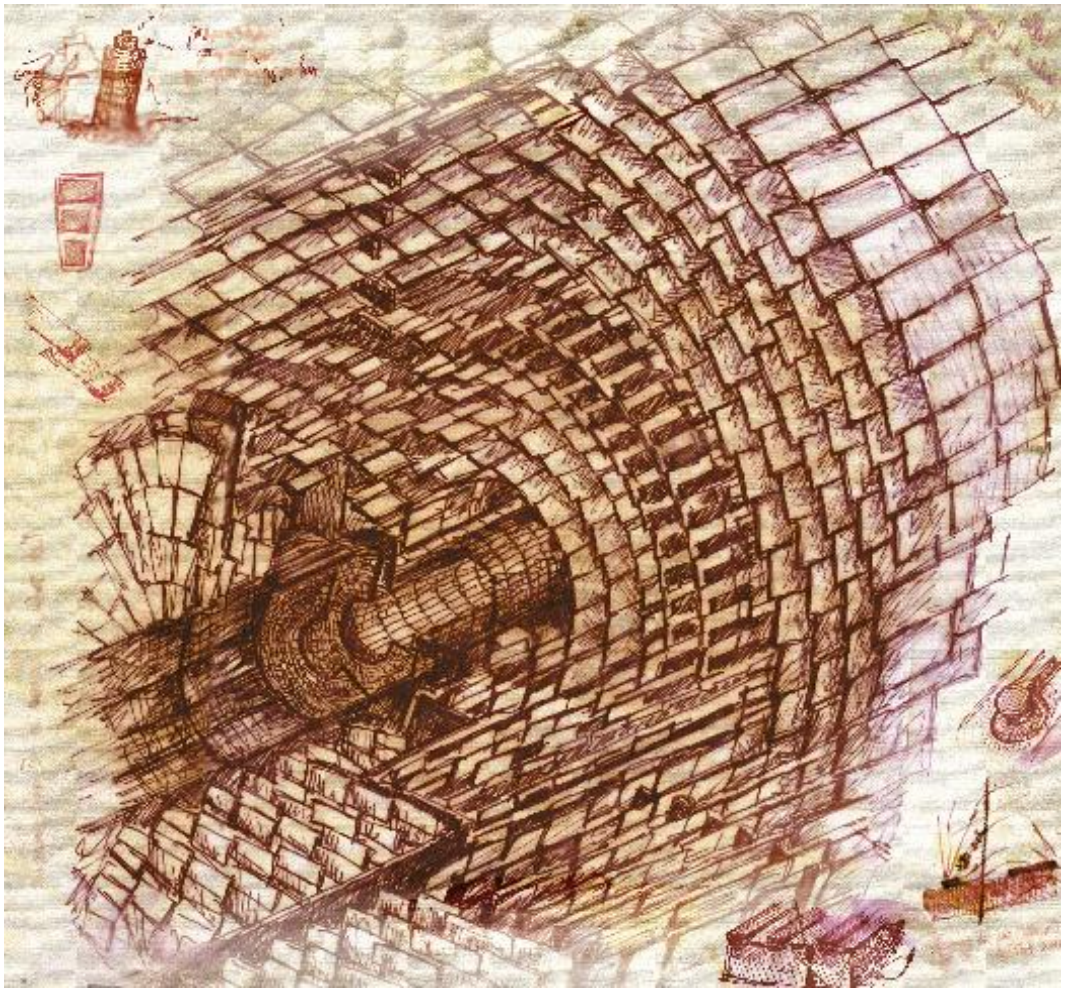
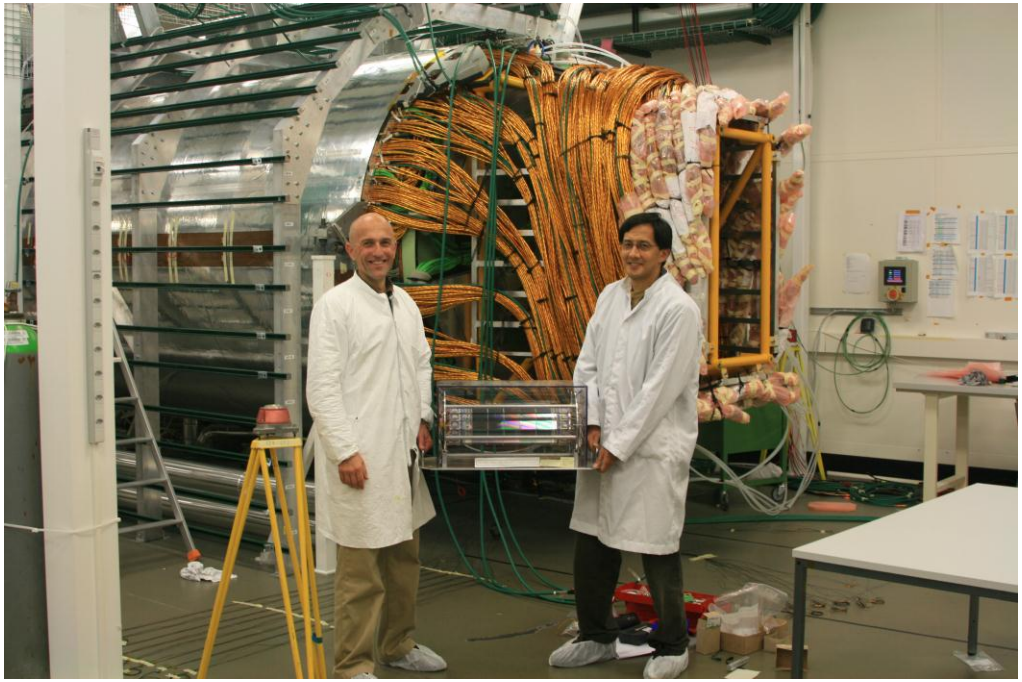
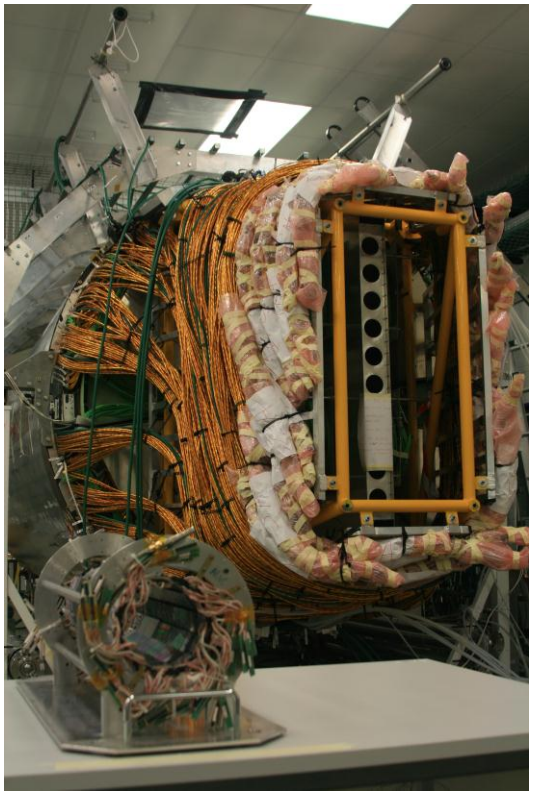
Hybrid Quality Issues for Present LHC Trackers: The CMS Example…



Hybrid Quality Issues for Present LHC Trackers: The CMS Example…

- **The Trackers of the Atlas and CMS Experiments, in particular, represent the largest ever deployment of Silicon Strip Sensors**
  - **~ 2 orders of magnitude larger than LEP Vertex Detectors**
  - **~ 1 order of magnitude larger than CDF / D0 Inner Trackers**





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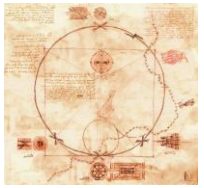

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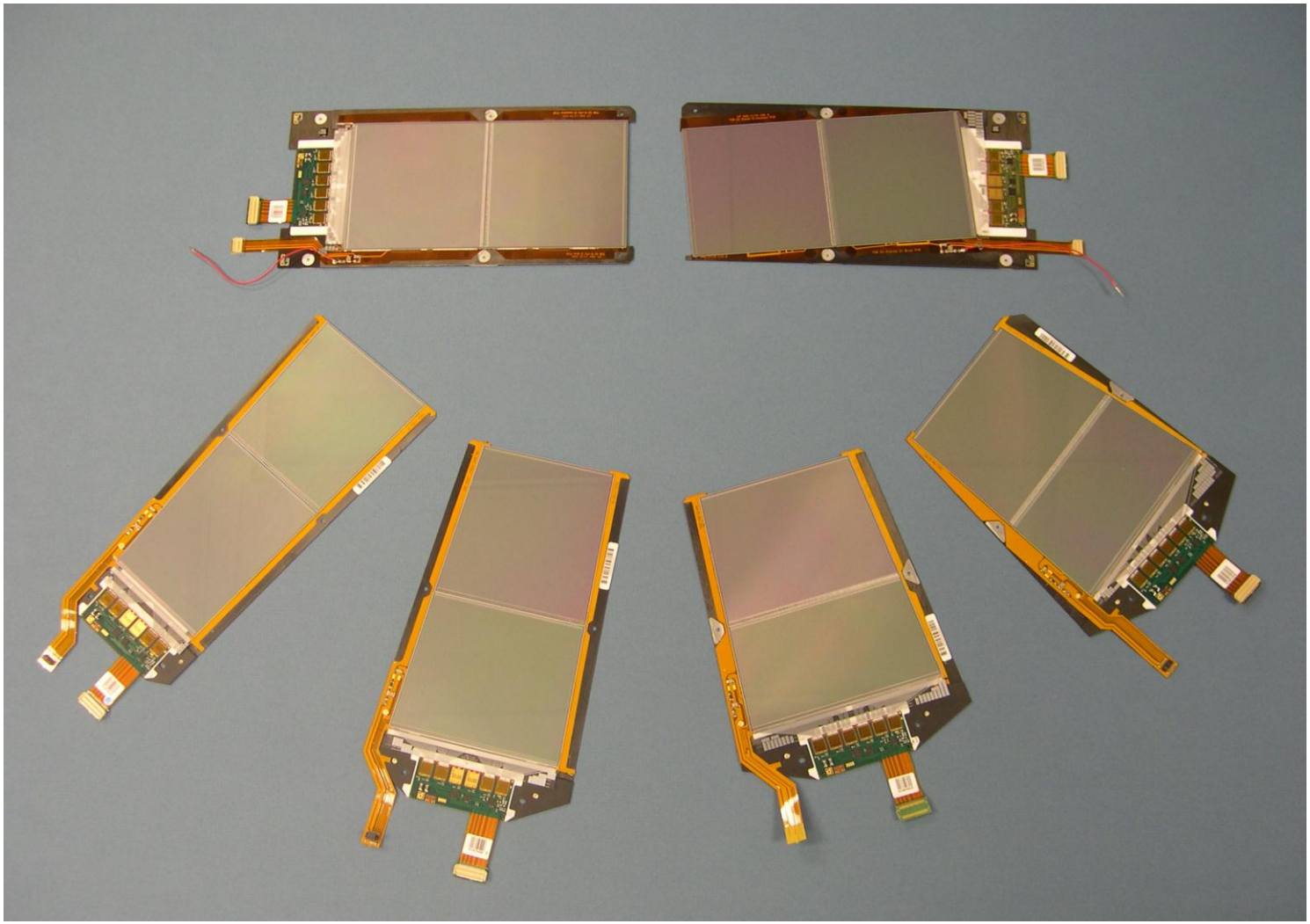
  - **~ 2 orders of magnitude larger than LEP Vertex Detectors**
  - **~ 1 order of magnitude larger than CDF / D0 Inner Trackers**

- **The CMS Tracker is instrumented with some 17'000 Silicon Strip sensor Modules, with an active area of about 200m^2**
  - **Previous Silicon detectors typically had a hundreds of (smaller) modules**

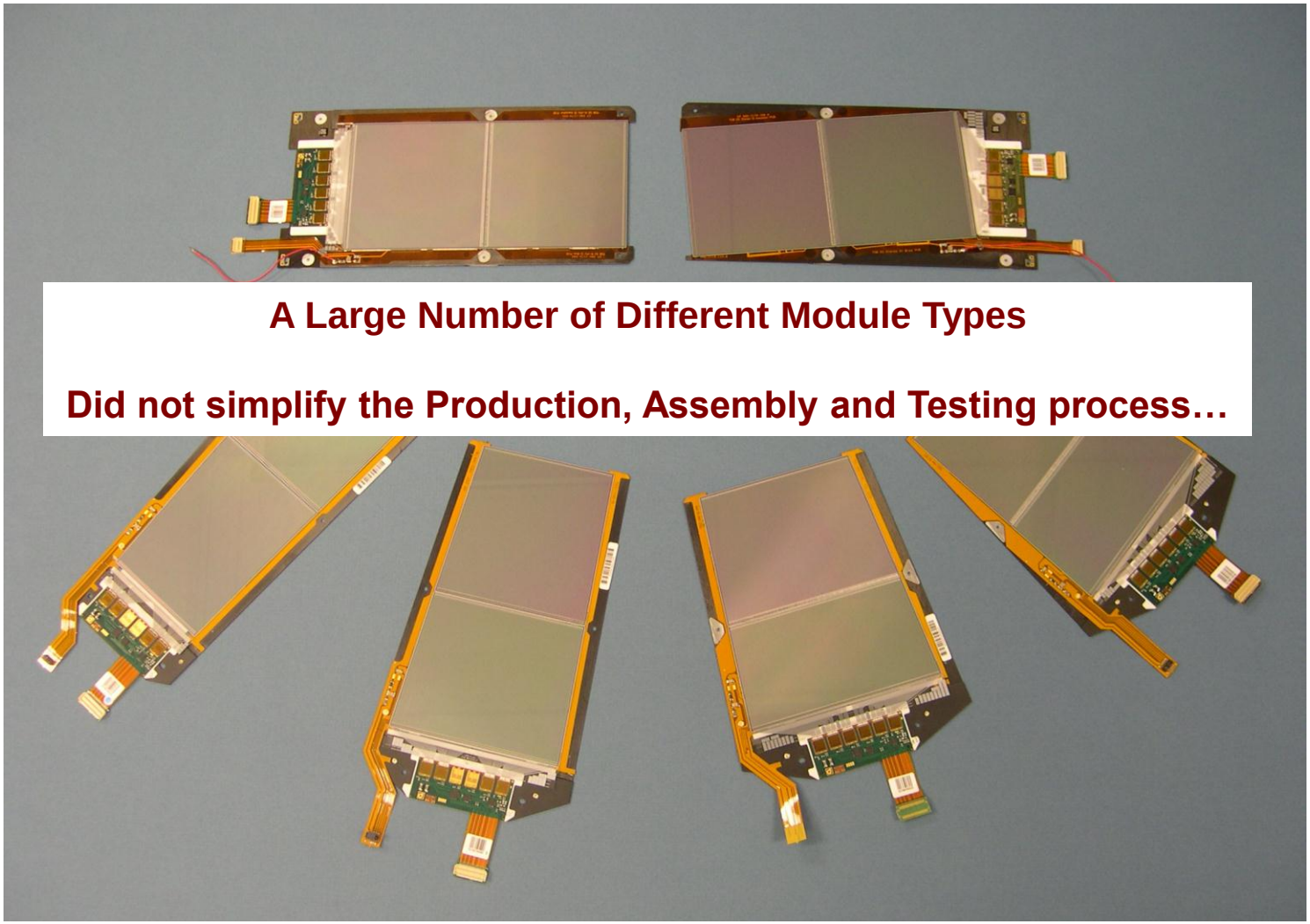
- **This required a much higher level of Industrialization and Automation of Production Assembly and Testing, from individual components to complete Modules**

⇒ **Much more emphasis on Quality Management and Quality Assurance**
  - **In addition to Quality Control**
  - **To ensure BOTH High Quality and High Throughput**

A Selection from the CMS Module Menu



A Selection from the CMS Module Menu

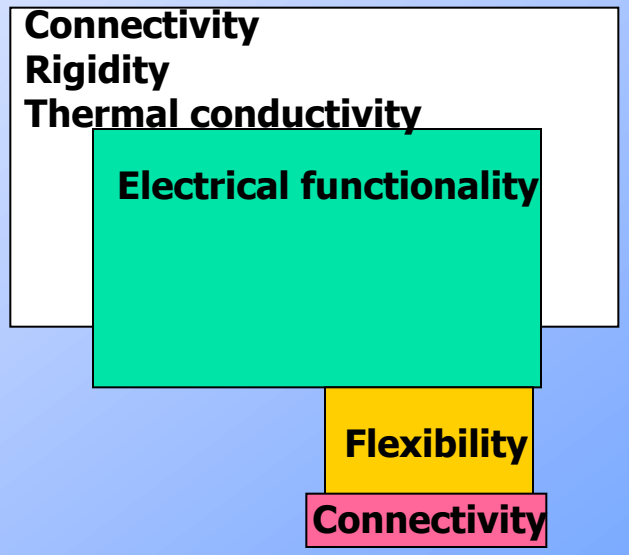


A Large Number of Different Module Types

Did not simplify the Production, Assembly and Testing process…

The CMS Tracker Front End Hybrid

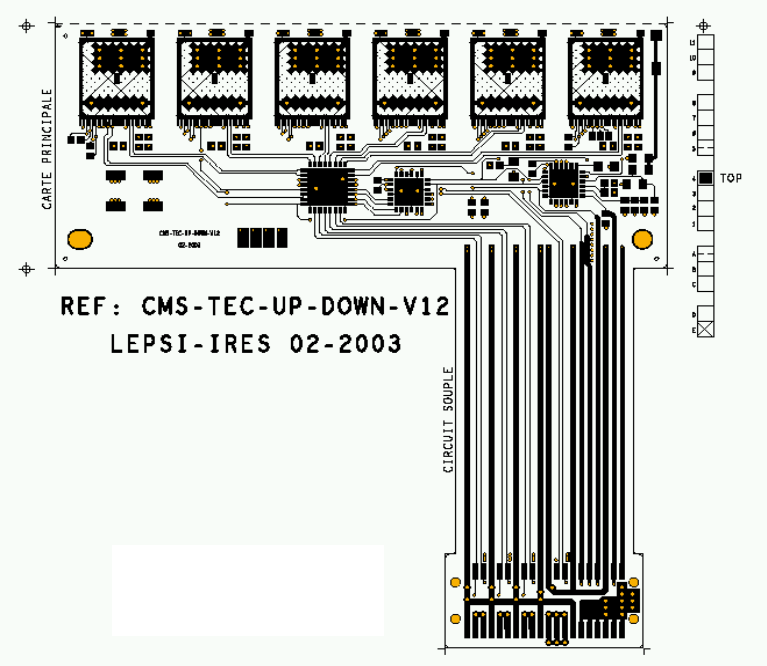
- Multiple functions
  - Electrical
  - Mechanical
  - Thermal
- Multiple constraints
  - Interface to pre-defined elements
    - Mechanical
    - electrical
  - Reworkable
  - Low mass
  - High reliability
  - Cheap

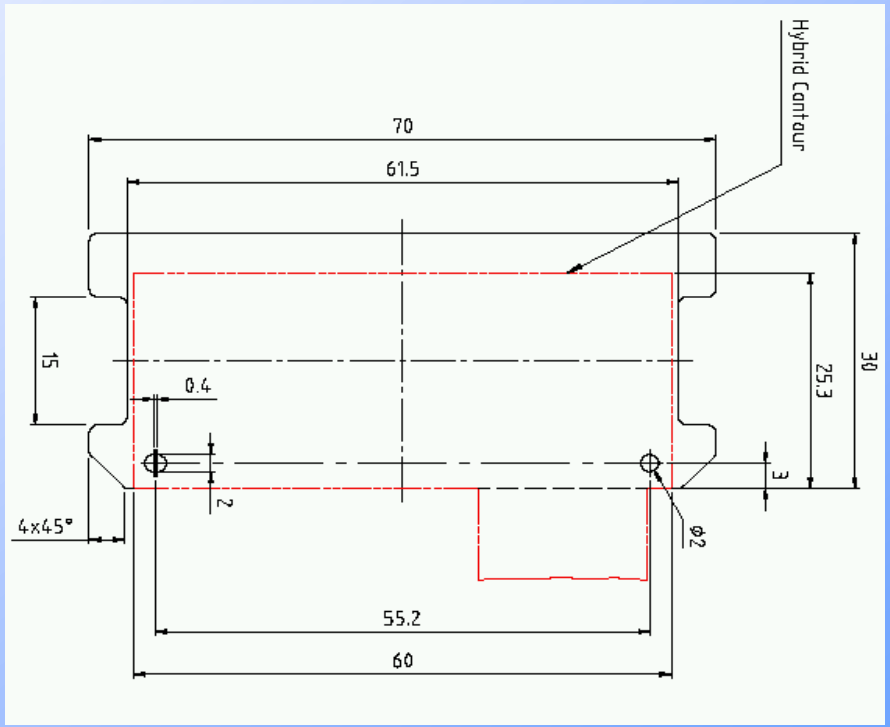


- Perceived as low profile, soft glue element

The Hybrid Layout

- 120μm min feature size
- Up to 768 electrical channels
- 17500 pcs



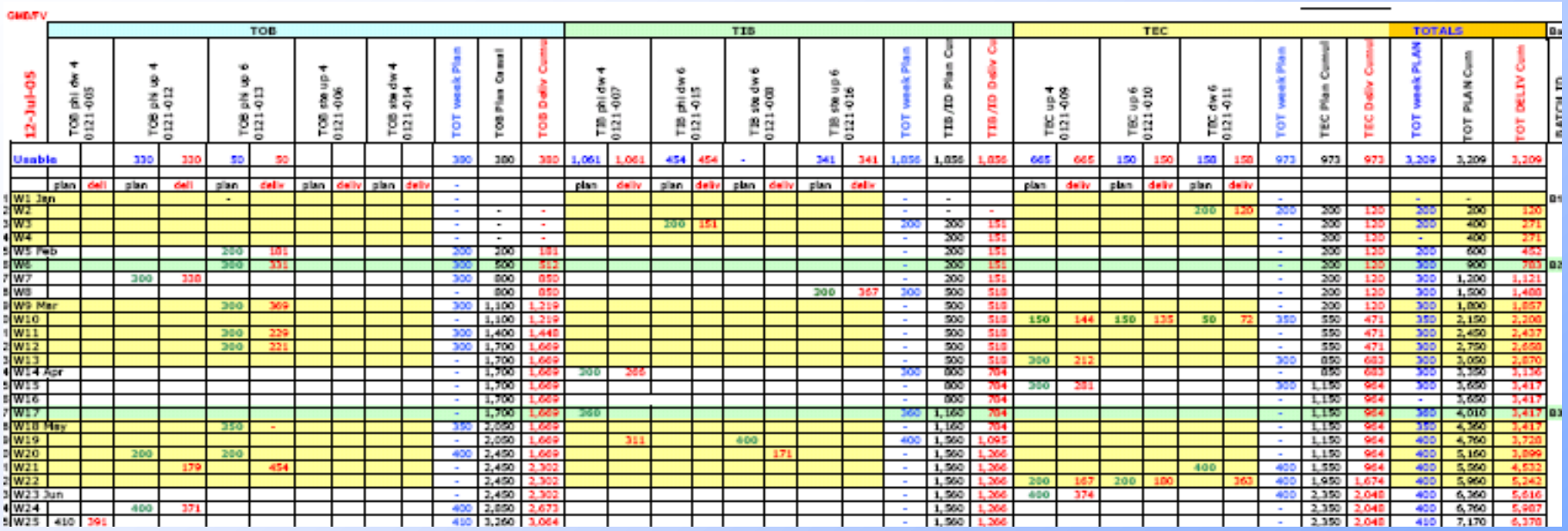


The Finished Hybrid

History

- Several technologies investigated
  - Thick film ceramic
  - FR4
  - Flex/Rigid
  - Flex
- Several teams with several opinions
- CMS-Tracker eventually converges on Flex solution
  - Project late start in 2002
  - Few companies involved
    - Design becomes technology driven
  - Chips and mechanics already frozen or well advanced
    - Constraints are hard
- Several design change requests from users
  - Resulting in several flavors and several modifications
- Several difficulties at production start
  - Technological
    - Circuit
    - Assembly
  - Organizational

Organizational difficulties



12-Jul-05	TOB phi dw 4 0121-005		TOB phi up 4 0121-012		TOB phi up 6 0121-013		TOB stw up 4 0121-006		TOB stw dw 4 0121-014		TOT week Plan	TOB Plan Cumul	TOB Deliv Cumul
Usable			330	330	50	50					380	380	380
	plan	deliv	plan	deliv	plan	deliv	plan	deliv	plan	deliv	-		
W1 Jan					-						-		
W2											-	-	-
W3											-	-	-
W4											-	-	-
W5 Feb					200	181					200	200	181
W6					300	331					300	500	512
W7			300	338							300	800	850
W8											-	800	850
W9 Mar					300	369					300	1,100	1,219
W10											-	1,100	1,219
W11					300	229					300	1,400	1,448
W12					300	221					300	1,700	1,669
W13											-	1,700	1,669
W14 Apr											-	1,700	1,669
W15											-	1,700	1,669
W16											-	1,700	1,669
W17											-	1,700	1,669
W18 May					350	-					350	2,050	1,669
W19											-	2,050	1,669
W20			200		200						400	2,450	1,669
W21				179		454					-	2,450	2,302
W22											-	2,450	2,302
W23 Jun											-	2,450	2,302
W24			400	371							400	2,850	2,673
W25	410	391									410	3,260	3,064

	TIB phi dw 4 0121-007		TIB phi dw 6 0121-015		TIB stw dw 6 0121-008		TIB stw up 6 0121-016		TOT week Plan	TIB/TID Plan Cu	TIB/TID Deliv Cu
Usable	1,061	1,061	454	454	-		341	341	1,856	1,856	1,856
	plan	deliv	plan	deliv	plan	deliv	plan	deliv			
W1 Jan									-	-	
W2									-	-	-
W3			200	151					200	200	151
W4									-	200	151
W5 Feb									-	200	151
W6									-	200	151
W7									-	200	151
W8							200	367	300	500	518
W9 Mar									-	500	518
W10									-	500	518
W11									-	500	518
W12									-	500	518
W13									-	500	518
W14 Apr	200	265							200	700	784
W15									-	700	784
W16									-	700	784
W17	360								360	1,060	784
W18 May									-	1,060	784
W19			311		400				400	1,560	1,095
W20						171			-	1,560	1,266
W21									-	1,560	1,266
W22									-	1,560	1,266
W23 Jun									-	1,560	1,266
W24									-	1,560	1,266
W25									-	1,560	1,266

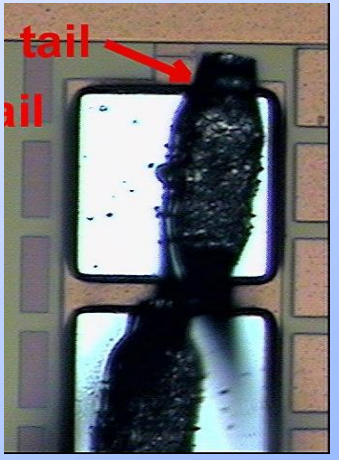
	TEC up 4 0121-009		TEC up 6 0121-010		TEC dw 6 0121-011		TOT week Plan	TEC Plan Cumul	TEC Deliv Cumul
Usable	665	665	150	150	158	158	973	973	973
	plan	deliv	plan	deliv	plan	deliv			
W1 Jan							-	-	
W2					200	120	200	200	120
W3							-	200	120
W4							-	200	120
W5 Feb							-	200	120
W6							-	200	120
W7							-	200	120
W8							-	200	120
W9 Mar							-	200	120
W10	150	144	150	135	50	72	350	550	471
W11							-	550	471
W12							-	550	471
W13	300	312					300	850	683
W14 Apr							-	850	683
W15	300	281					300	1,150	964
W16							-	1,150	964
W17							-	1,150	964
W18 May							-	1,150	964
W19							-	1,150	964
W20							-	1,150	964
W21					400		400	1,550	964
W22	200	167	200	180		363	400	1,950	1,674
W23 Jun	400	374					400	2,350	2,048
W24							-	2,350	2,048
W25							-	2,350	2,048

	TOTALS PLAN	TOT PLAN Cum	TOT DELIV Cum
Usable	3,209	3,209	3,209
W1 Jan	-	-	
W2	200	200	120
W3	200	400	271
W4	-	400	271
W5 Feb	200	600	482
W6	300	900	783
W7	300	1,200	1,121
W8	300	1,500	1,480
W9 Mar	300	1,800	1,857
W10	350	2,150	2,200
W11	300	2,450	2,437
W12	300	2,750	2,658
W13	300	3,050	2,870
W14 Apr	300	3,350	3,136
W15	300	3,650	3,417
W16	-	3,650	3,417
W17	360	4,010	3,417
W18 May	350	4,360	3,417
W19	400	4,760	3,728
W20	400	5,160	3,899
W21	400	5,560	4,532
W22	400	5,960	5,242
W23 Jun	400	6,360	5,616
W24	400	6,760	5,987
W25	410	7,170	6,370

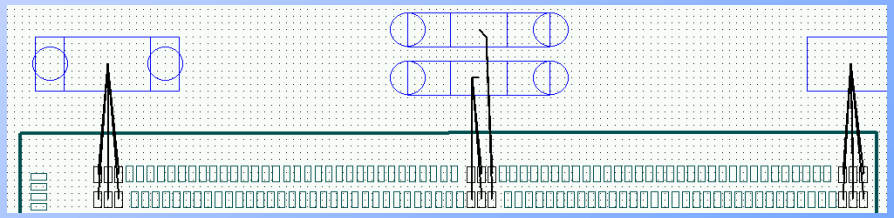
- 12 hybrid variants
  - transform a high volume production into a multi-batch logistic nightmare
  - Complex delivery schedule
  - All variants needed simultaneously
  - Difficult stock build up and management
  - Management of ancillary hardware becomes problematic (boxes, adapter cards, etc…)
- heterogeneous CMS community
  - Unclear internal definition of responsibilities
  - Multiple interfaces to company
  - Incompatibility between academic and industrial ways

Technological difficulties, assembly

- Bonding
  - chip pad structure optimized for ball bonding
  - Unsuited chip pad size
  - Irregular pad quality on circuit (and on chip?)
  - Special dicing requirement
- ➢ Large effort to optimize and maintain bonding quality, several production stops



- Mixed bonding at company and CERN
  - Chip loading accuracy +/- 22μm
  - No globe top possibility
- ➢ Long term bond adherence is a prime concern



- ASIC LPCC Package difficult to inspect
  - No boundary scan possibility
- ➢ Detailed analysis of all functional test results required

Technological difficulties, circuit

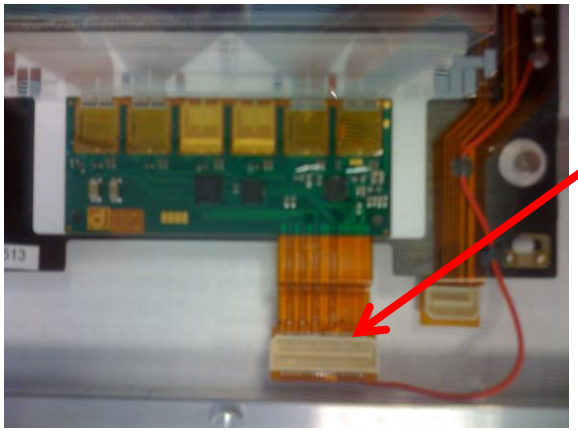
- Metal on flex
- Lamination on ceramic
- Via metallization
  - Hidden defect
- ➢ Fast production / Slow QA feedback
- ➢ Irreversible addition of value when mounting hybrid on sensor module
- ➢ Large effort to recover

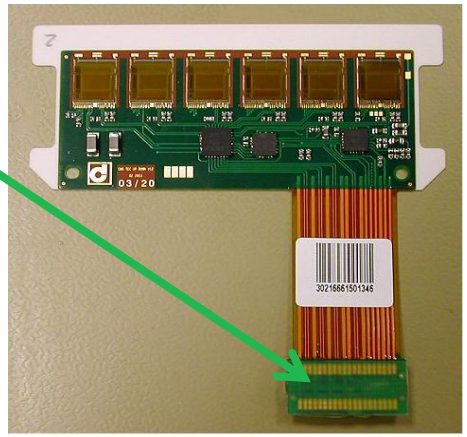
Recognizing the Tip of an Iceberg

- **A first, potentially serious problem:**

  Fragile solder joints from the Flex Cable to the Connector

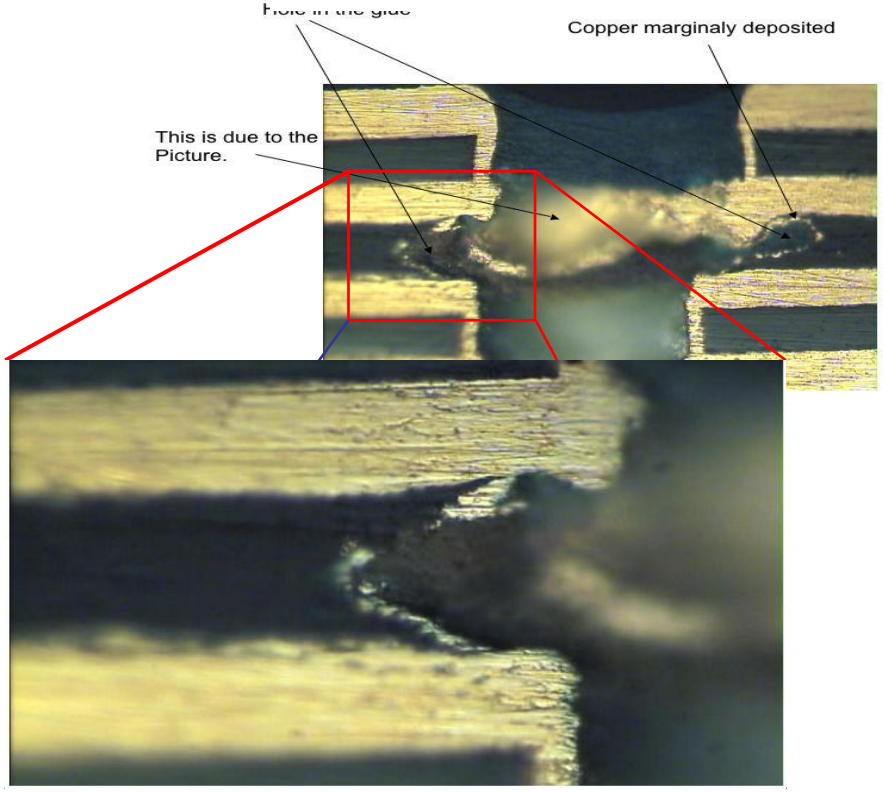
  - **The problem was not seen in the Qualification phase**
  - **But became apparent as soon as hybrids were handled, connected & disconnected for Testing**
  - **Production was interrupted, and resumed after re-qualification of hybrids with a stiffener behind the connector which resulted in robust assembly**





Recognizing the Tip of an Iceberg

- **A second, Far More Serious Problem:**
  Fragile Via Metallization



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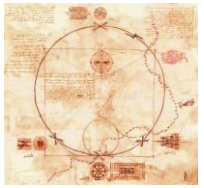
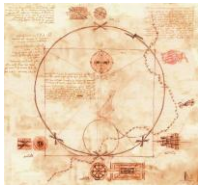


- **A second, Far More Serious Problem:**

  Fragile Via Metallization

- **What made this problem Potentially Fatal was that**
  - **The vast majority of vias had an electric contact and the Hybrids were initially fully functional**
    - As a result, the problem was not seen during the Qualification phase, and only became apparent once a small number of initially good hybrid failures were scrutinized in detail
  - **The vias, however, were fragile and a large fraction would inevitably fail with time**
    - All hybrids produced with this process had to be rejected, and all modules assembled with these hybrids were un-useable!
  - **By the time the problem was fully recognized, some 8'000 hybrids had already been produced, and many modules assembled with them**
    - The impact on the schedule was about a year
    - And the financial impact amounted to several % of the overall cost of the Silicon Strip Tracker

Recognizing the Tip of an Iceberg



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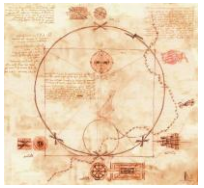
  - **The vias, however, were fragile and a large fraction would inevitably fail with time**
    - All hybrids produced with this process had to be rejected, and all modules assembled with these hybrids were un-useable!
- **As bad is this was, it could have been A Lot Worse!**
  - **Had this very small rate of apparent failures not been immediately acted upon and recognized for what is was, the Iceberg could have sunk us**

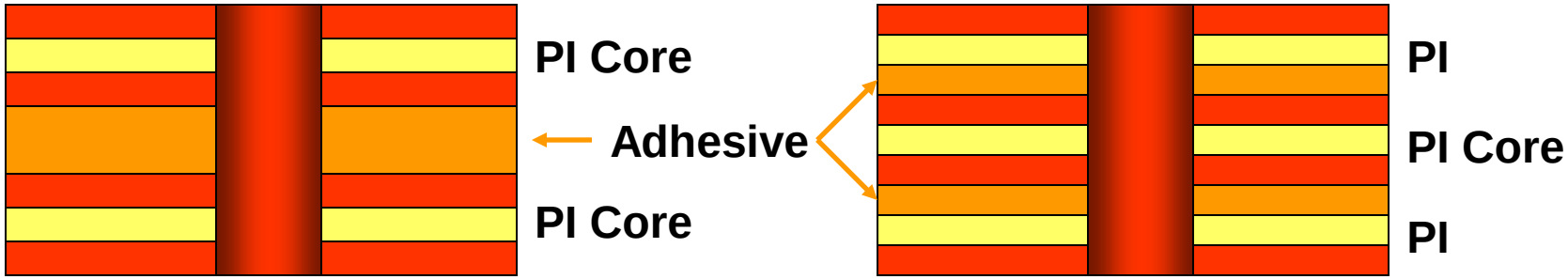
Steering the Project back onto a safe course

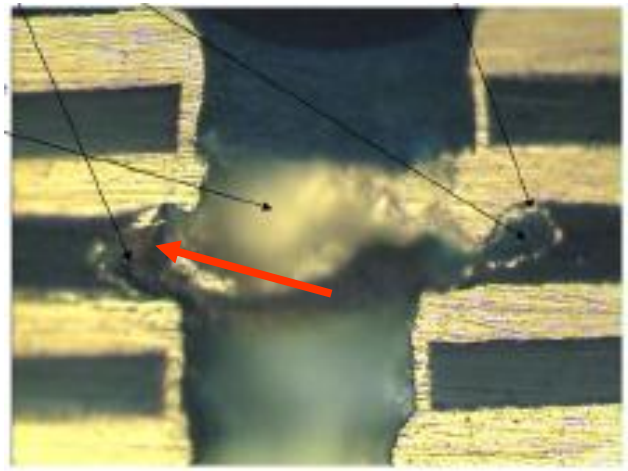


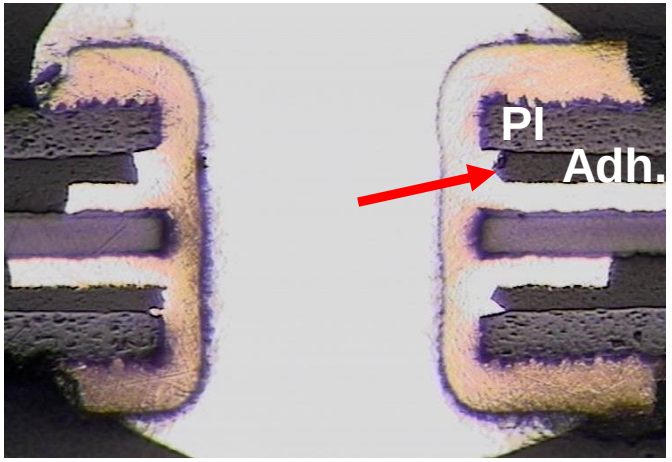
- "A good QA plan should avoid bad surprises before getting to this point"
  - What went wrong?
  - Quality improvement
- Improve Organizational Structure
  - Strengthen Hybrid Project Management
  - Clarify and Formalize lines of Communication between CMS and Suppliers
- Analyze cause of via process failure, and identify a solution
- Establish QC protocols for prompt quality feed-back at each process and assembly step
  - Reduce reliance on delayed feed-back at end of long process pipe-line
  - Ensure All relevant quality parameters are Identified and Controlled
    - Test structures etc.
- A Cautious and deliberate re-Qualification and re-Start of Production

Steering the Project back onto a safe course

Original ➔ **Improved**

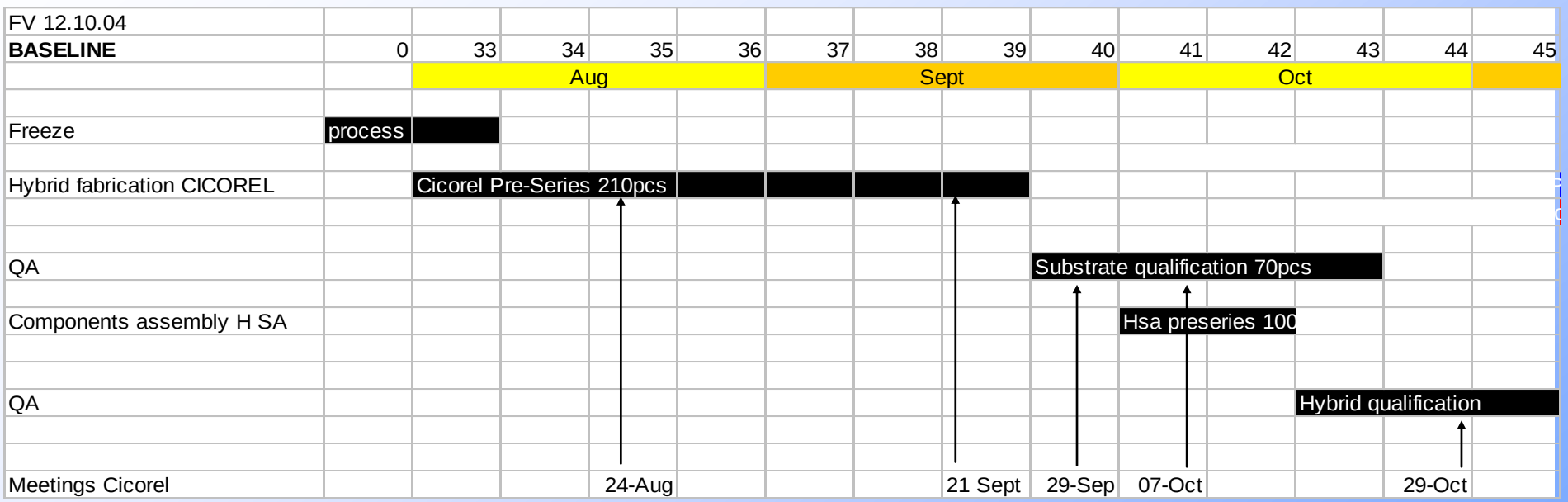






Test Structures with daisy-chains on 2'800 Vias implemented and Systematically Controlled for each plate

Qualification Schedule



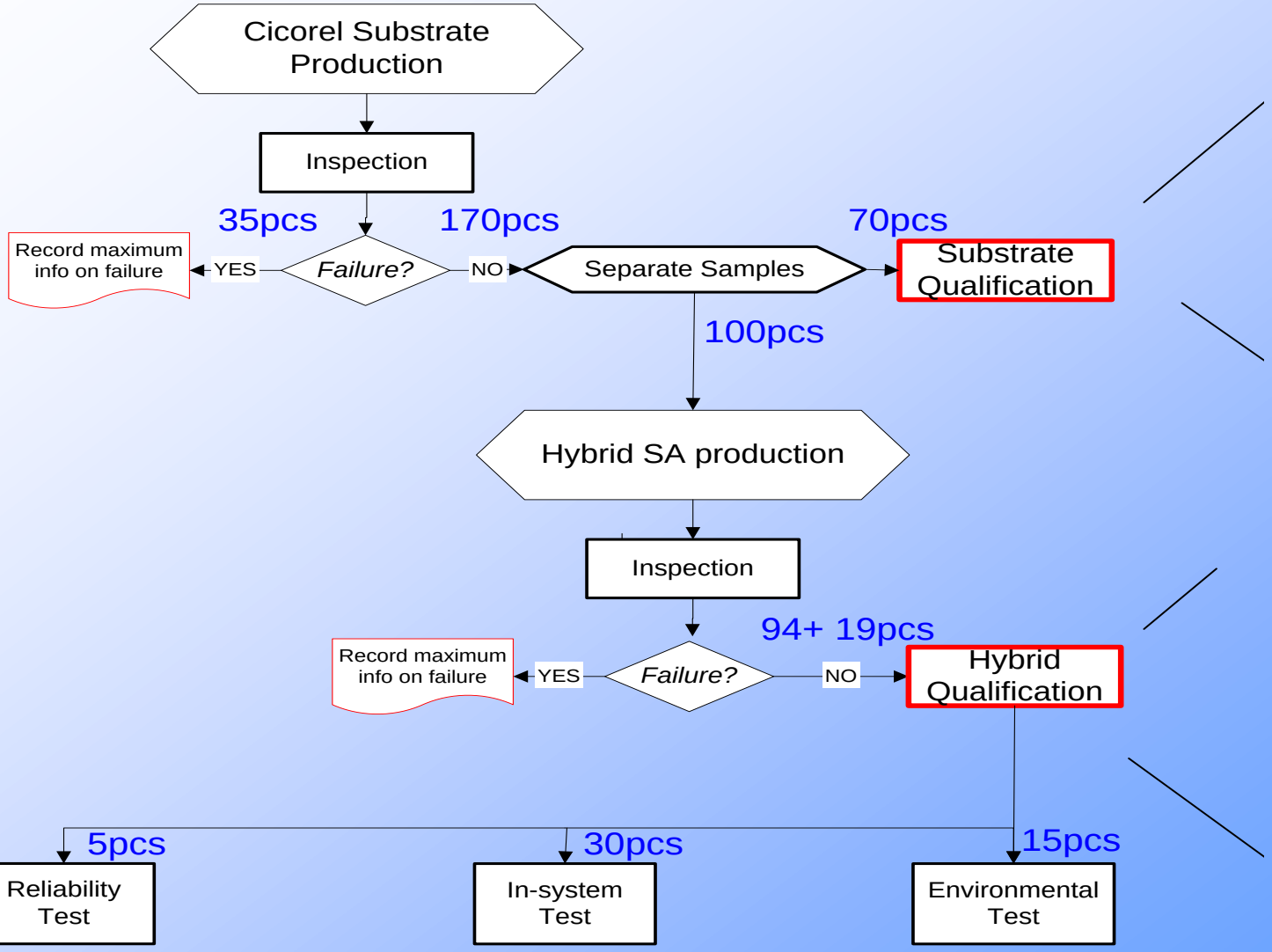
- 3 Quality Audits (29Sep Cicorel, 7Oct Cicorel, 29Oct H SA)
- Substrate Qualification (Strasbourg and CERN)
- Populated Hybrid Qualification (Strasbourg and CERN)

Quality Audits (2xCicorel, 1x H SA)

- Process flow and control points reviewed and frozen
- Specification and control pass/fail criteria synchronized
- Documentation defined
  - Passed AND failed devices documented
- Device traceability achieved

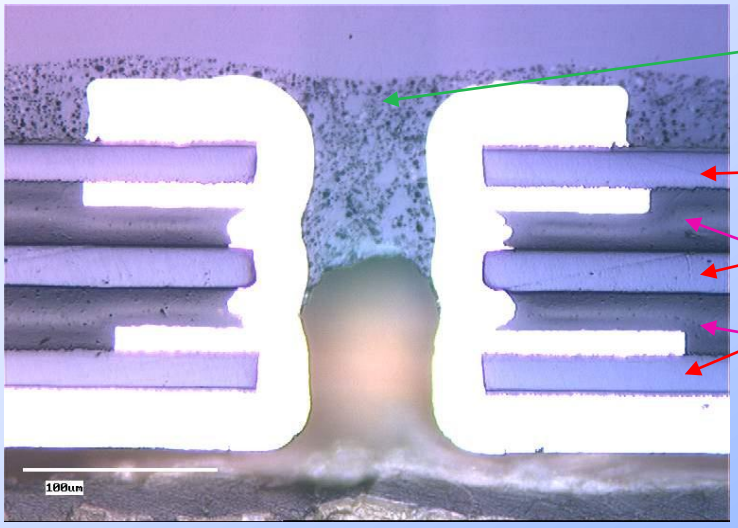
- CMS qualification procedure defined, documented and presented

Qualification flow



Substrate qualification

- The only problems found were a minor thickness uniformity problem, presence of foreign material on a bondpad, a small zone of poorer quality bondability, and the presence of rather large metal bumps on some pieces. The latter two should be surveyed closely in upcoming pieces from the same batch and from future batches.
- All other measurements and checks showed very good overall quality and the results within specifications.



Solder mask

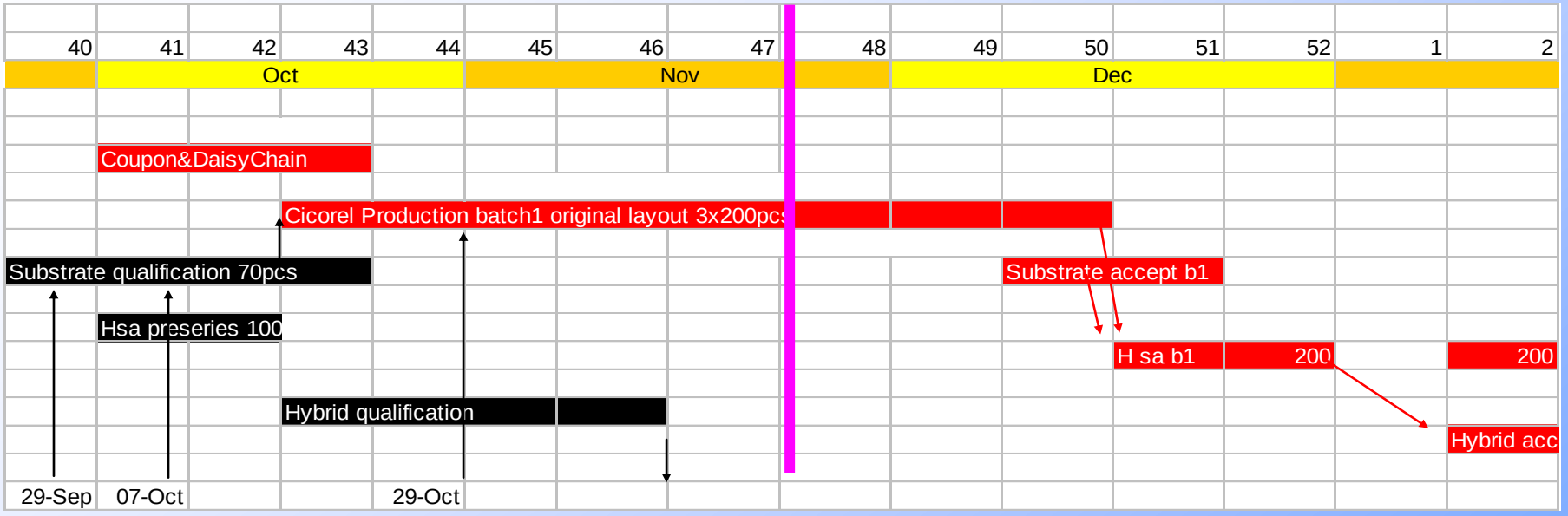
Kapton

Glue

100 µ

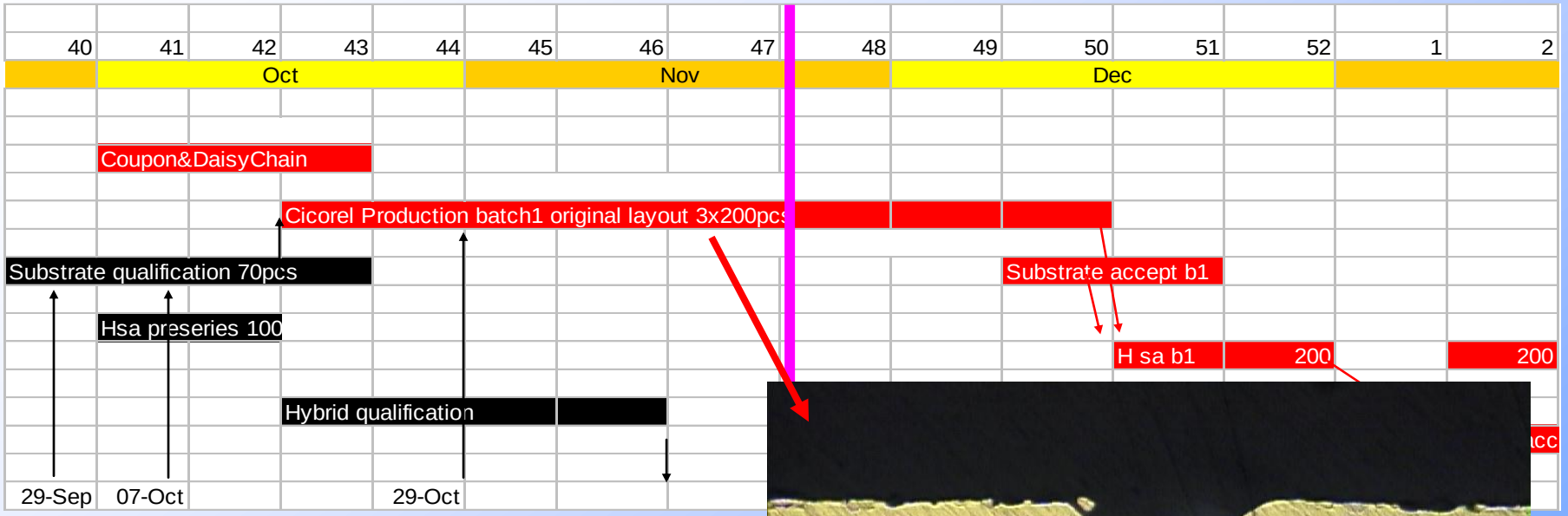
Substrate qualified

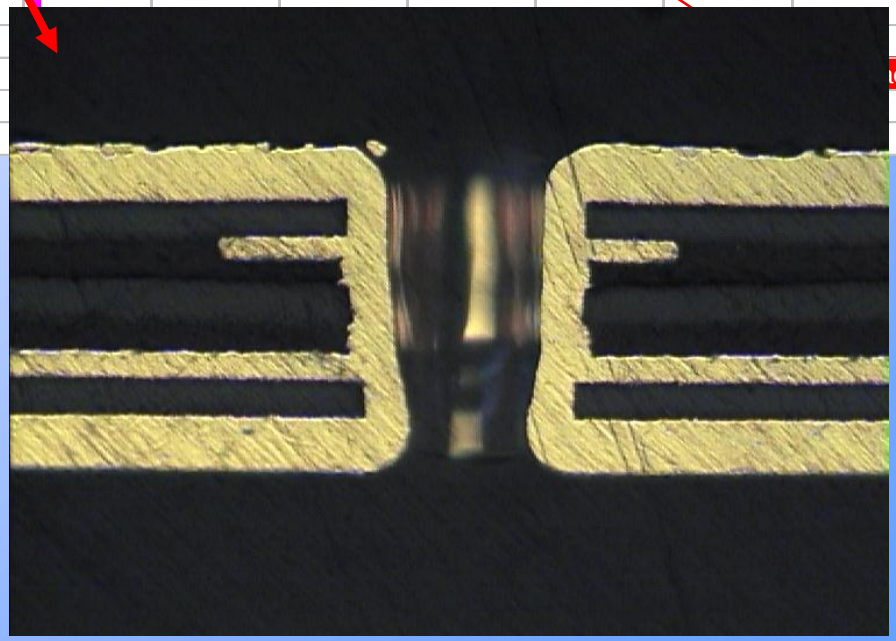
FEH Production: a) Cautious Re-Start



- Small production batch b1 launched based on substrate qualification
- Original layout (120um vias) plus test coupon and daisy chain
- 10 weeks turnaround time
- Deliveries are Known Good Hybrids
- Throughput is half expected final capacity
- TOB, TIB and TEC types

FEH Production: a) Cautious Re-Start





- Vias from b1 successfully metallized

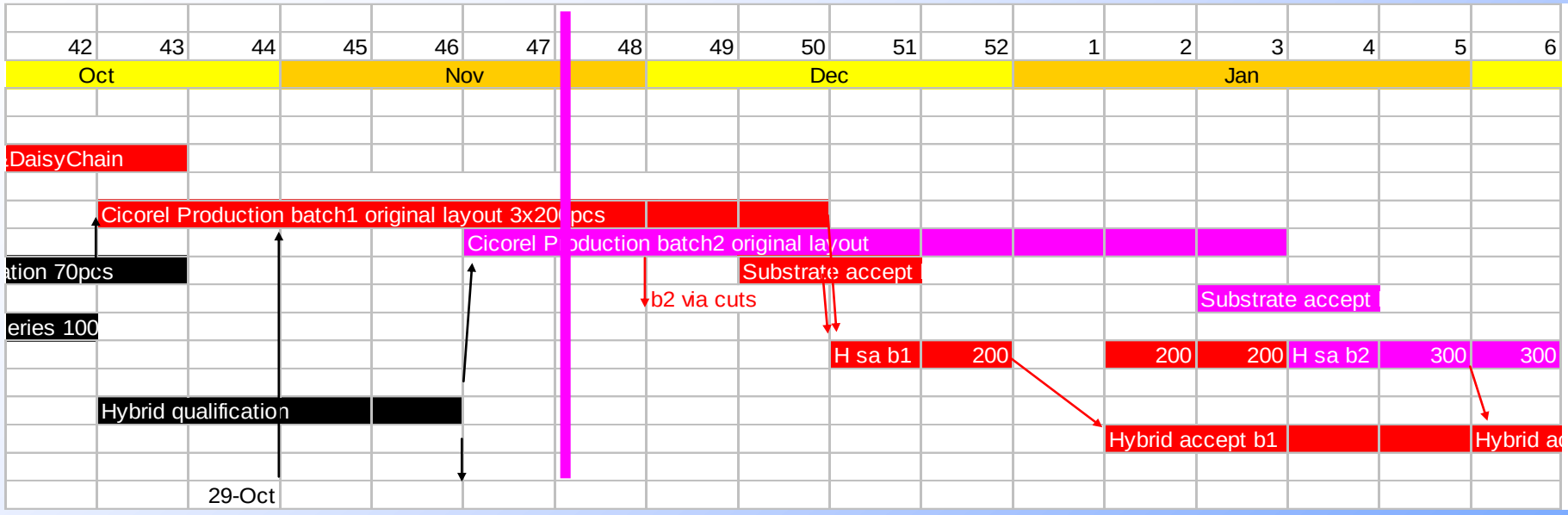
Hybrid Qualification

- Overall the quality of component loading and bonding was good and comparable to the previously delivered batches with the exception of the bonding quality problems noted below.
- The LPCC (PLL, MUX and DCU) chips have poor soldering aspects. This is due to poor chip packaging and could be a long-term QC issue (reliability).
- None of the failed hybrids in the electrical (FHIT) test was found to be attributable to either Cicorel or H SA

- Bondfoot deformation on APVs found to be large. Slightly reduced bond pull strength averages and significantly larger RMS, especially for upper APV control bonds. Many low strength wires found. This result does not pass the bonding specifications.
- 20 unloaded circuits kept aside at CERN were given to HSA for a test of improved bonding quality. These were loaded, bonded. 19 good pieces were delivered to CERN.
- Results of the 2nd try show improved quality (just passes specifications) although further improvements would be desirable. The bonding quality will need to be monitored more closely than in the past.

→ **Hybrid qualified, coaching will be required**

FEH production: b) Ramp up



- Production batch b2 launched based on hybrid qualification
- Throughput limited by Cicorel to 300KGH/week
- ~10% contingency built-in (300-350KGH)
- Discussion on capacity increase in January
- TOB TIB TEC distribution matching construction schedule and priorities

Conclusion

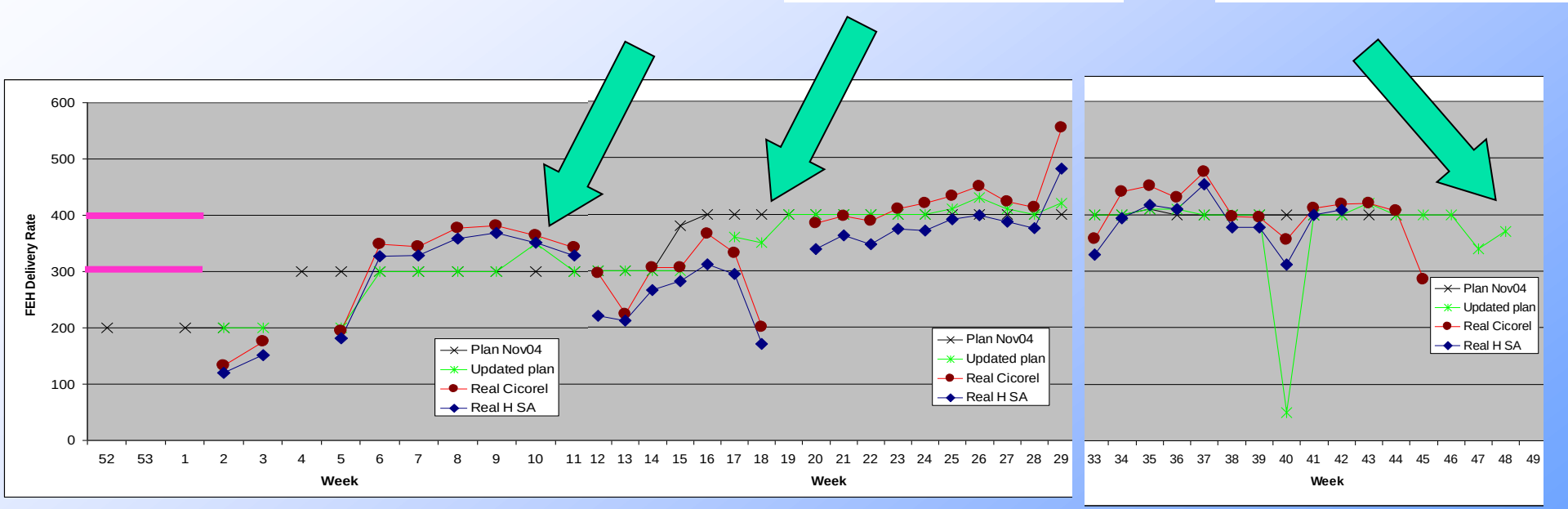
- Process under control at Cicorel
- Quality control and Quality assurance implemented
- Documentation available at:
  - EDMS FE-Hybrid Electronics: CMS-0000008151
- Qualification
  - Substrate: complete
  - Populated hybrid: partially complete
    - Long term tests on-going
    - Module-level tests on-going
- Production re-launched
  - Low speed delivery in January
  - Ramp up in February
- Major effort from all parties (incl. Industry)
- Still a long way to go
  - last delivery Nov 05
- Past still haunting us
  - Need to build confidence and stability
  - Need to settle commercial claim

Weekly H SA deliveries

Quantity drop

Delivery stop

Production End



Summer break

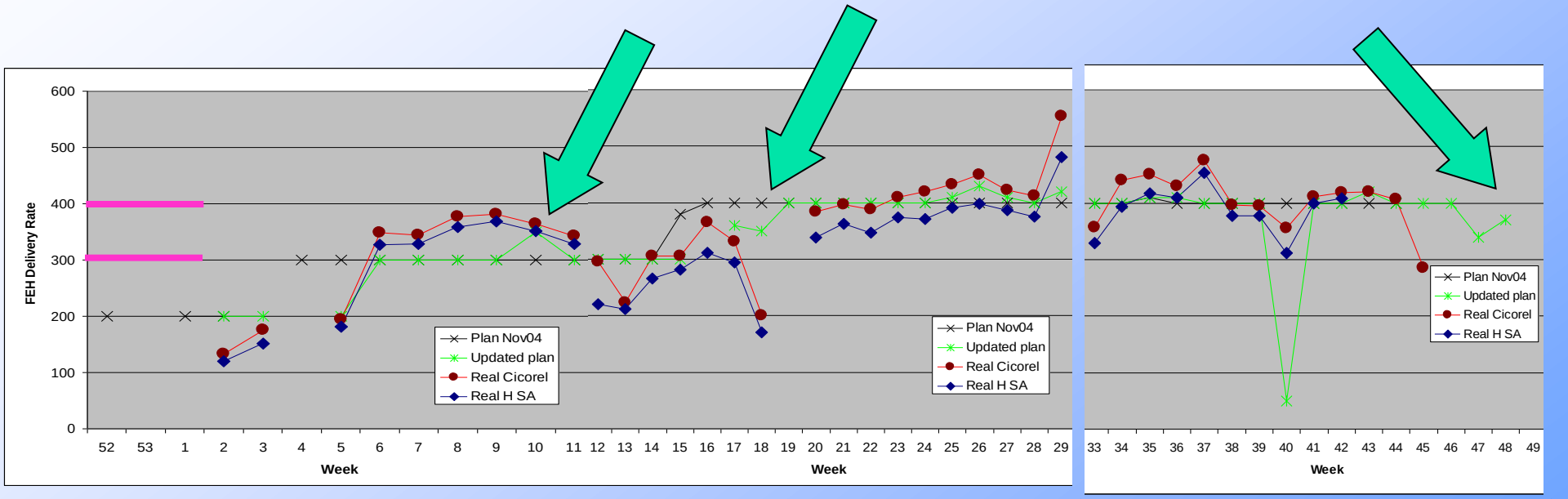
Winter break

Weekly H SA deliveries

Quantity drop

Delivery stop

Production End



OUFF…

Summer break

Winter break

CMS Tracker Hybrid Experience: a user and a manufacturer perspective

- A User:

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On behalf of the CMS collaboration

- A Manufacturer:

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Anne-Sophie Golsong agolsong@cicorel.ch

User recommendations

- **Hybrids must be part of system level design from the start**
  - Define and advertise hybrid related constraints early
  - Include hybrid experts in system-level discussions
- **Hybrids for large scale detectors must be designed for volume manufacturability, not for cutting edge performance**
  - Avoid state of the art technology
  - Add margin wherever possible
  - Limit variants
- **Hybrids must be designed for testability, with direct feedback possibility to production process**
  - Include panel-level test structures and chip-based test schemes
- **Production ramp up must be slow and allow full qualification**
  - Count on multiple steps from development to production
- **QA and QC must be robust with rapid feedback possibility**
  - Manufacturer and user QA schemes must be synchronized
- **Organizational structure must be clear and well defined.**
  - Members of the structure must trust each other and communicate frequently.

Manufacturer Recommendations

- Technology driven projects should involve early, a team of experts, where each step of realization and manufacturing are represented.

  Research-Development (with different industries)-Product management-Testing-Implementation.

- Define a team with a project leader, open and multi skills
- Always think best case, worst case. Find agreement with all parties involved.
- Be aware that a theoretical solution needs an industrializing expertise and consideration

Manufacturer Recommendations

- Consider intermediary Quality controls in manufacturing processes (quick failure reactions, statistics, preventive actions)
- Consider time for prototypes and corrective actions before definitive launch
- Guarantee base material continuity standard
- Maintain constant communication and working teams

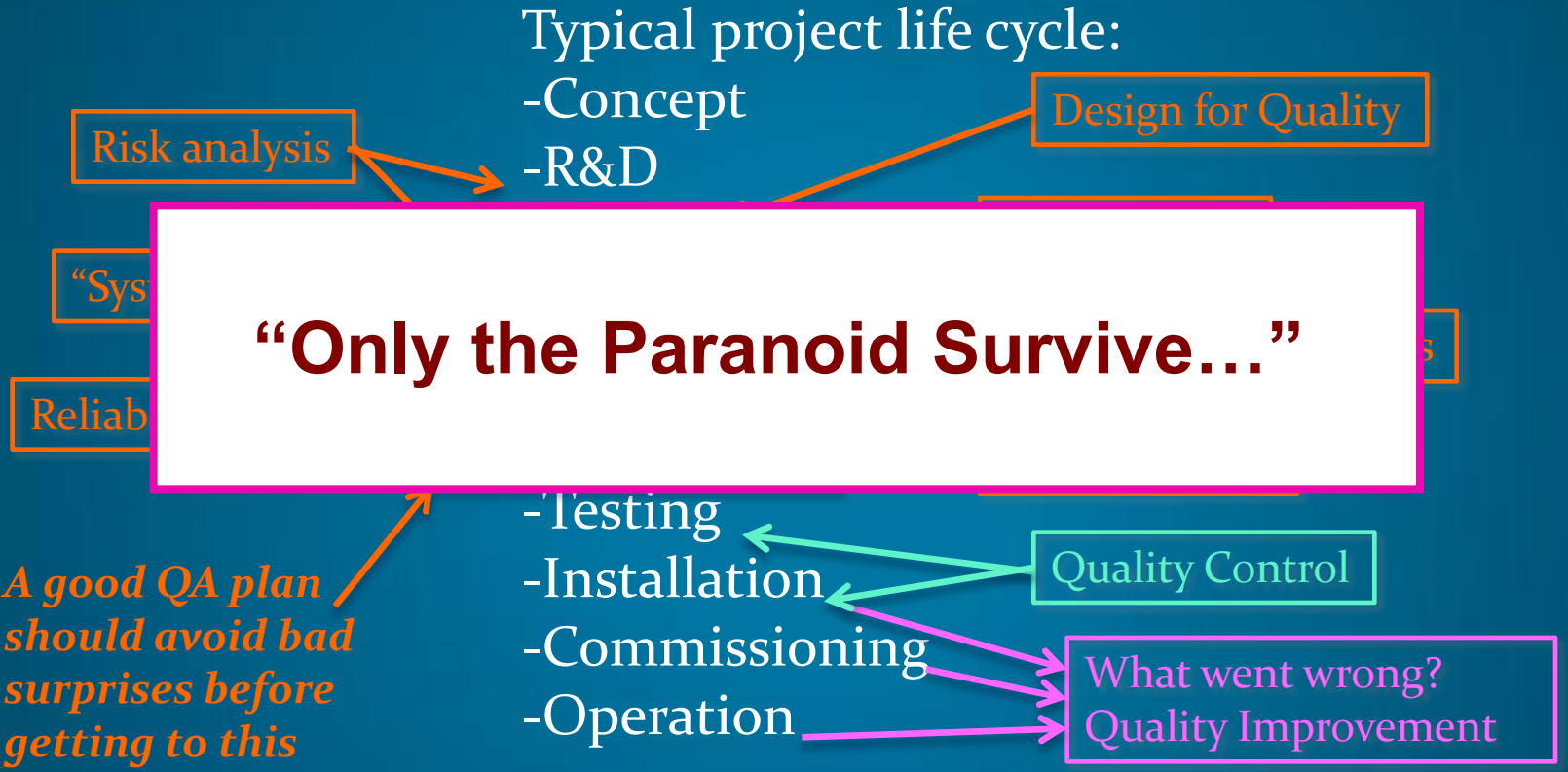
- Work together with a competent partner
- **Get PCB manufacturer involved at an early stage**
- Share application and utilization of PCB
- Follow design rules and discuss possible areas of concern (reduce risk)
- Learning cooperation
- Allow enough time for prototype and design revue
- Use dual sourcing or dual lot strategies

- Risk assessment
  - What manufacturing processes are limiting?
  - Are multiple suppliers available? (2nd Source)
  - Are special materials used? (lead time)
  - Is the supply chain covered?
  - Invest time in ramp readiness!
  - Share information with supplier!

→ Can be Contradictory to Tender Process

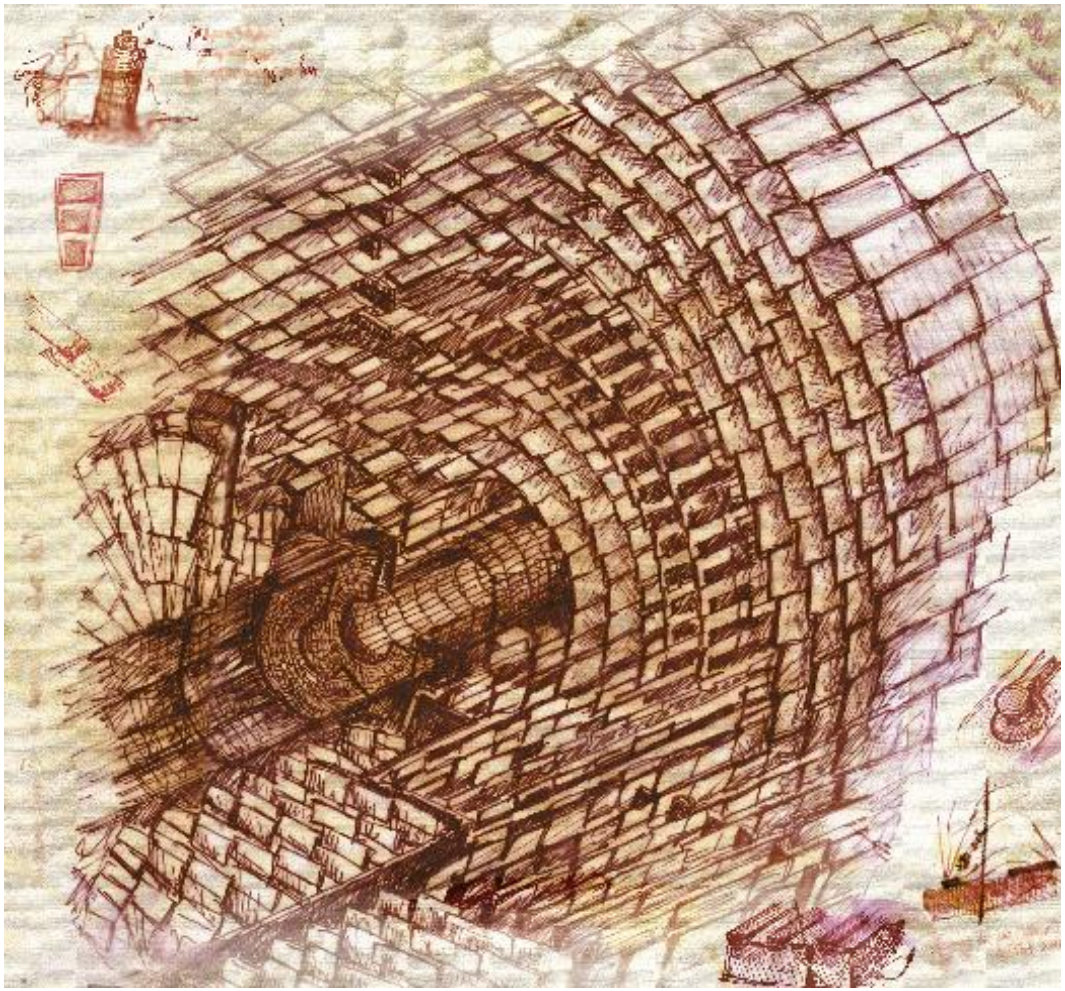
What elements of QA are important in a project?

In the past: select some elements as considered useful for our QA planning

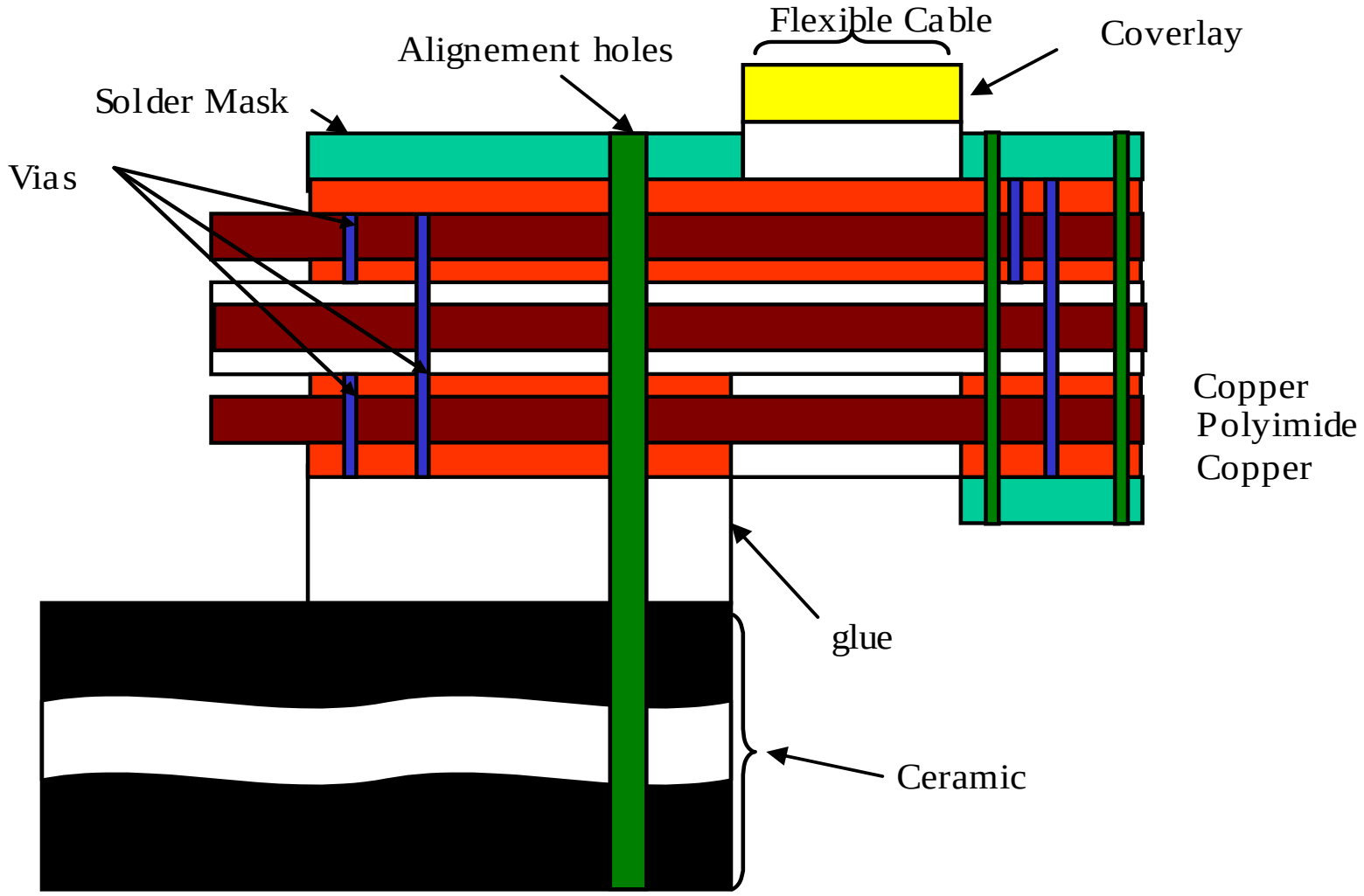


Increased complexity, cost and long-term reliability required of silicon detectors imply a need to consider all these elements in QA planning.

Hybrid Quality Issues for Present LHC Trackers: The CMS Example…



The Hybrid Layup



Technological difficulties, circuit

- Metal on flex
- Lamination on ceramic
- Via metallization
  - Hidden defect
- ➢ Fast production / Slow QA feedback
- ➢ Irreversible addition of value when mounting hybrid on sensor module
- ➢ Large effort to recover