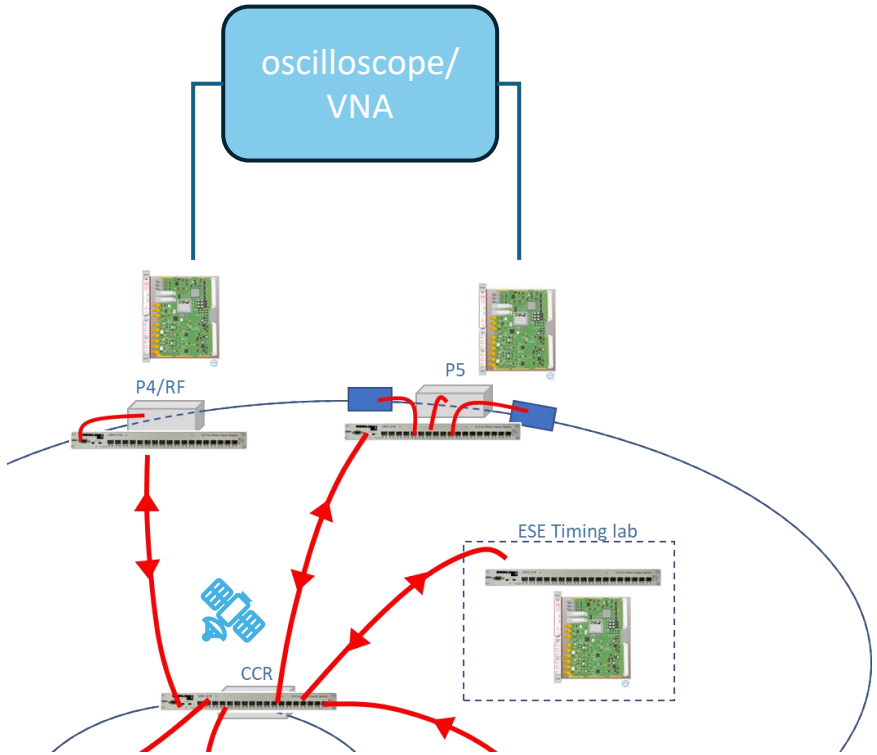
# Purpose of Work and Objectives

## Understand the system and its constraints

- Measure the phase between **replayed RF** (and derived signals) generated by **different WR2RF boards**
- Assess the system under a **variety of conditions**
- Understand performance between **RF driving cavity** and **experiments**.

## Assess the performance

## Collaborate with the BE-CEM and SY-RF teams



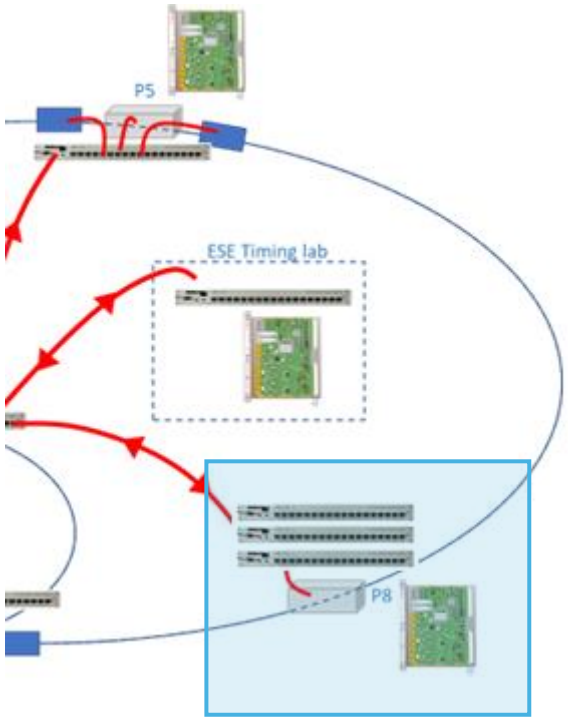
# Purpose of Work and Objectives

Understand the system and its constraints

Assess the performance

- Jitter & determinism with respect to number of WR switches

Collaborate with the BE-CEM and SY-RF teams



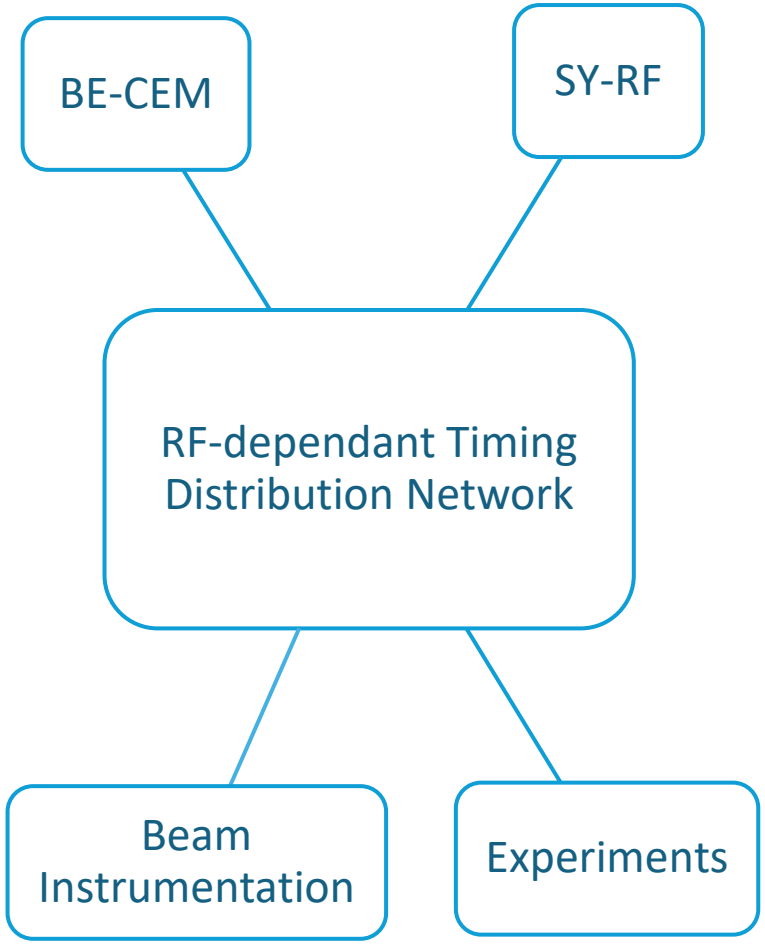
# Purpose of Work and Objectives

Understand the system and its constraints

Assess the performance

Collaborate with the BE-CEM and SY-RF teams

- 3 years of active collaboration



# Specification

**The RF-dependant Timing Distribution backbone needed to:**

- compensate for **phase drift**
- phase variation over time: **± 1 degree** of **RF frequency***.
- jitter rms: **< 5ps** for **Experiments**.
- minimise the **phase shifts** if **disturbances** occur in the **network**
- assess the technical **hard limit** of the system.

# Specification

**The RF-dependant Timing Distribution backbone needed to:**

- compensate for **phase drift** and **avoid phase shifts**
- phase variation over time: **± 1 degree** of **RF frequency***.

*

- Figure of merit (FoM)
- max. range of phase offsets during **N** consecutive measurements
- i.e. pk-pk phase.

# Specification

**The RF-dependant Timing Distribution backbone needed to:**

- compensate for **phase drift** and **avoid phase shifts**
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*

- SPS WR2RF boards -> **RF frequency @ 200 MHz**
  - **FoM < 28 ps**
- HL-LHC WR2RF boards (being designed) -> **RF @ 400 MHz**
  - **FoM < 14 ps.**
- **Retest** once boards are available.

# Specification

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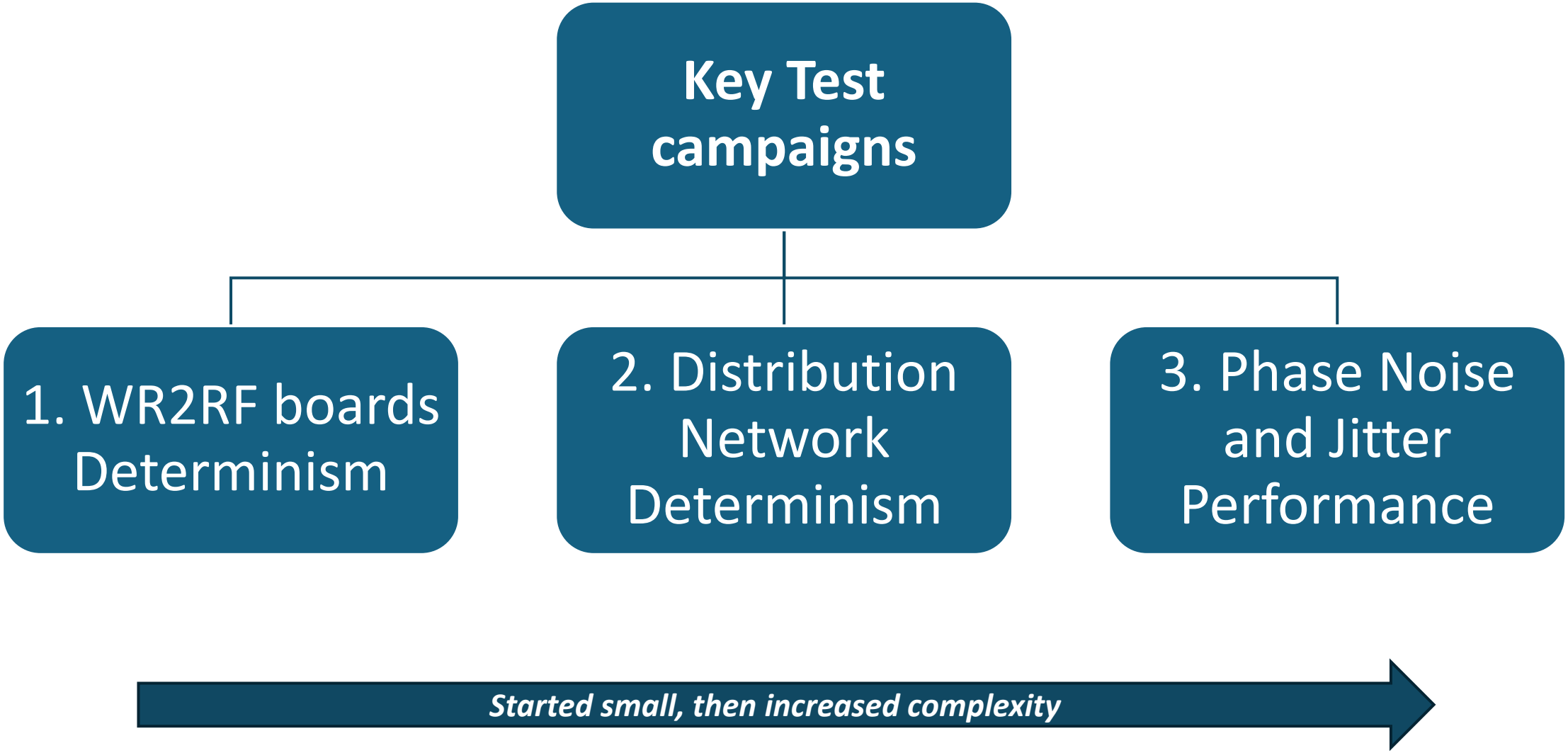
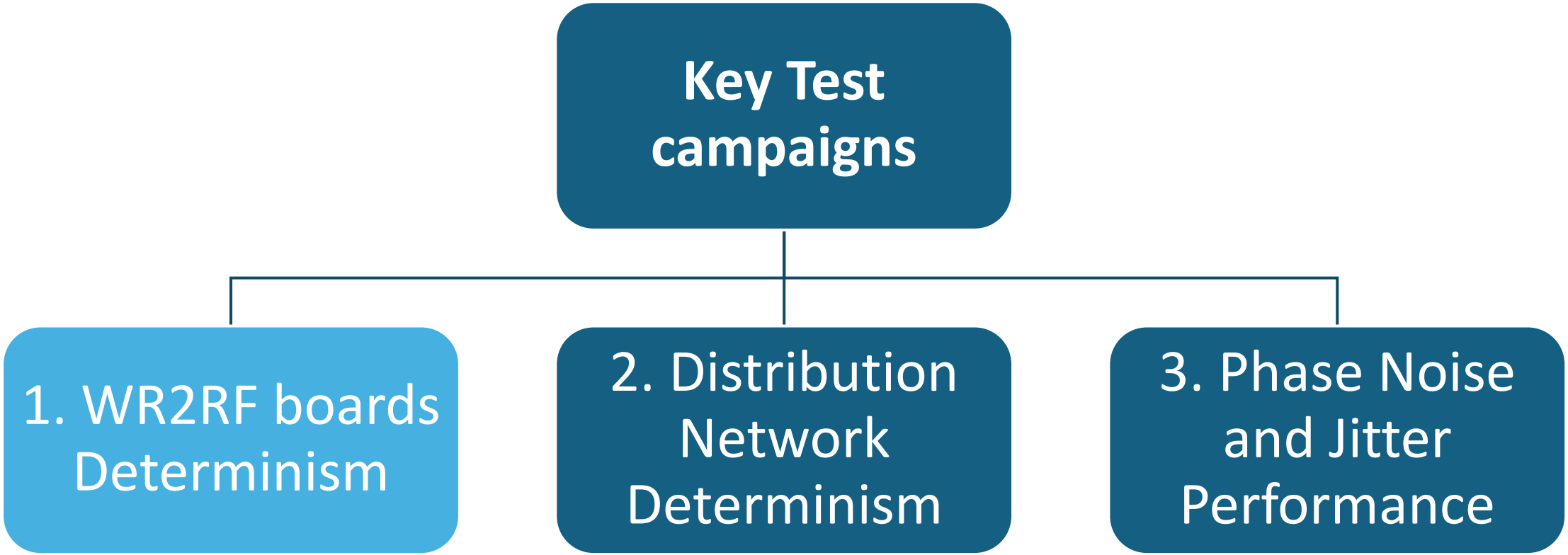

Key Test campaigns
1. WR2RF boards Determinism
2. Distribution Network Determinism
3. Phase Noise and Jitter Performance
Started small, then increased complexity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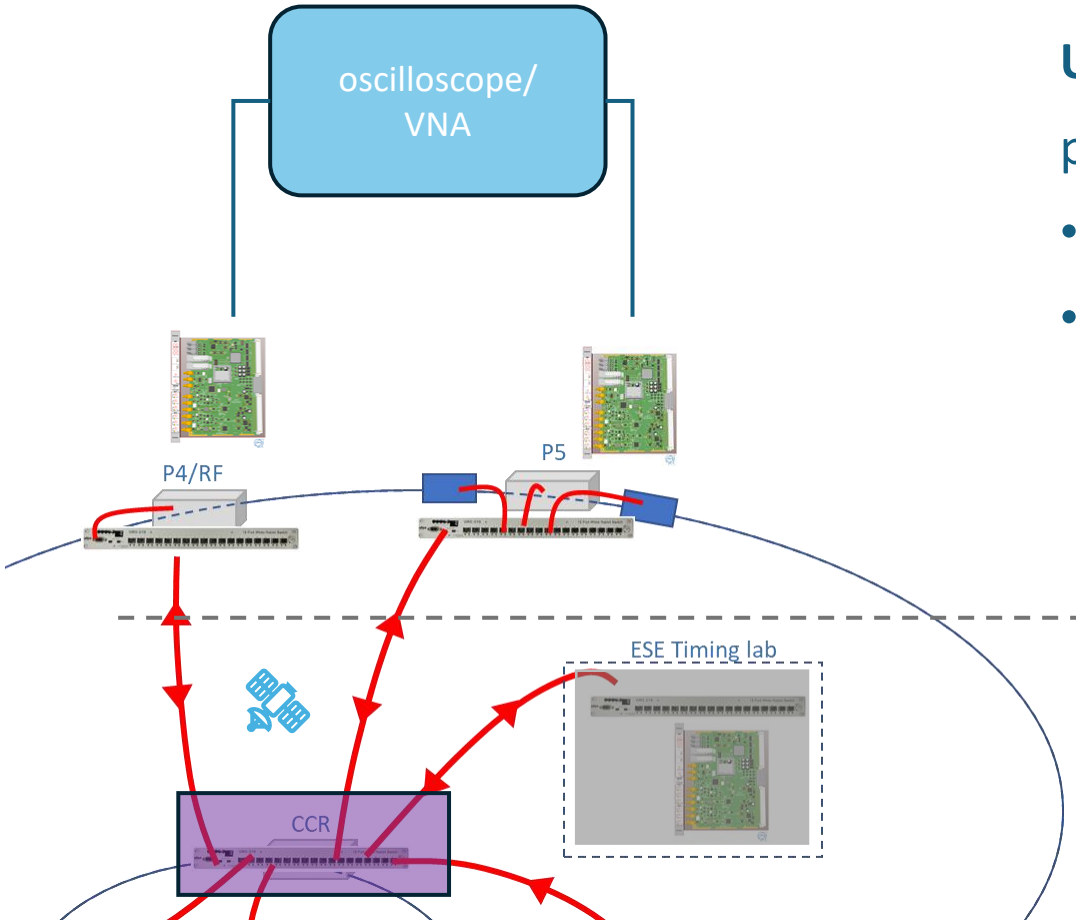
# Single Switch System



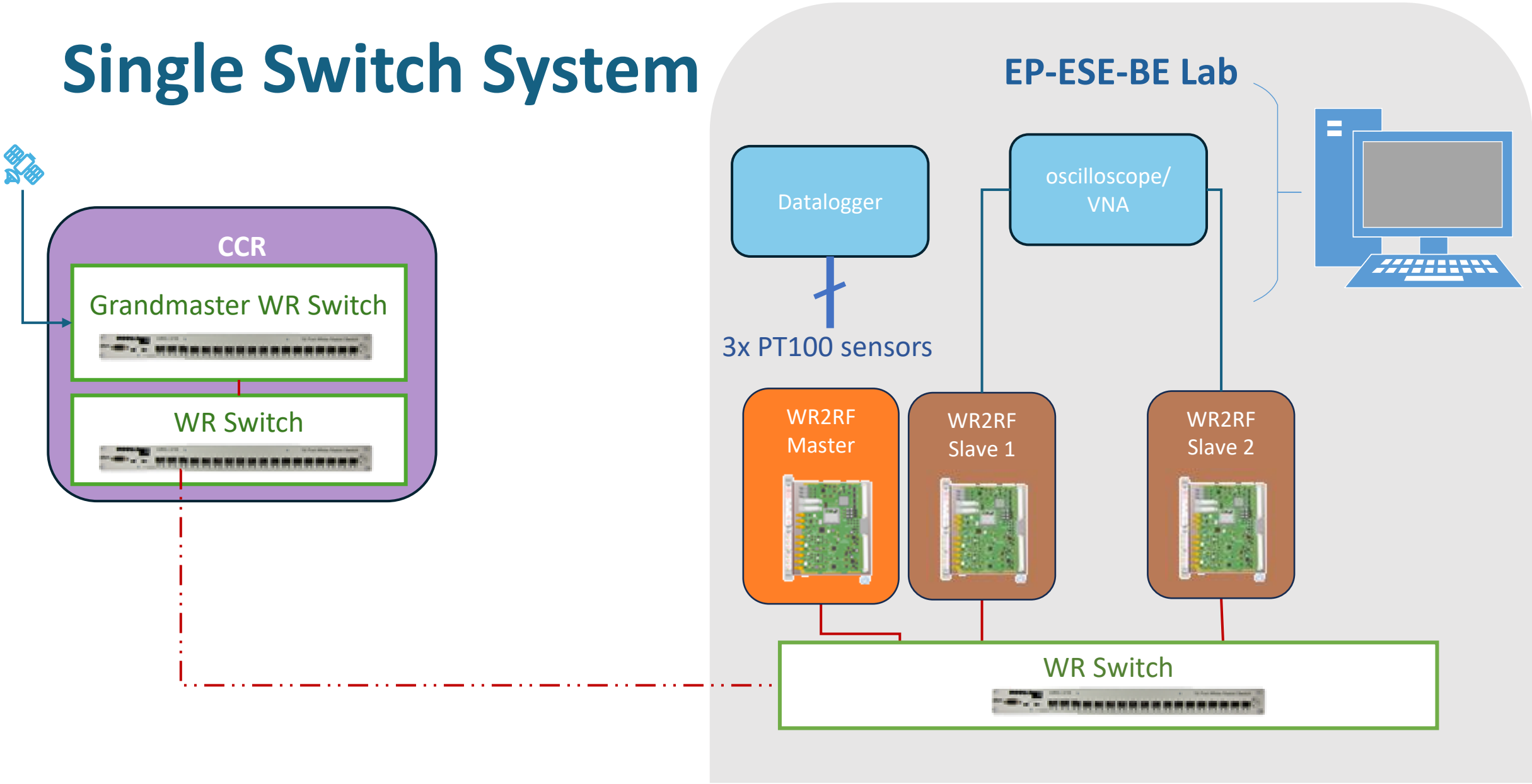

**Understanding the system and its constraints:**

phase stability between **2** WR2RF boards during:

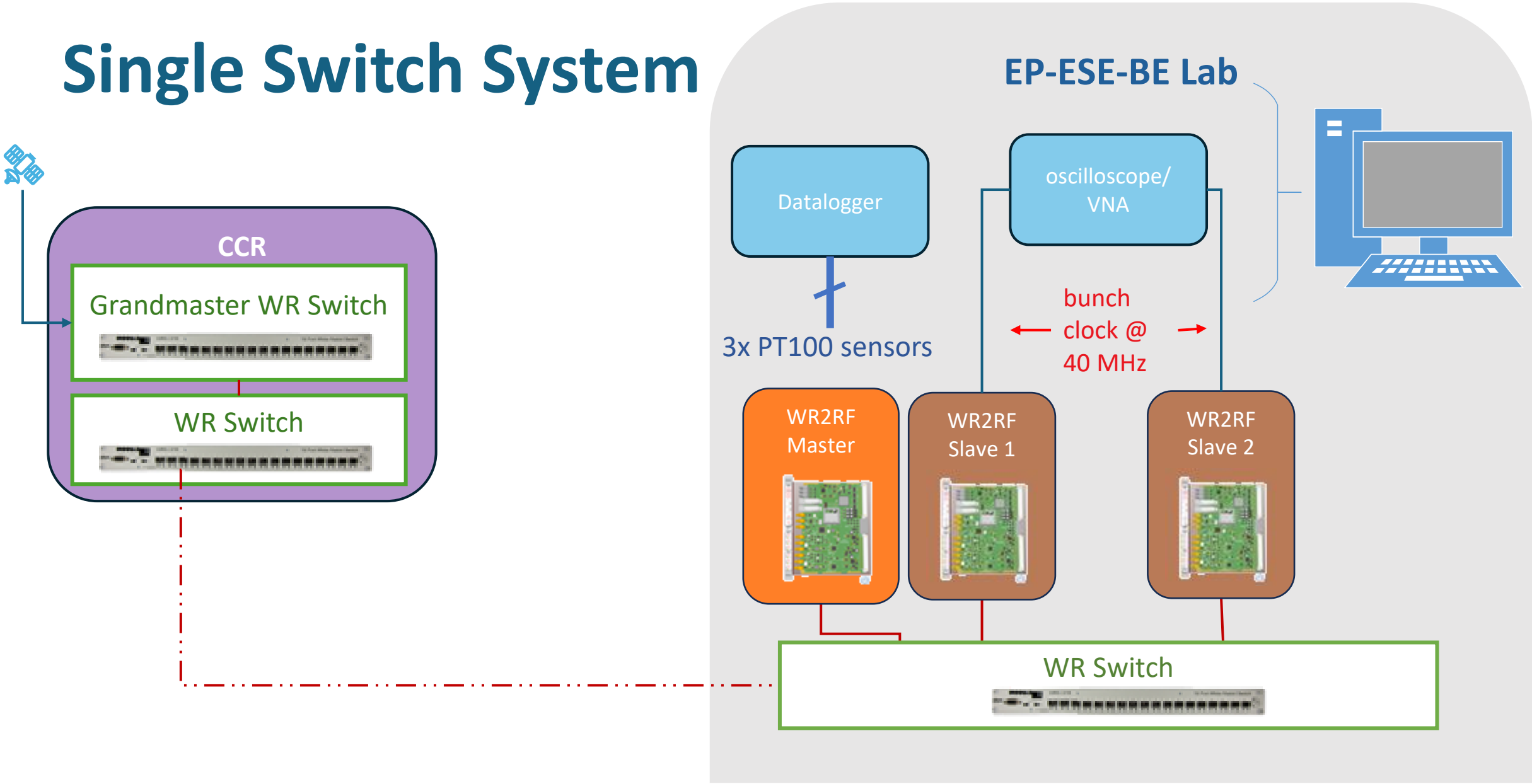
- normal operation
- resetting a WR2RF slave board

⟵ Areas concerned during testing.

# Single Switch System

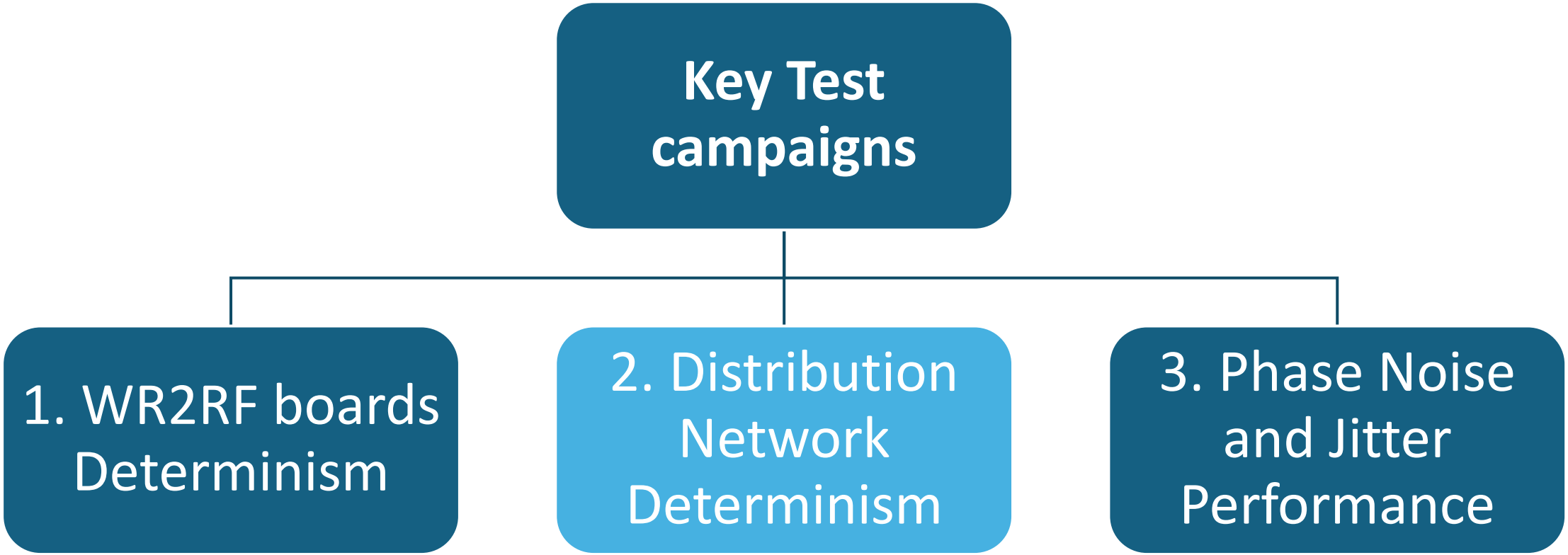


# Single Switch System



# Phase Determinism Testing of WR2RF Boards

- FoM requirement of met (< **28 ps phase pk-pk)**? - **YES**
- Observed phase fluctuations **~ 15 ps** between consecutive measurements (**normal operation**)
- Know phase fluctuations are from system –> Measurement instruments **~ 1ps noise floor**
- Fluctuations not linked to temperature (**was measured**)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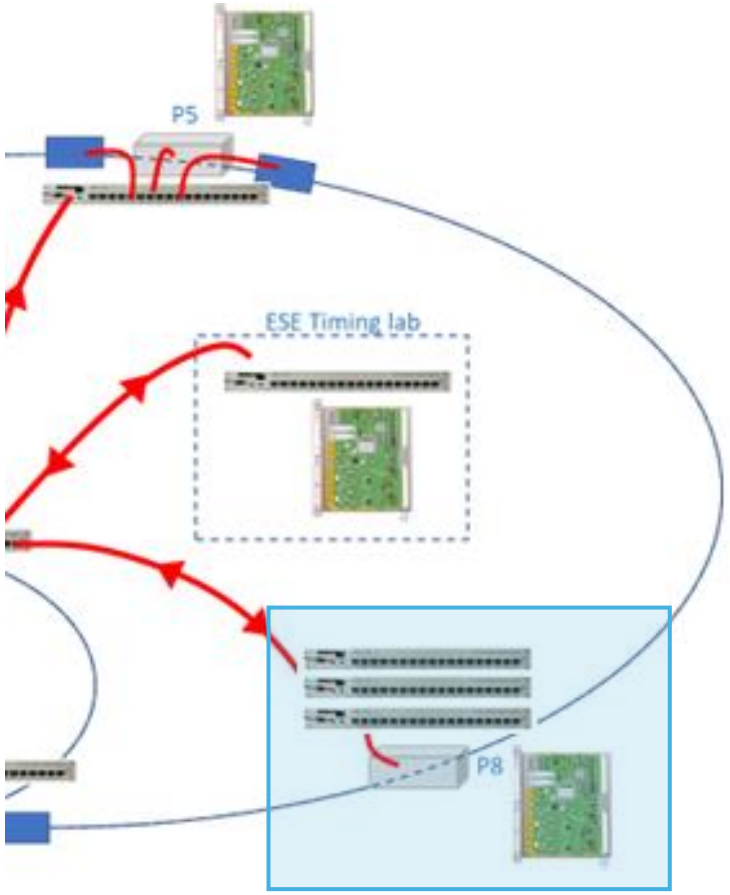
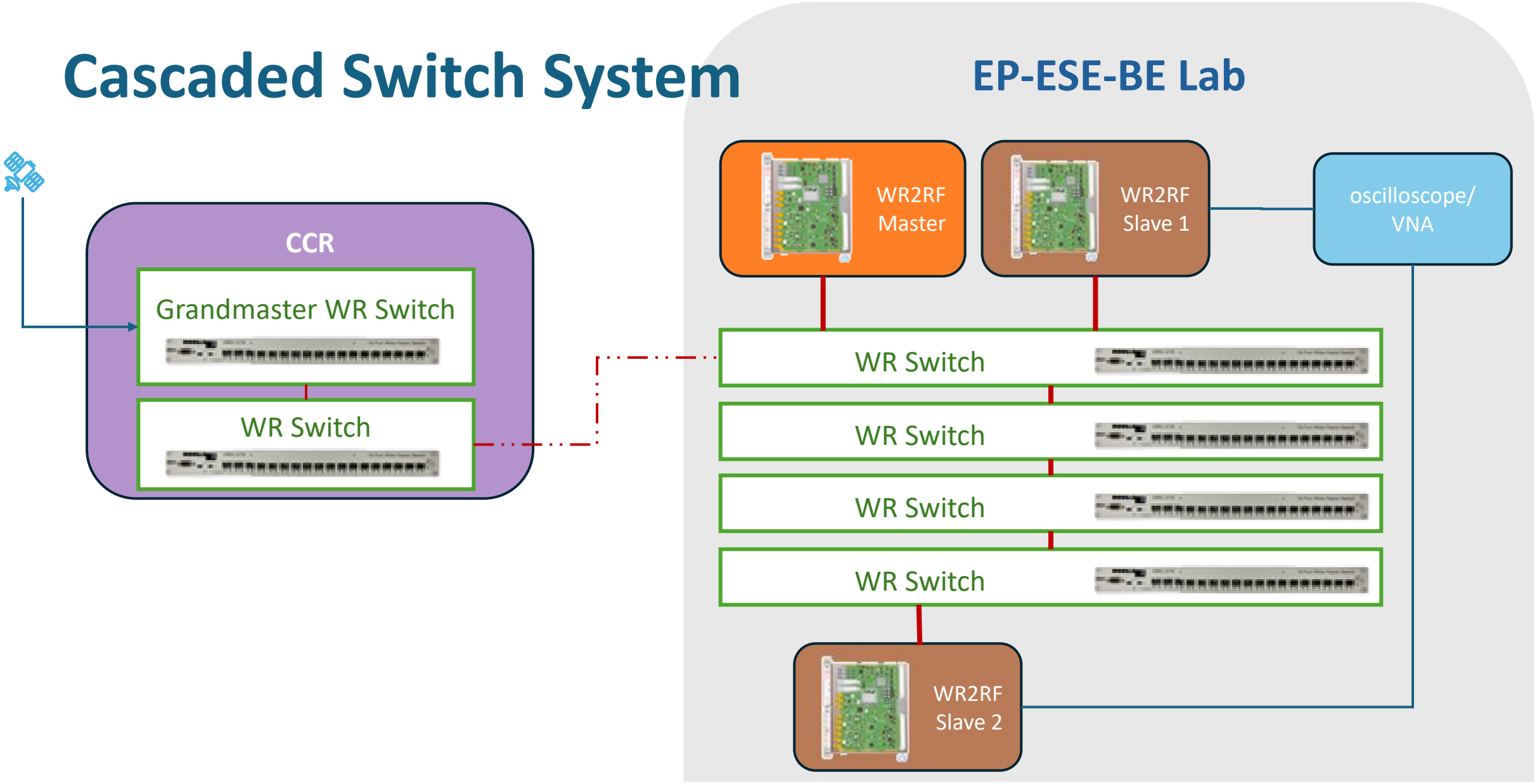
# Cascaded Switch System

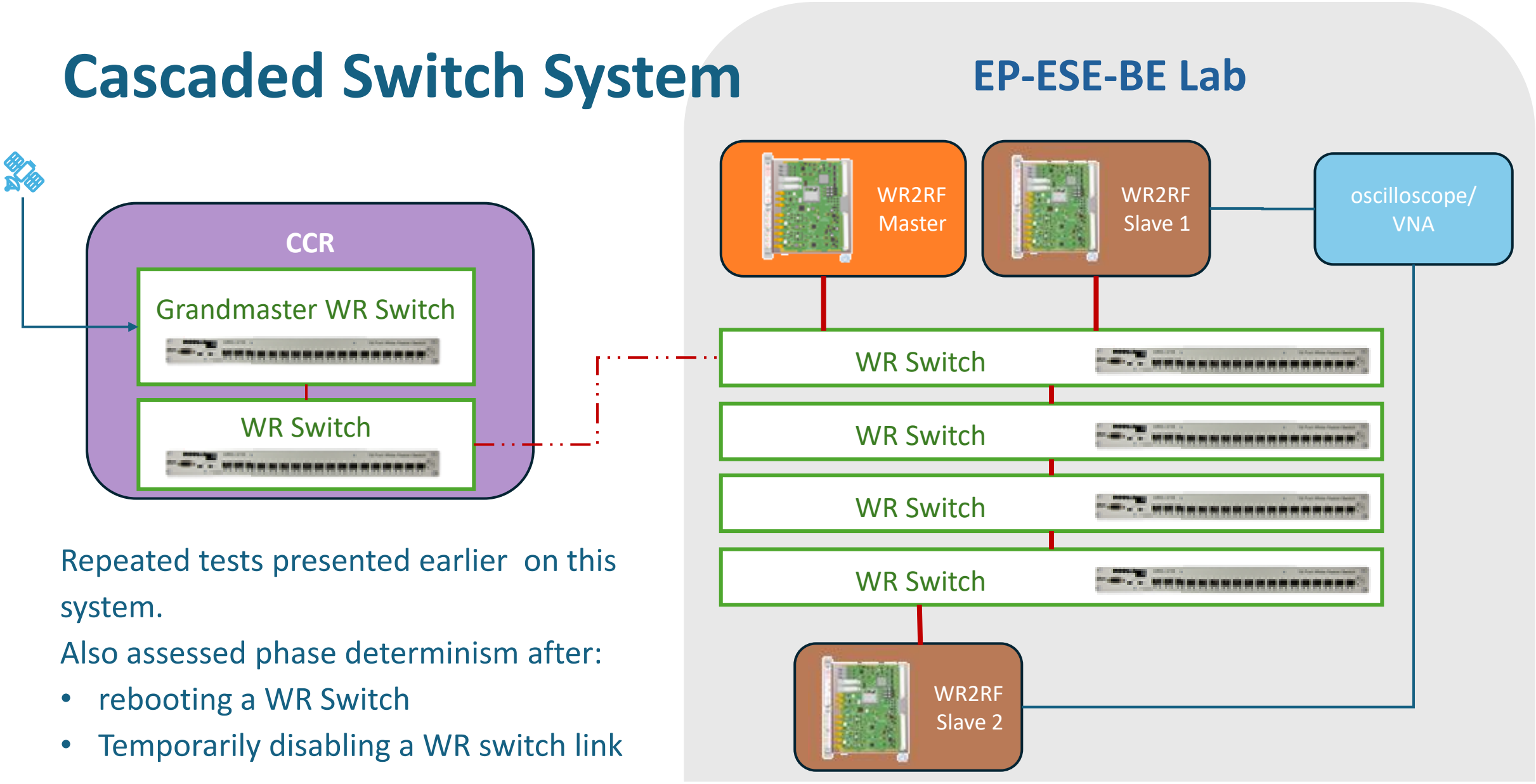



- There will be **multiple, cascaded WR switches** between **P4, CCR and the experiments**.
- What happens:
  - To **phase stability over time** with more switches?
  - If there is a **disturbance** in the **network**?

# Cascaded Switch System



# Cascaded Switch System



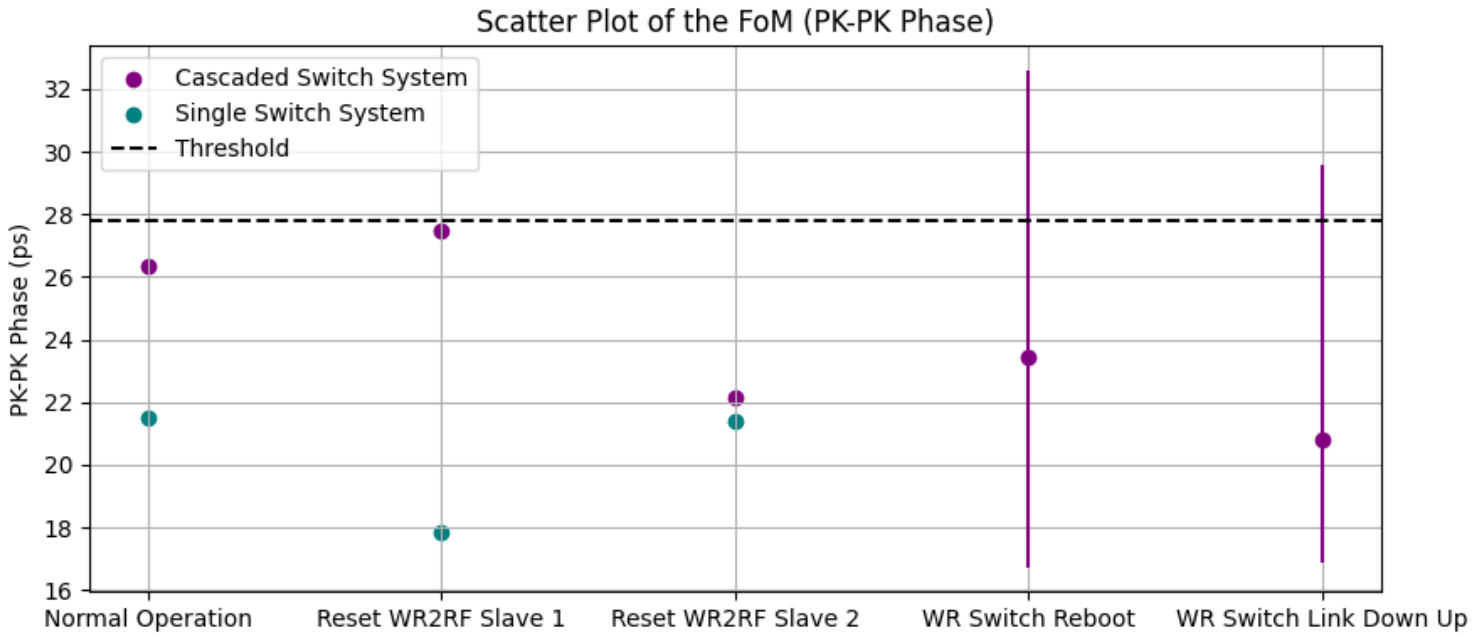

Repeated tests presented earlier on this system.

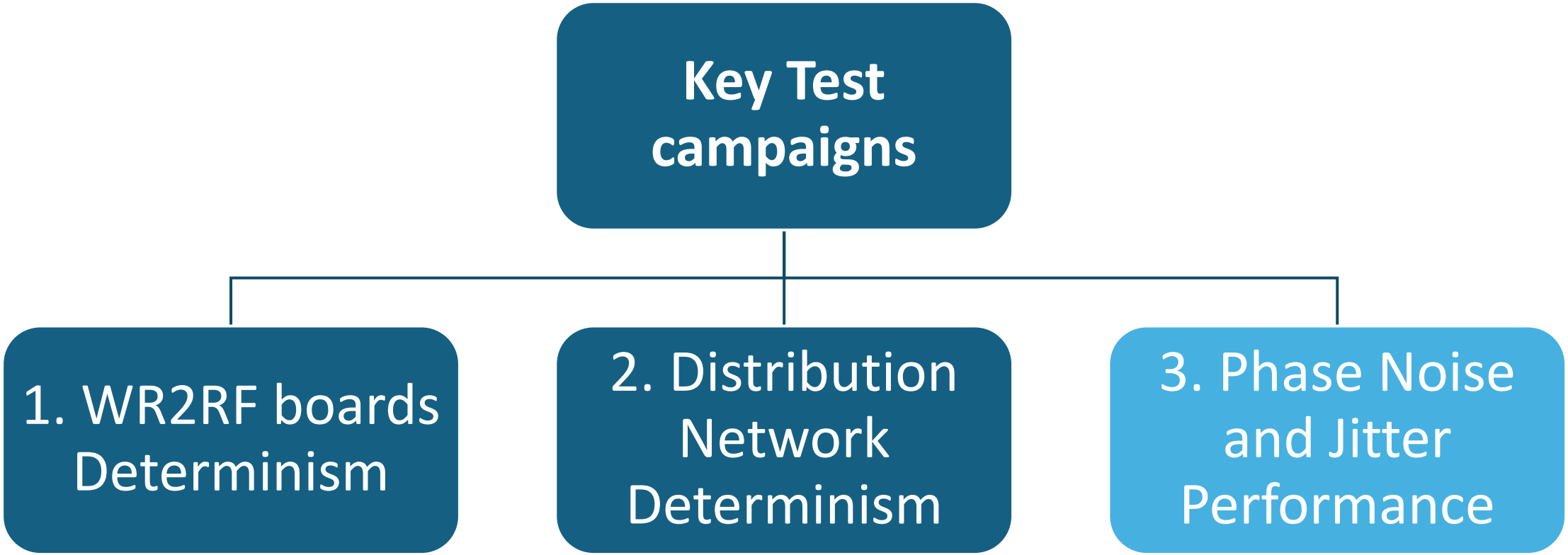
Also assessed phase determinism after:

- rebooting a WR Switch
- Temporarily disabling a WR switch link

# Phase Determinism Testing of Network

- After a **disturbance** in the **network, recovery plan** is required.
- With **cascaded switch** system, acceptable **FoM limit sometimes exceeded**, even during **normal operation** (observed with **other signals**).
- Phase determinism after **WR Switch reboot** and **temporary port de-activation comparable** with **normal operation performance**

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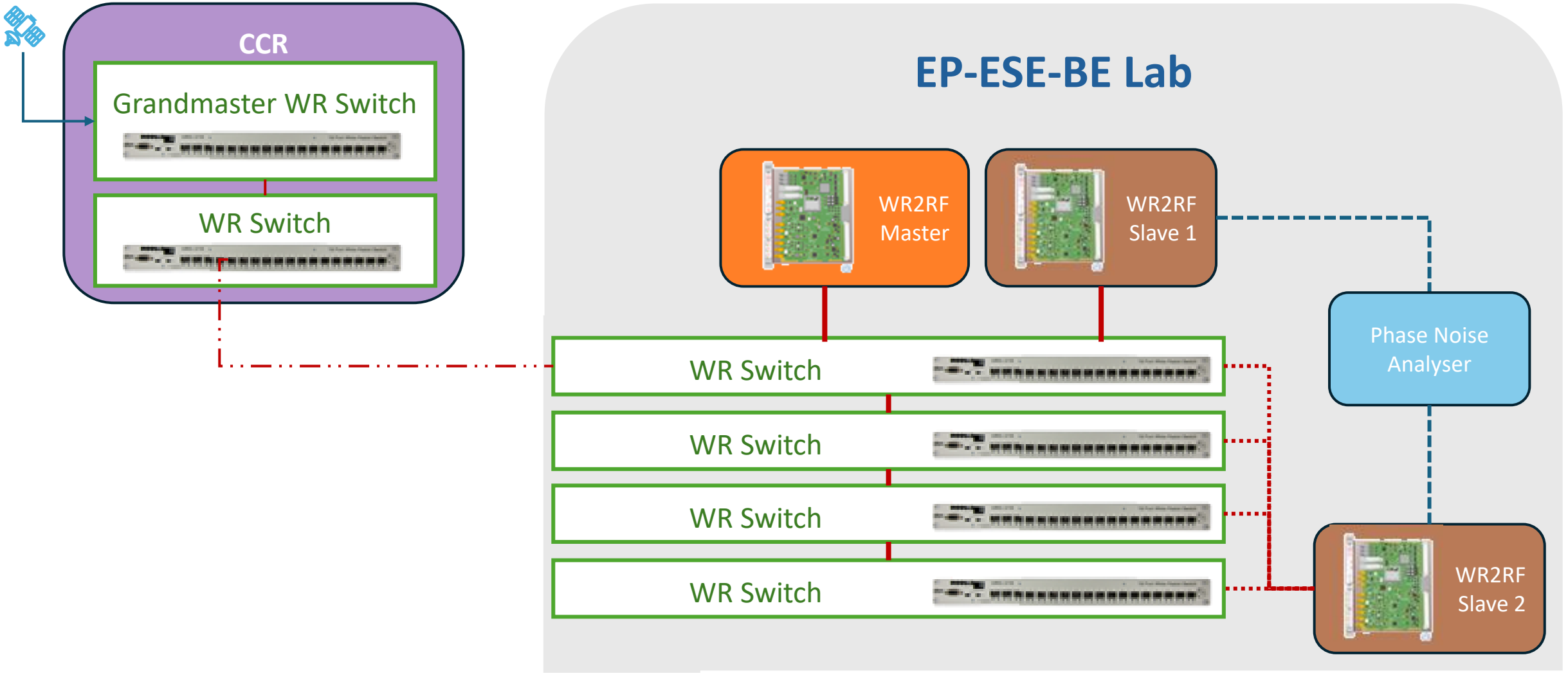
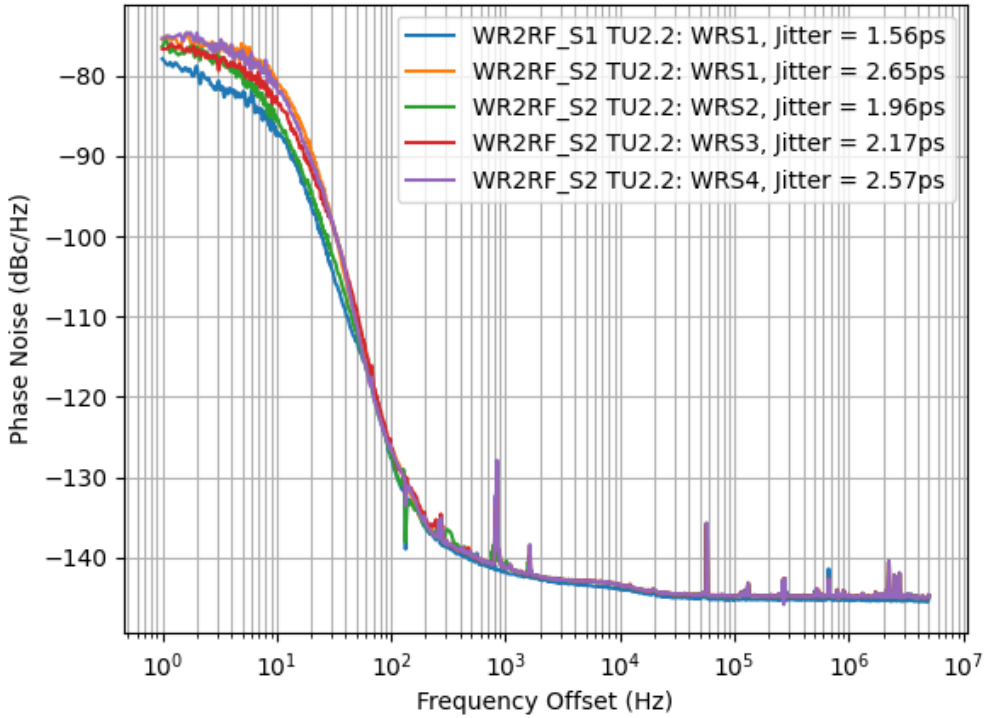
# Phase Noise Performance

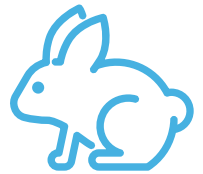


# Phase Noise Performance

- Jitter values acceptable for experiments **(< 5 ps rms).**
- Poorer phase noise **< 100 Hz** when WR2RF board is connected further down a cascade of WR switches.
- Jitter, in turn, over this frequency range also deteriorates.




S1 – WR2RF Slave 1
S2 – WR2RF Slave 2
TU2.2 – Bunch Clock



# Where does this leave us?

- Know the **baseline** performance of what the **RF Dependant Timing Distribution Backbone** Upgrade could achieve @ 200 MHz RF
- Found areas of improvement**,** which are being taken care of by **BE-CEM**
- Created standardised test procedures for assessing the future HL-LHC (400 MHz) WR2RF redesign performance

# Thank you for Listening!

# Any Questions?

# And finally…

Where does this leave us?

What next?

- **Redesign** of WR2RF boards to generate **LHC 400 MHz RF** frequency (**already started**).
- **Test** redesigned WR2RF boards:
  - to be taken **in house** by the **RF team**, in collaboration with **experiments and WR-team**
  - Test procedures will be **based of this work**.
- **Planned test in CMS**
- **Need monitoring system**
  - i.e. current system needs to be kept.
  - Keep an eye on phase between beam vs recovered clock