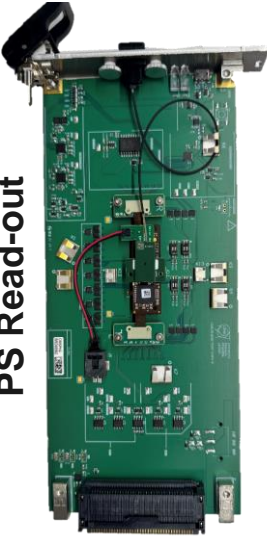


Test Cards

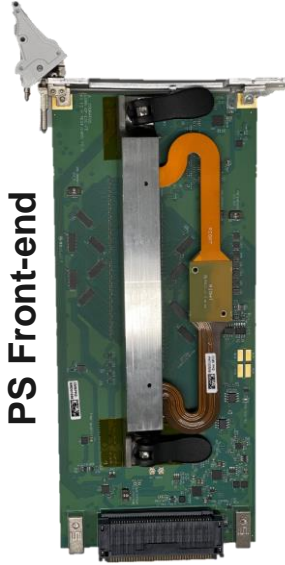
PS Read-out



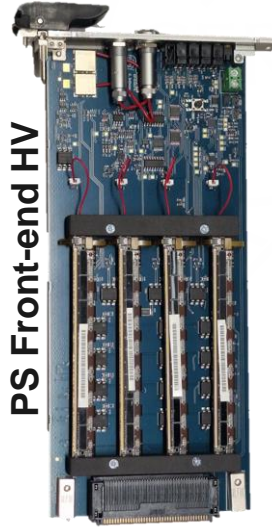
PS Power



PS Front-end



PS Front-end HV



2S Front-end



2S Service



## Insights gained from test system preparation for the hybrids production for the CMS Outer Tracker Phase-2 Upgrade

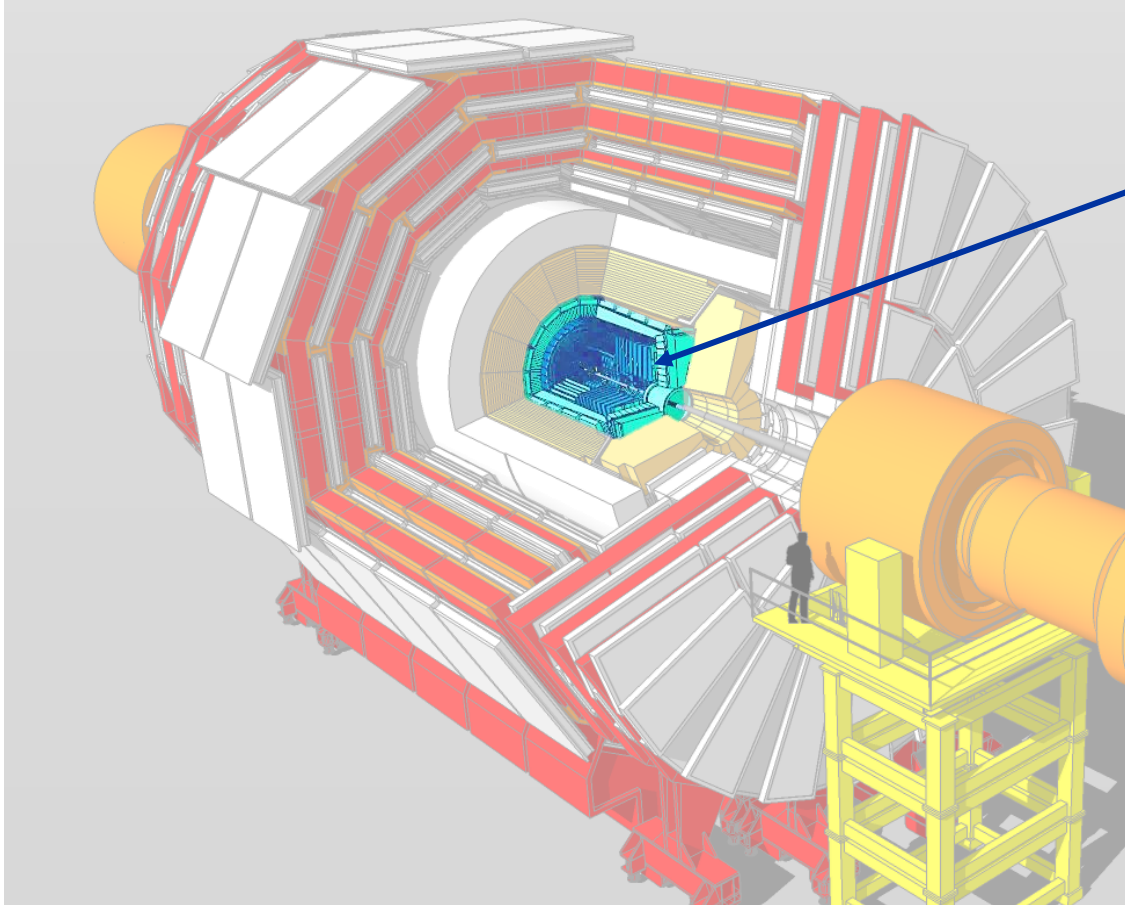
P.Szydlik<sup>1</sup>, M.Abbas<sup>1</sup>, I.Ahmed<sup>1</sup>, B.Allongue<sup>1</sup>, D.Andreou<sup>1</sup>, G.Blanchot<sup>1</sup>, R.Carnesecchi<sup>1</sup>  
K.Klein<sup>2</sup>, M.Kovacs<sup>1</sup>, A.Lapornik<sup>3</sup>, A.La Rosa<sup>1</sup>, M.Lipinski<sup>2</sup>, D.Louis<sup>2</sup>, M.Mohammadi  
Najafabadi<sup>1</sup>, A.Pauls<sup>2</sup>, A.Sultan<sup>1</sup>, F.Thurn<sup>2</sup>, A.Zografos<sup>1</sup>

<sup>(1)</sup> CERN, Route de Meyrin, CH-1211 Geneva 23, Switzerland

<sup>(2)</sup> RWTH Aachen, I. Physikalisches Institut B, Sommerfeldstraße 14 52056 Aachen, Germany

<sup>(3)</sup> University of Southern Denmark, Alsion 2, 6400 Sønderborg, Denmark

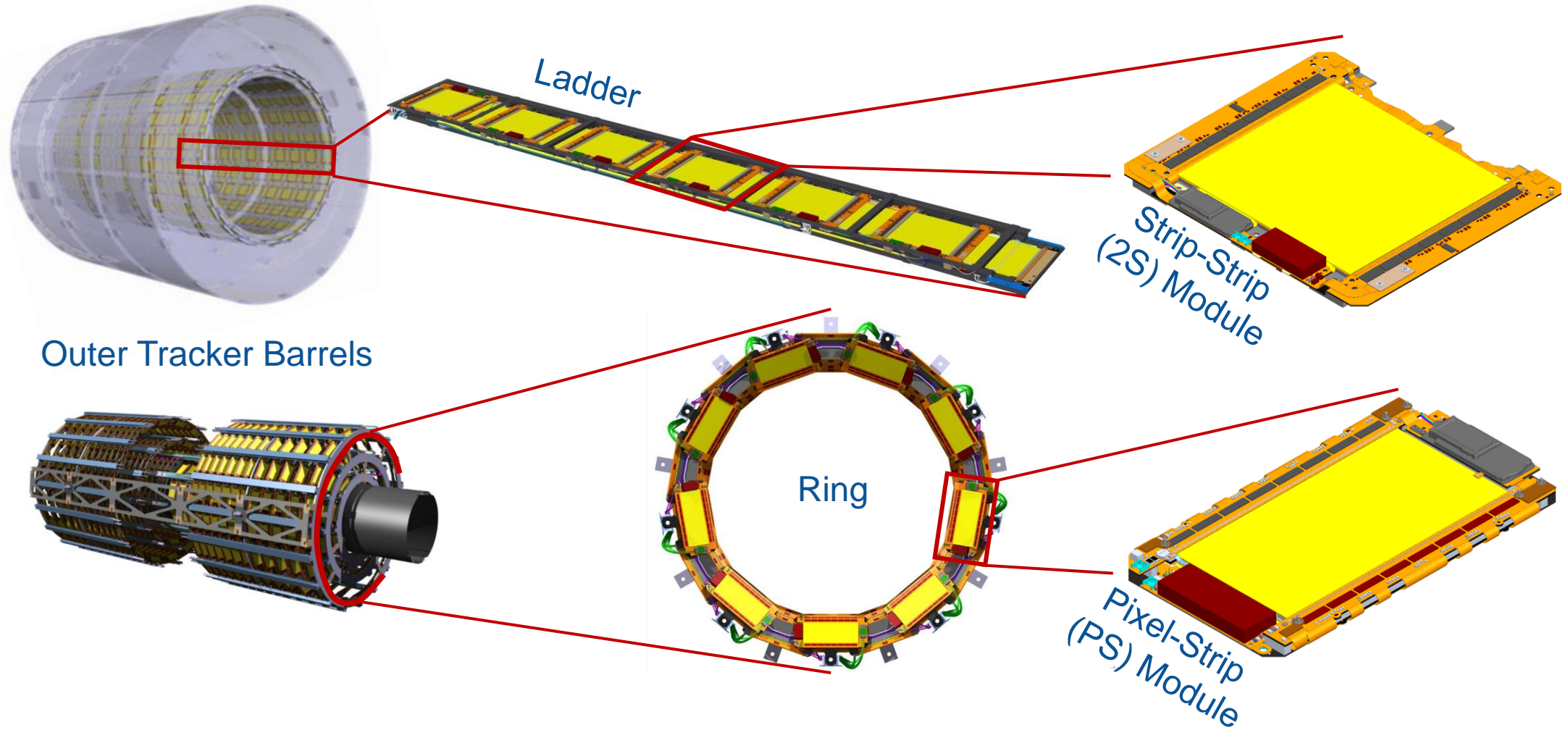
# CMS Outer Tracker Phase 2 Upgrade



## Silicon Tracker

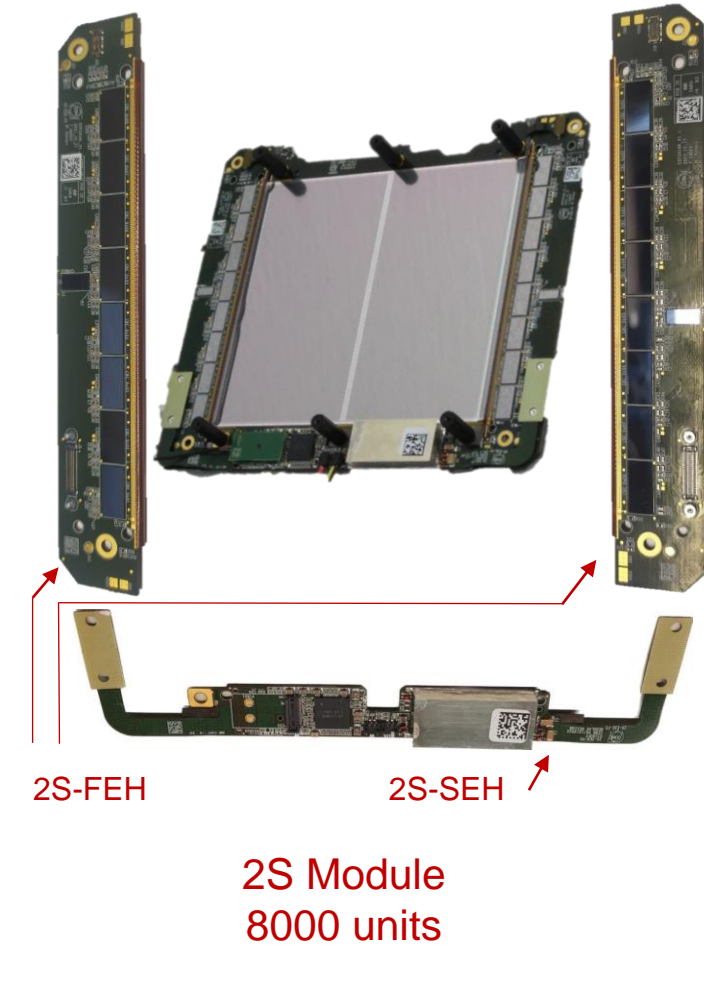
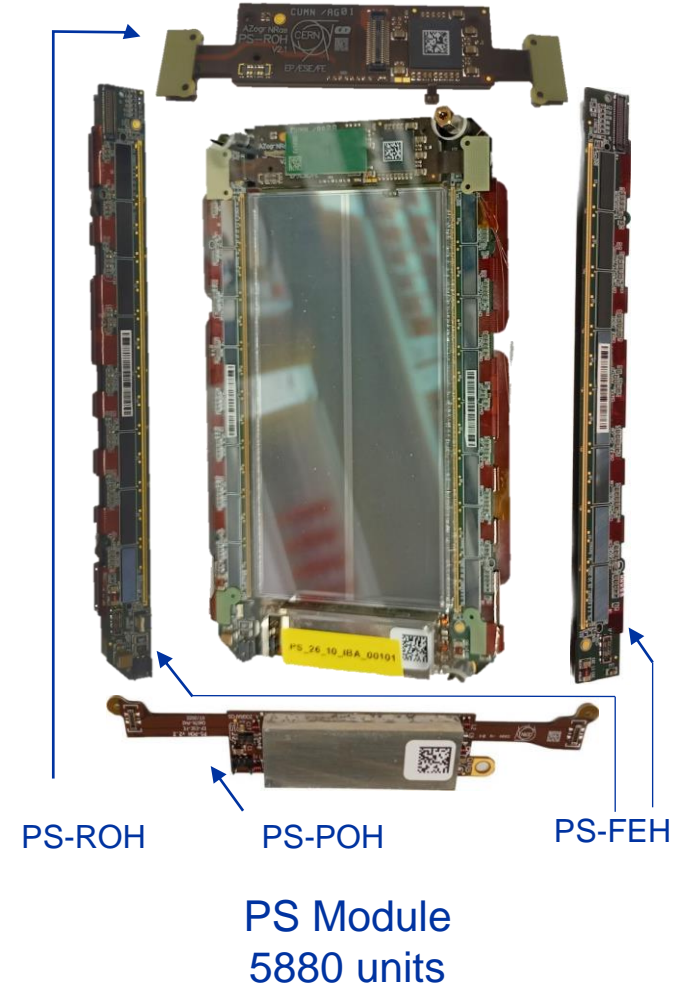
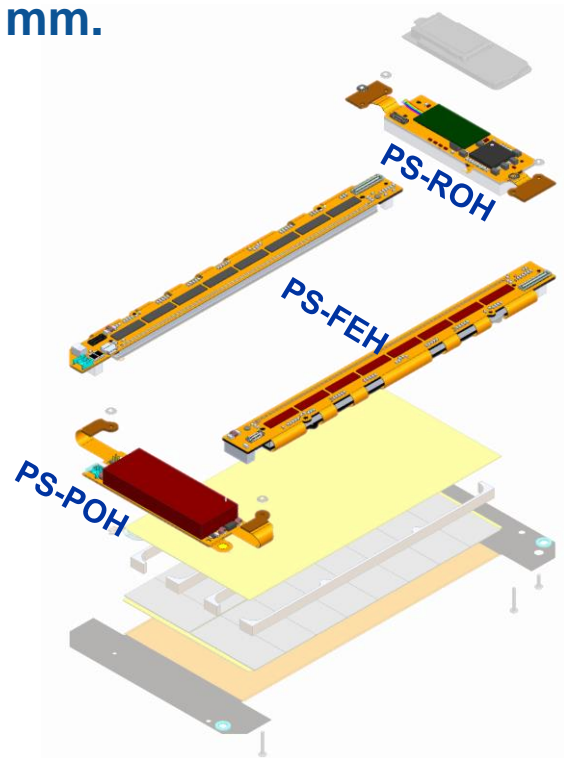
- Unique combination of Pixel and Strip sensor technology.
- Operating temperature of  $-35^{\circ}\text{C}$ .
- Expected lifetime 10-15 years.
- No access to perform repairs.

# CMS Outer Tracker Phase 2 Upgrade



# CMS Outer Tracker (OT) Hybrids project

- Permanently glued.
- Thickness variants:
  - PS - 1.6, 2.6, 4.0 mm,
  - 2S - 1.8, 4.0 mm.



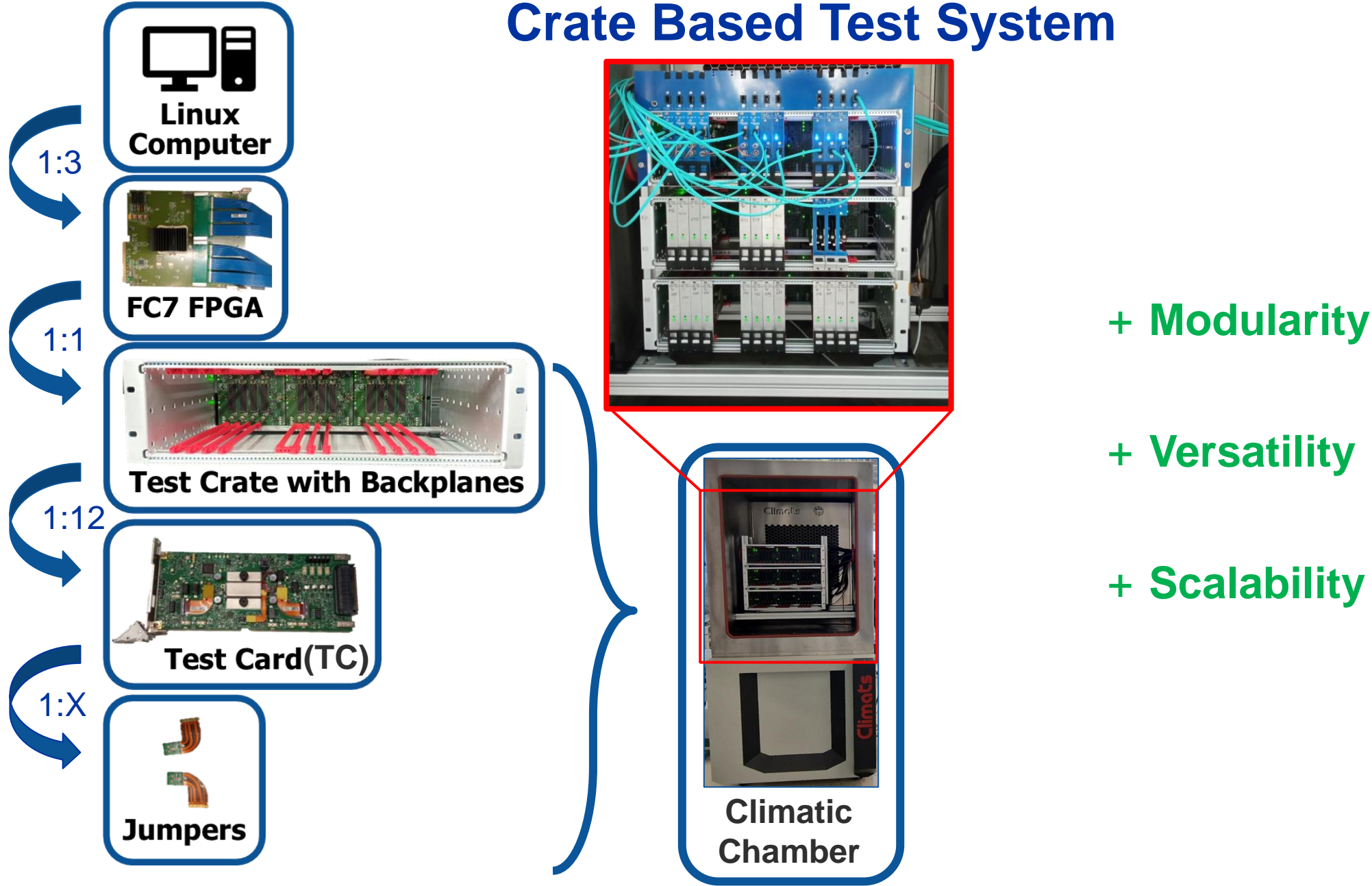
**Hybrid:** Circuit combining unpackaged ASICs with passive components; **FEH:** Front-End Hybrid; **SEH:** Service Hybrid; **POH:** Power Hybrid; **ROH:** Read-Out Hybrid

# Motivation for test system design

- **5 main types,**
- **18 variants,**
- **~ 48 thousands units,**
- **Strict acceptance criteria,**
- **Not feasible to replace on module.**



# Crate Based Test System



# Test Cards and jumpers



PS-ROH Test Card 90 pcs



2S-SEH Test Card 90 pcs



PS-POH Test Card 88 pcs



↕ Optical readout and control.

🔌 DC-DC powering.

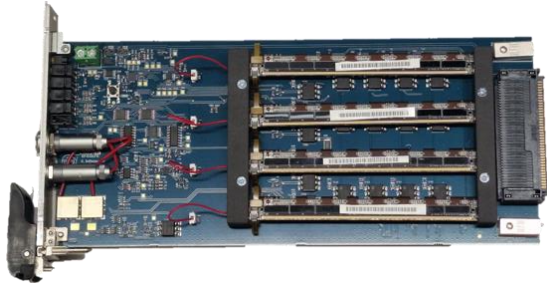
🧠 Front-end ASICs.

⚡ HV circuitry.

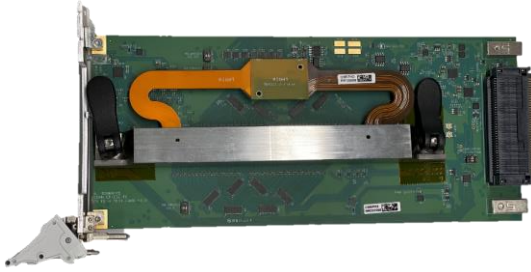
Flex jumpers ~3000 pcs



PS-FEH-HV Test Card 81 pcs



PS-FEH Test Card 170 pcs



2S-FEH Test Card 125 pcs



# Overview of software tools

**Database**

**Databases**

- Test System Monitoring DB
- CMSDCA Production DB

**Linux Computer**

**Services**

- PSU Control
- Chamber Control

**User Interfaces**

- GUI OTHYB
- Test System Monitoring GUI

**Test Software**

- Ph2\_ACF SEH ROH FEH
- TC\_Controller POH FEH-HV

**Test Card**

**Test Card**

- Microcontroller Firmware
- USB drivers

**FC7 FPGA**

**FPGA**

- uDTC Firmware 9 variants

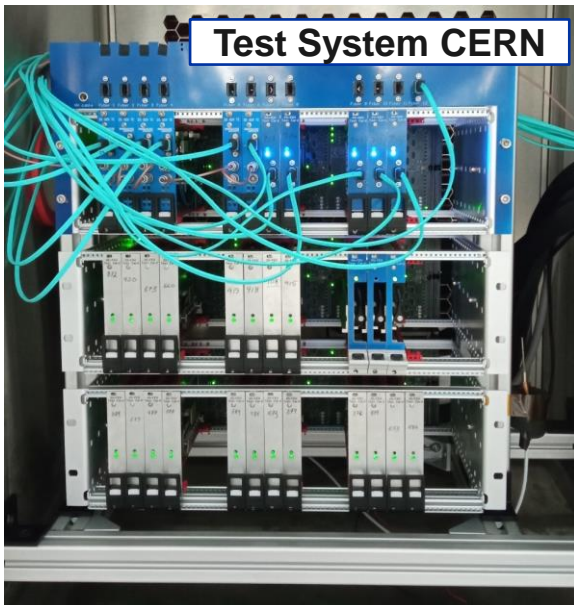
# Testing workflow

Parallelizing most of the operations allow for significant time gain on production scale.

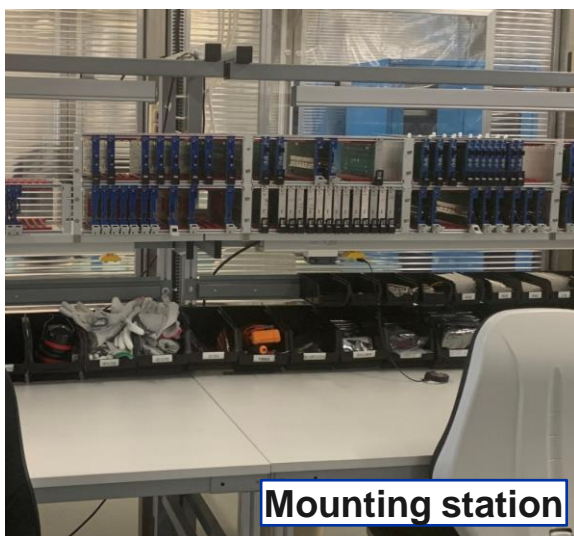
Target throughput 108 hybrids / 8h shift



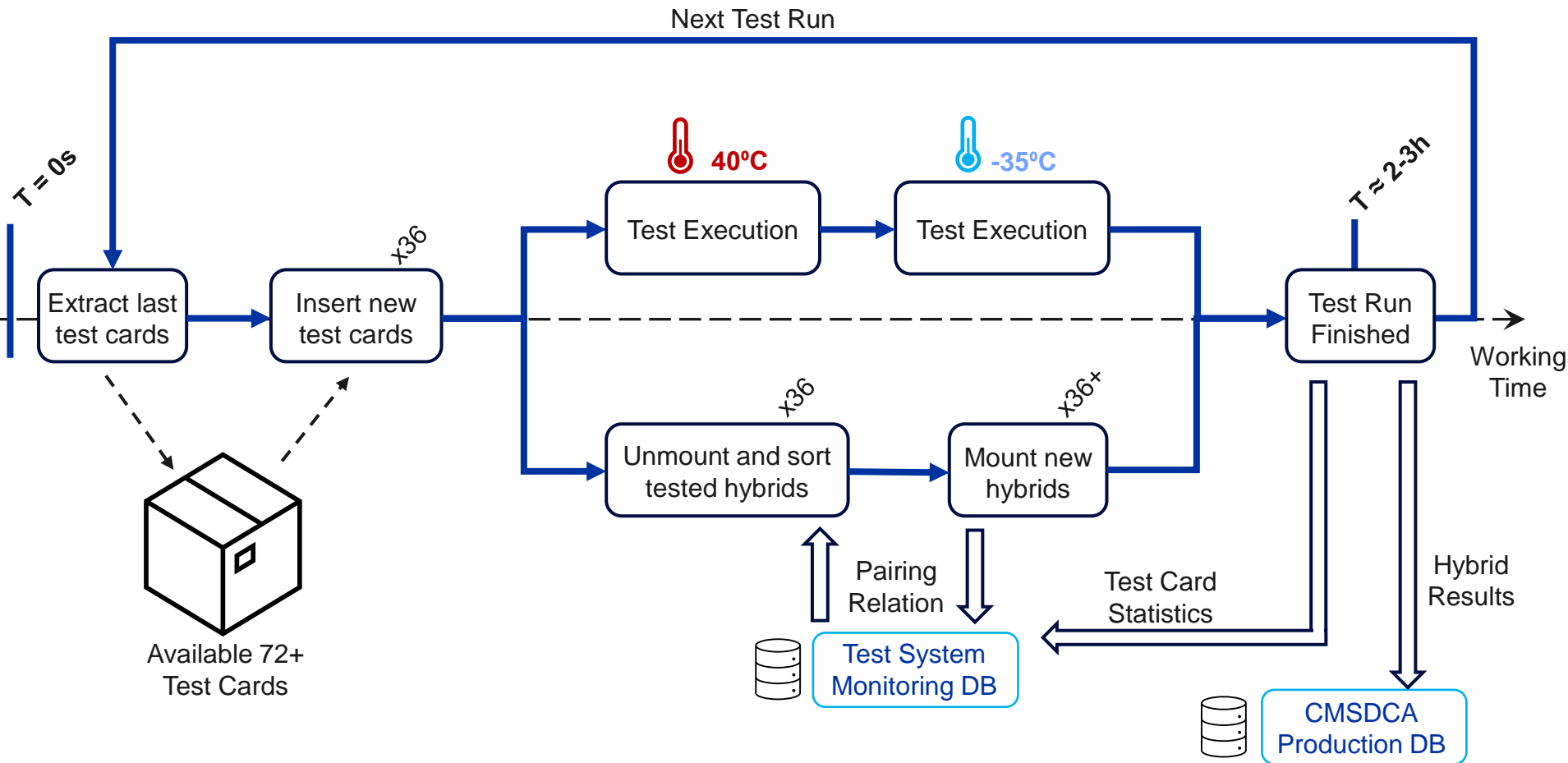
~2300 hybrids / month



Test System CERN



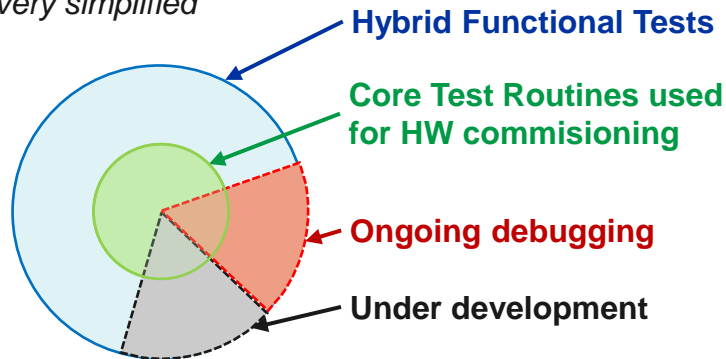
Mounting station



# Commissioning challenges

Test Software at start of commissioning\*

\* very simplified



Save engineering effort.

Logic table\* to decide the component status

\* very simplified

Backplane	Test Card	Jumper	Hybrid	Result
Good	Good	Good	?	PASS / FAIL
Good	?	Good	Good	PASS / FAIL
?	?	?	?	PASS / FAIL

? Hybrid → Good / Bad

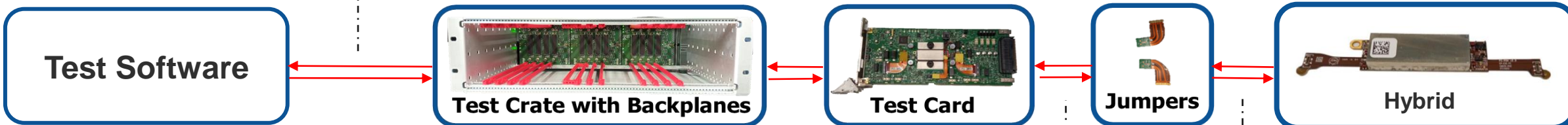
? Test Card → Good / Bad

x 110 pcs

x 645 pcs

x 3000 pcs

x Available prototypes



Can it be more simple?

- Visual inspection
- Smaller test station for components

Test Card	Jumper	Hybrid
Good	?	?
?	?	Good

Recognize need for dedicated approach.

Why bad hybrids are still useful?

Test Card	Hybrid	Result
?	Good	PASS
?	Bad	FAIL

→ True Positive

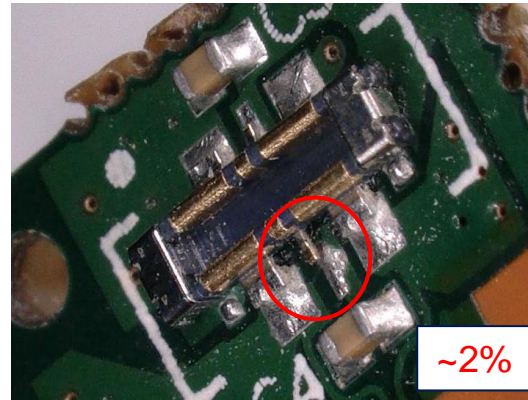
→ True Negative

? Test Card → Good

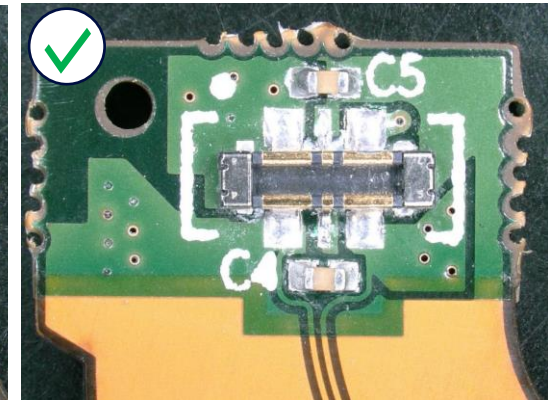
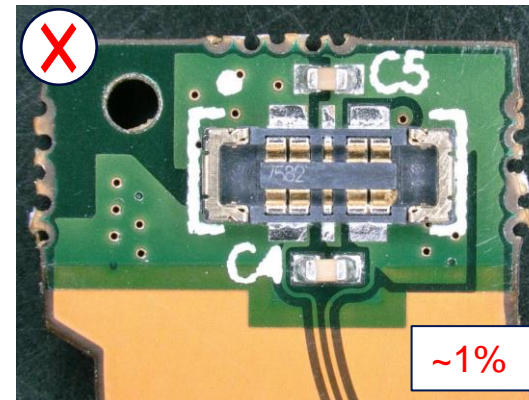
Reserve sufficient prototypes.

# Faults discovered by extensive usage

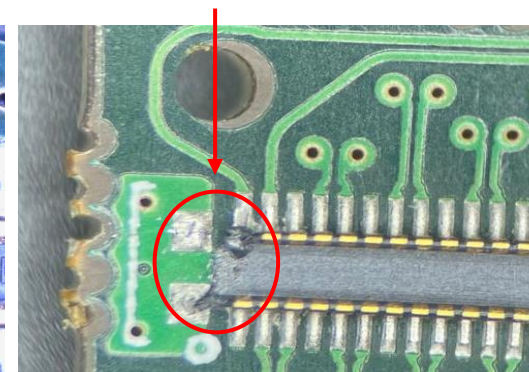
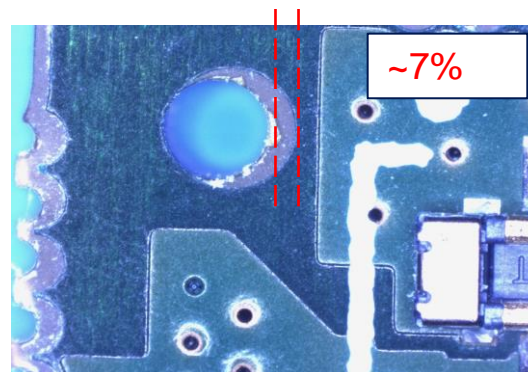
Soldering defects caught by VI



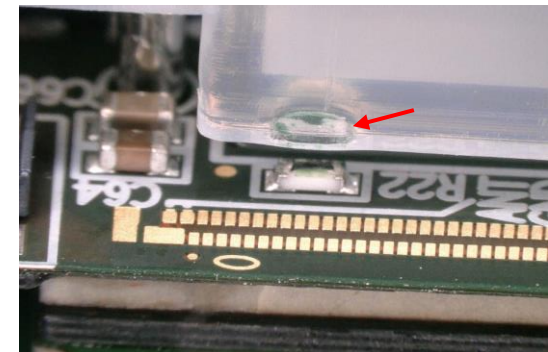
Wrong connectors missed by VI



150 $\mu$ m misalignment causing connector damage



Spacer colliding with resistor



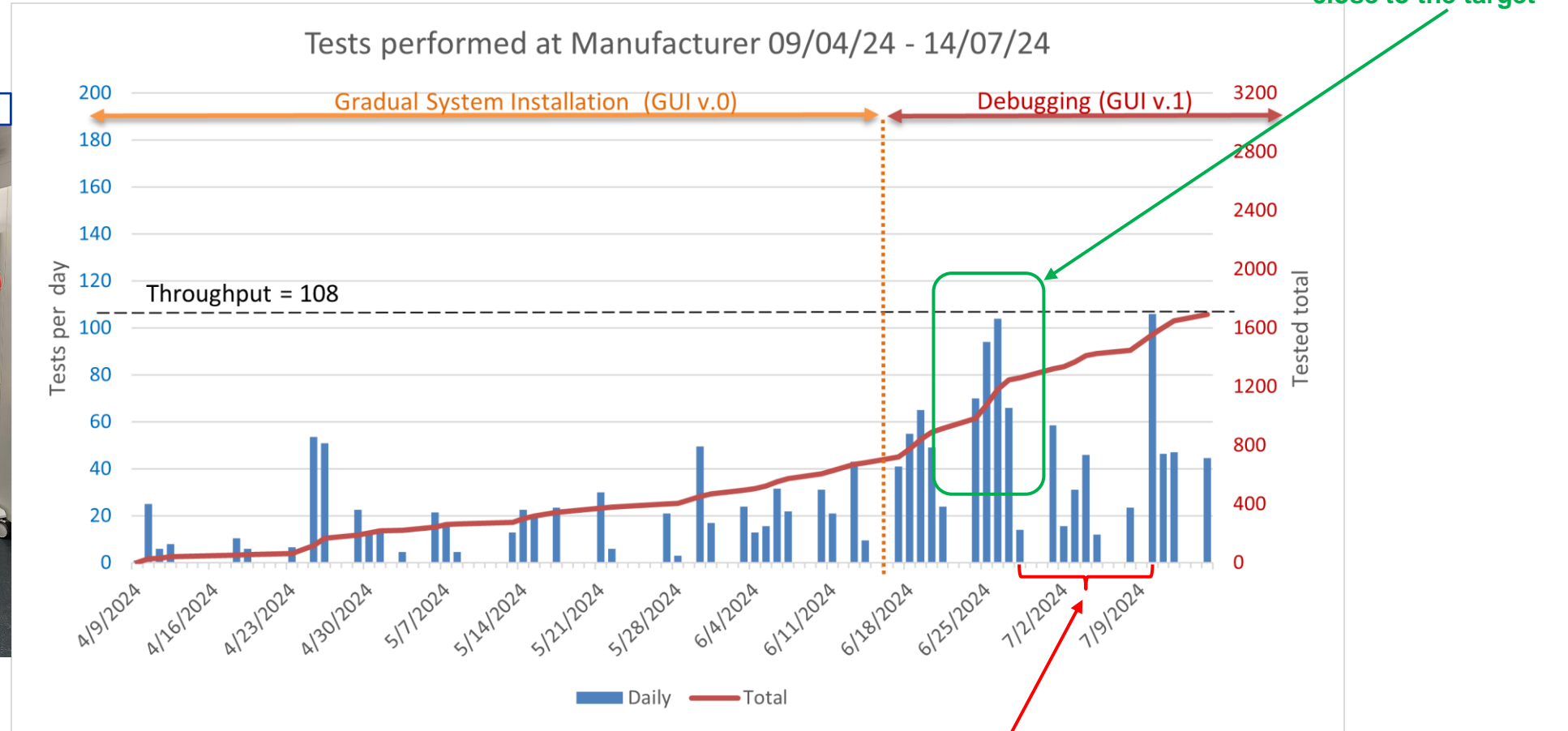
Those faults were causing **invalid test results** or even **damages to the hybrids**, which required additional repairs.

Even the simplest but critical components should undergo careful inspection.

# Deployment of test system at the manufacturer

First installation step made on 20/12/2023

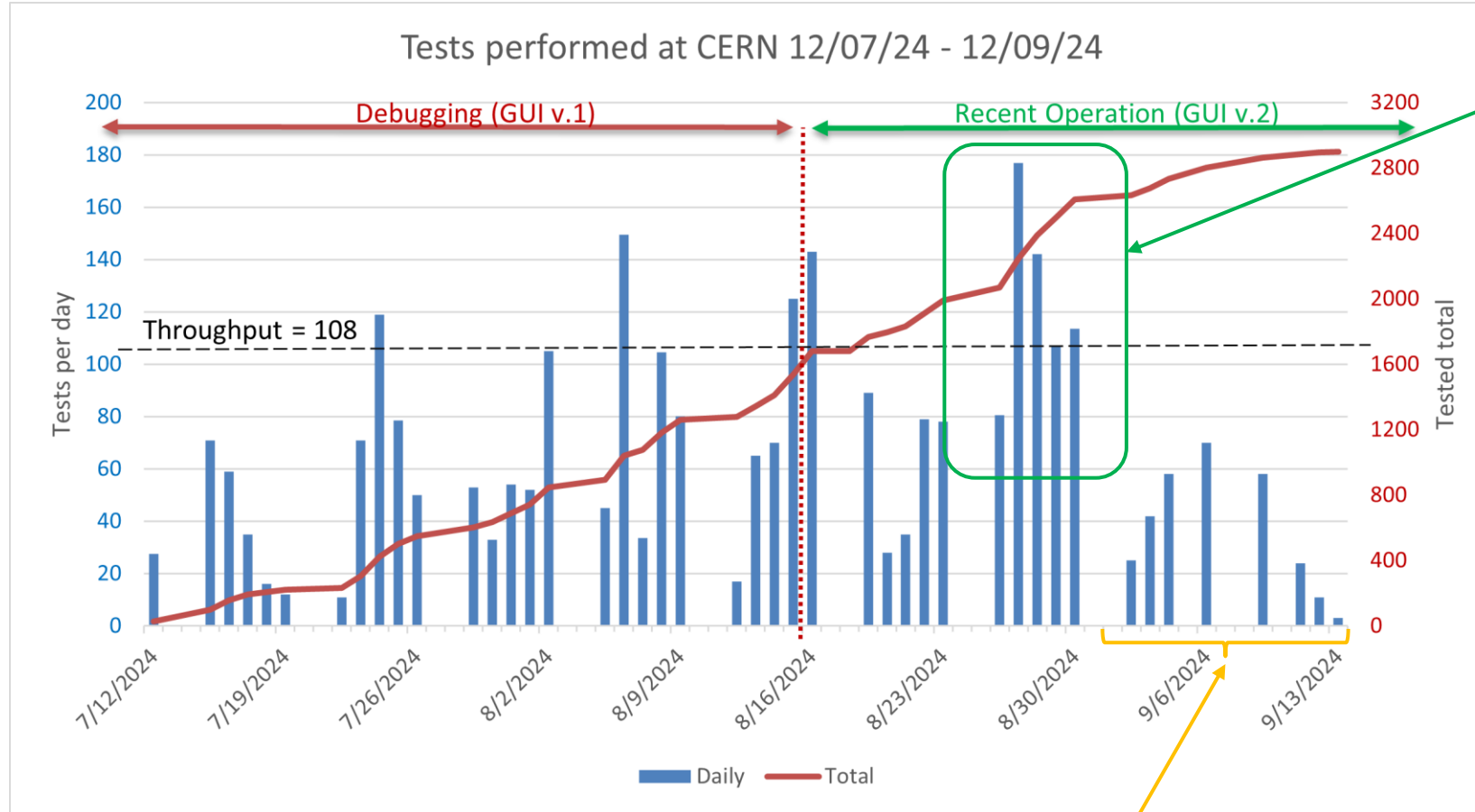
Test System at the manufacturer



Severe bug interrupted the testing at manufacturer.

# Testing experience at CERN

In the best week the throughput at CERN was above expectation!



Finished testing of pre-series hybrids.

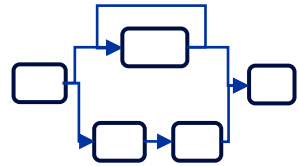
# Example repeatability exercise

Conducted tests at the manufacturer with **36 mixed hybrids**, in **32 test cycles** (cold + warm).

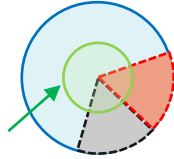
Repeatability of the test results per hybrid											
2SSEH x 6						PSROH x 6					
100 %	98 %	97 %	95 %	95 %	78 %	100 %	100 %	98 %	97 %	81 %	64 %
2SFEH x 8				PSPOH x 8				PSFEH x 8			
100 %	100 %	100 %	94 %	97 %	97 %	95 %	95 %	100 %	100 %	97 %	77 %
100 %	100 %	100 %	100 %	100 %	100 %	100 %	98 %	100 %	100 %	100 %	100 %

- Summarizing:
  - **50%** returned always the same result,
  - **36%** with minor interruptions (score  $\geq 95\%$ ),
  - **14%** with various failures.
- Most common interruptions:
  - Issues in connection with the test card or the hybrid. ( x58 )
  - Problems with power supply control. ( x10 )
  - Instabilities in optical communication. ( x13 )
- More debugging and tests are still needed.
- Further repeatability exercises allow to keep improving during ongoing operation of the system.

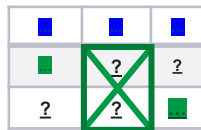
# To highlight the insights gained



➤ Parallelize work.



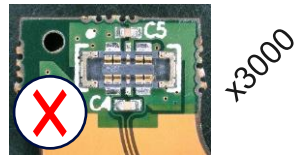
➤ Save engineering efforts when possible.



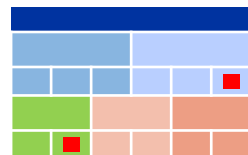
➤ Recognize the need for dedicated solutions.



➤ Reserve sufficient prototypes.



➤ Pay attention to every critical component.

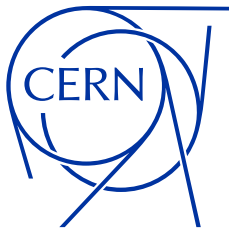


➤ Keep improving during operation.

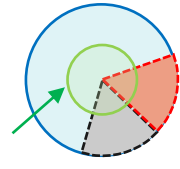
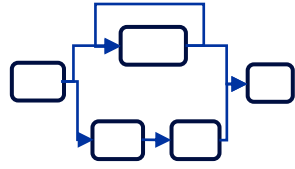
# Conclusions and future plans

- The commissioning process provided many experiences.
- Usability of test system was demonstrated during pre-series.
- More debugging and tests are still needed to improve.
- HW and SW maintenance will be required for stable operation.
- Testing at manufactures has been resumed in recent weeks.
- Production is starting with peak of 3000 hybrids per month.

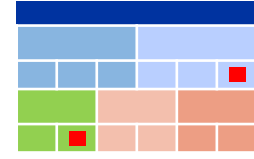
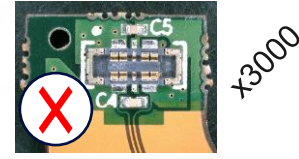




**TWEPP 2024 Topical Workshop on Electronics for Particle Physics**  
**Glasgow, United Kingdom, 30 September - 4 October 2024**

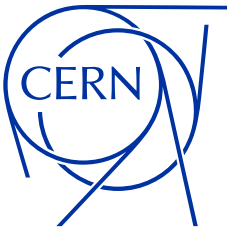


■	■	■
■	?	?
?	?	■

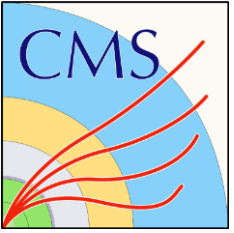


**Thank you for your attention**  
**Merci de votre attention**

**Any questions/suggestions?**

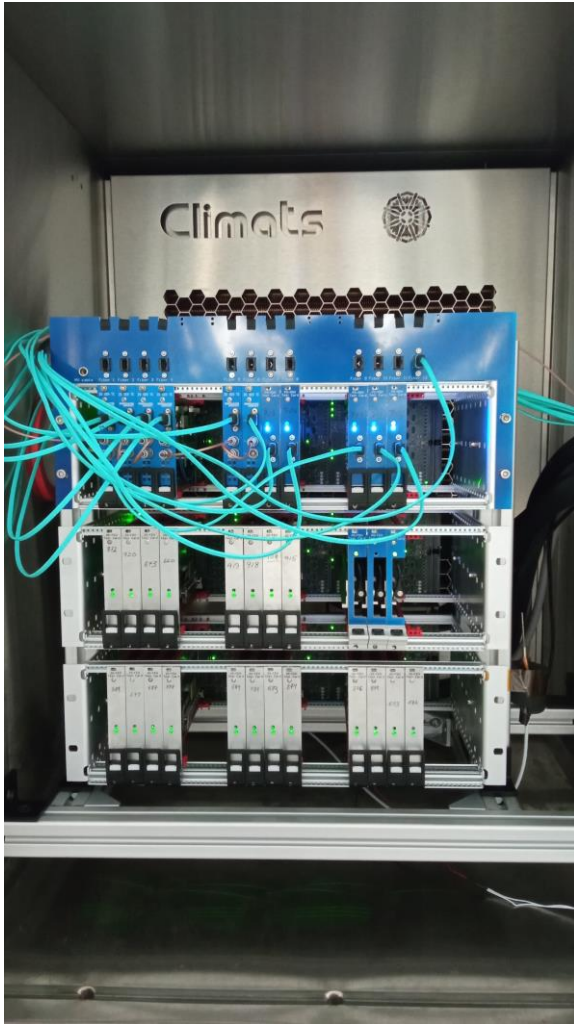


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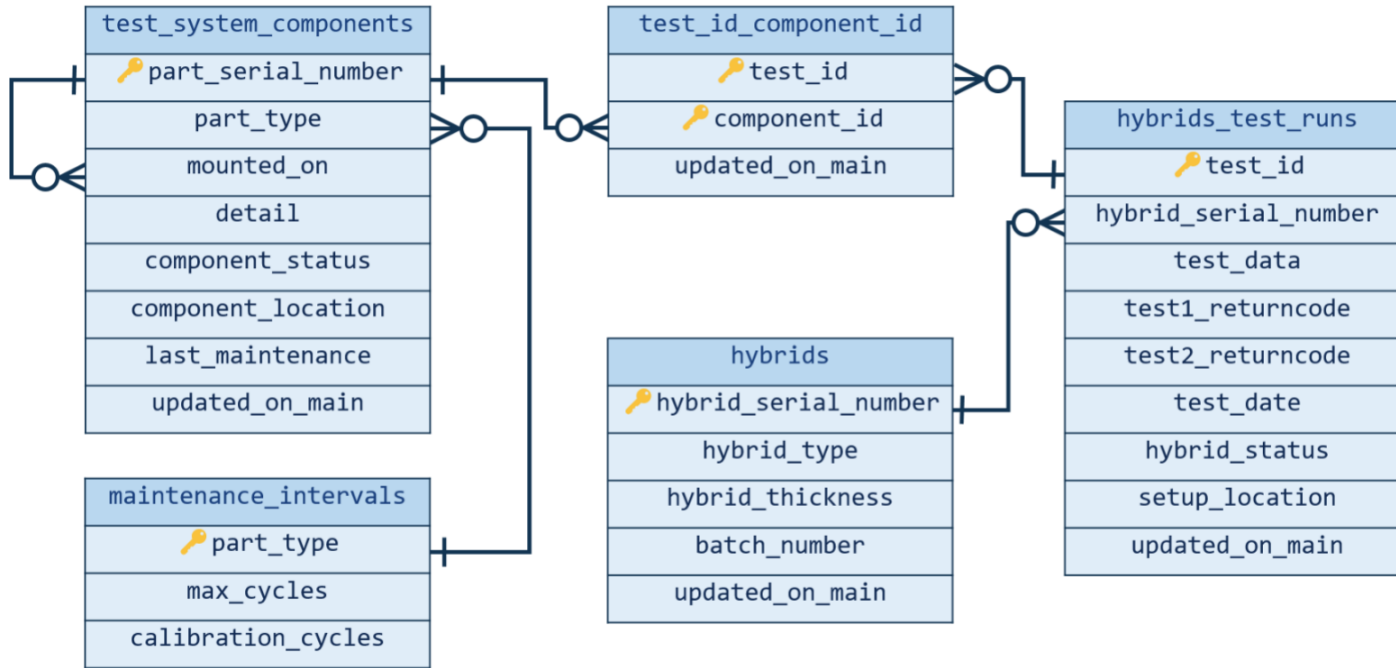


# Backups

# OT Hybrids Test System – CERN lab



# Test System Monitoring



View Component Details@localhost.localdomain

Component Serial Number:

Component Type:

Mounted On:

Component Status:

Component Location:

Component Details:

Last Maintained On:

Uploaded to Main:

Tests to display:

Test ID	Hybrid ID	Test Date	Test Result
1 138	PSFEH40R-212000028	18/06/2024 13:09	Good
2 116	PSFEH40R-212000028	18/06/2024 12:01	Good
3 94	PSFEH40R-212000028	18/06/2024 10:08	Good
4 66	PSFEH40R-212000004	17/06/2024 16:27	Bad

Total tests:4 Failed Tests:1 Failed Ratio:25.0% End of Life at:500

# System dependencies

