Summary Talk

Paula Collins
nd CERN

Usual caveats

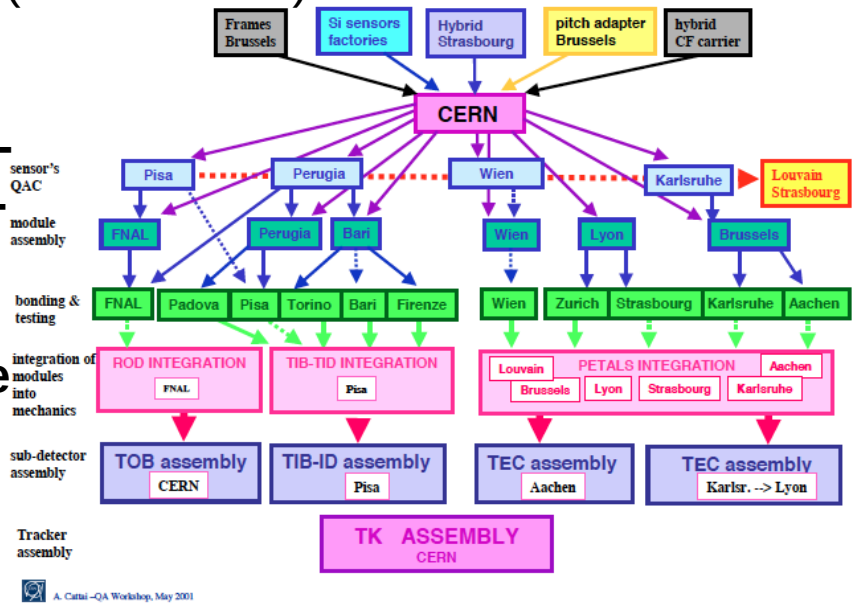
- 1000 slides in 2 packed days
- Luckily there is no way I can do justice or represent even a fraction fairly
- So here come some personal impresssions…

10 years ago…

This was music in my car (at least, that I listened to from time to time)

"1st Workshop on Quality Assurance Issues in Silicon Detectors", CERN, 17-18 May, 2001; CERN-Proceedings-2001-001 (page numbers are given in the table below)**.**
A paper-copy of the proceedings can be ordered from our Secretary: Susan-Ferrand Cousins

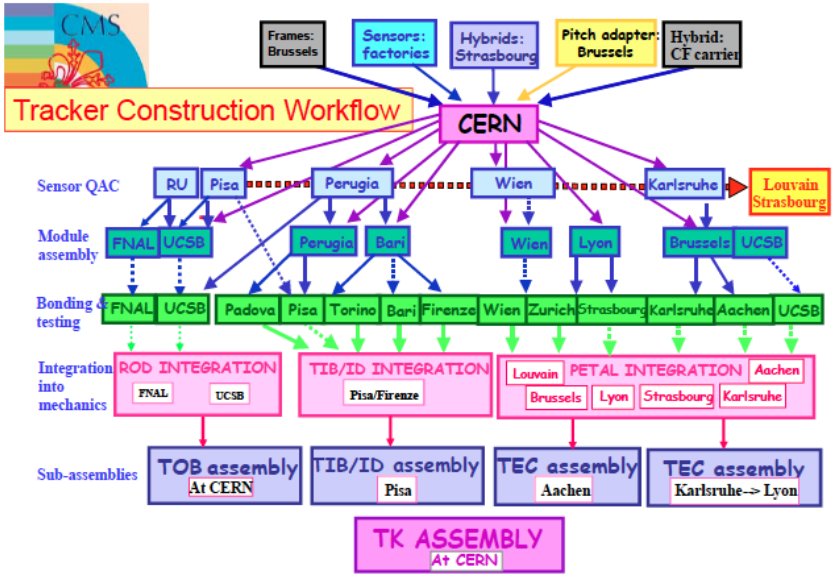
And this was the CMS flow chart (Ariella Cattai)



Today, what has changed?

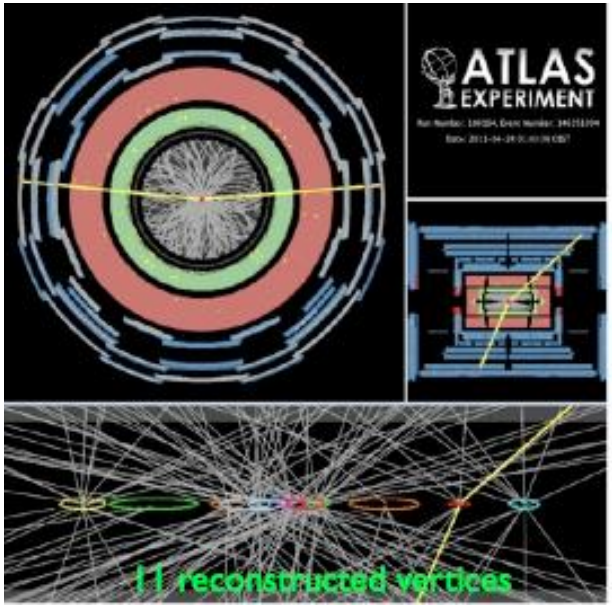
Music in my car has evolved a (little) bit

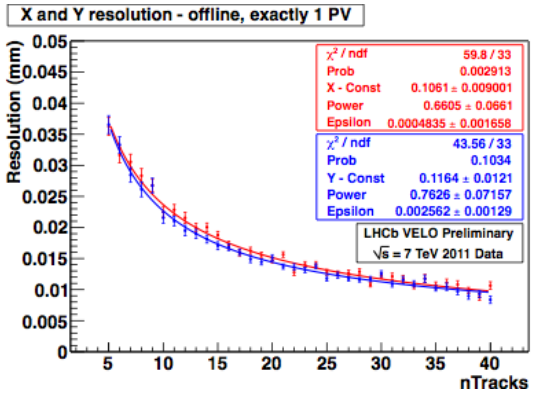
And this is the CMS flow chart (Marco Mescini)

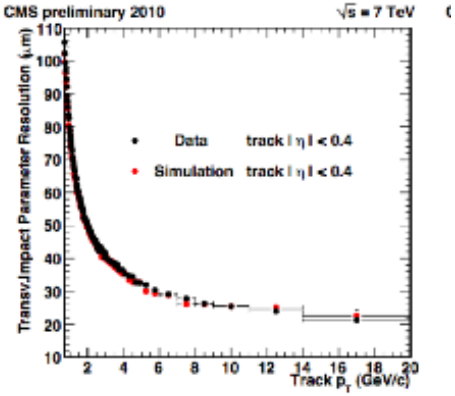


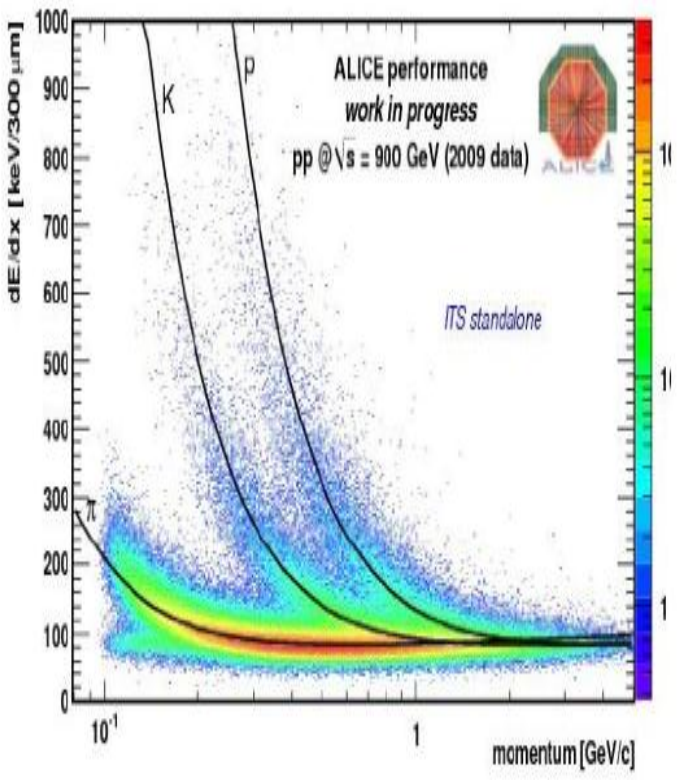
Workshop on Quality Issues in Current and Future Silicon Detectors from Thursday, November 3, 2011 at **09:00** to Friday, November 4, 2011 at **18:00** (Europe/Zurich) at **CERN (Filtration Plant)**

We have the statistics to assess the QA









And are in the happy position of knowing that things worked out (in general) – the silicon detectors are delivering LHC physics

How to judge QA performance?

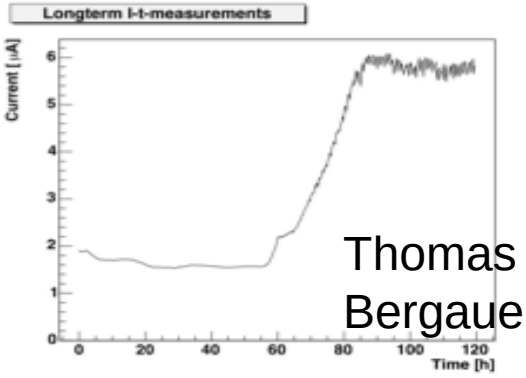
How are our assessments based on reality and how much on a warm fuzzy feeling

- "Hamamatsu sensors are good!"
- "Splices are risky!"
- "DSSDs are more risky than SSSDs!"

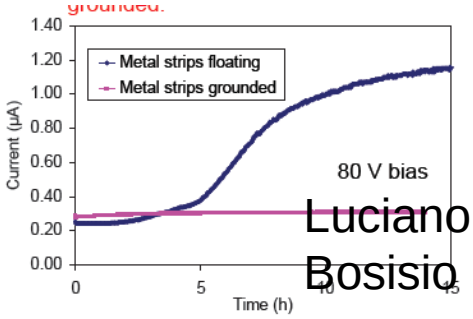
- Who is willing to talk about failures?
  - When they become famous
    - Exploding bus bars
- Does a more careful QA delay the project? (Yes, especially if you find something bad you should not ignore)
- Overwhelming evidence from this workshop that the process of testing was not destructive
- What is a proper risk analysis (10^{-8} for bad splices….)
- ALICE: "A few thousand double-sided sensors represent a practical limit to what can be tested without fully automated systems"

Some focal points from this workshop

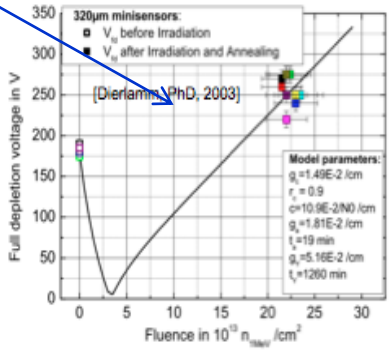
- Full Industry participation – wonderful input!
- Elements of quality which are general and which apply specifically to a silicon detector – what's special about our case?
  - Interaction between physicists and industry; production and assembly split in different ways between the institutes
  - Time dependence – under control of institutes and manufacturer (don't change any processing/packing/supply parameters during production phase) Alan reminded us that detectors must function for 10-20 years
  - Should there be intermediate radiation steps
  - Is it more typical for physicists to be "artisanal"?
- Not limited to quality control: project quality
- Learning from each other still one of the hardes things to do; repeat problems seen from differer groups

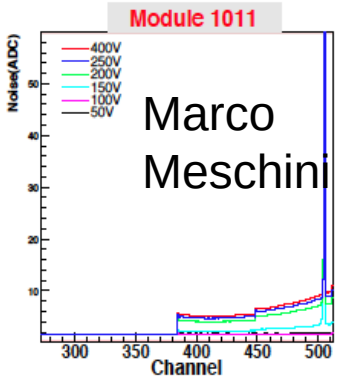


Thomas Bergauer



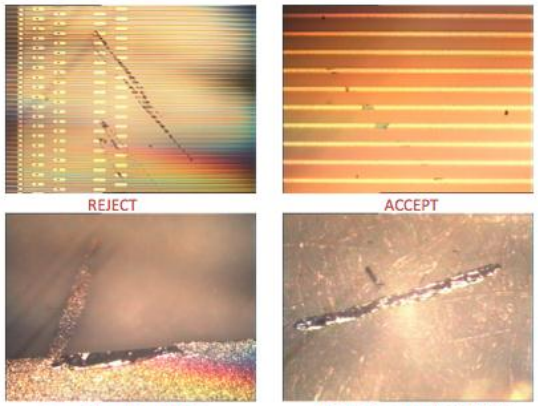
Luciano Bosisio

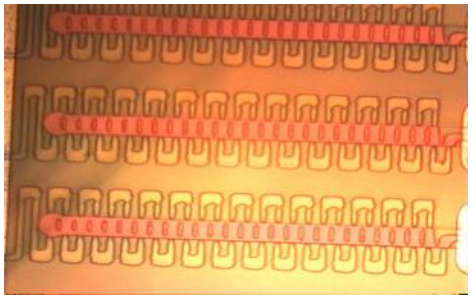




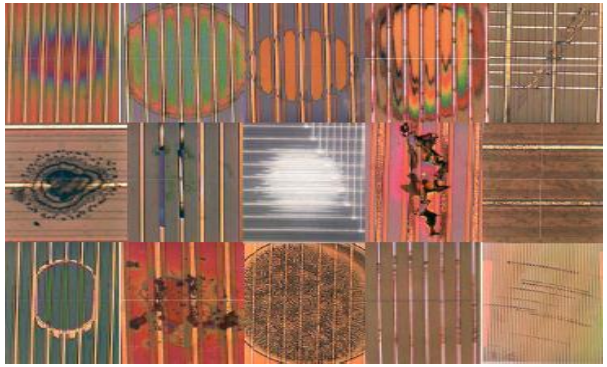
Marco Meschini

Rogue's gallery: some usual suspects



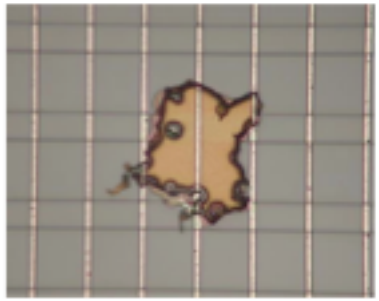


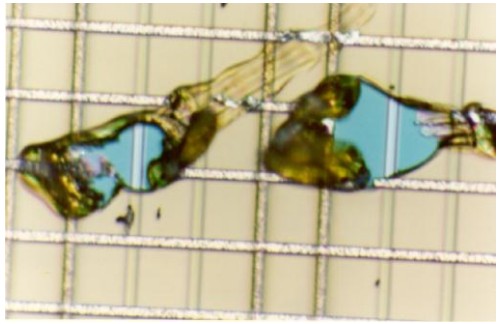
Open Strip:



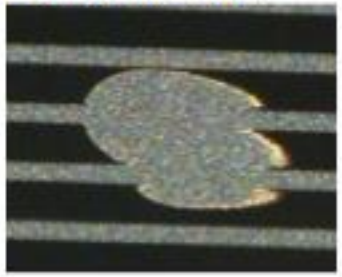
Metal short

Open implant:



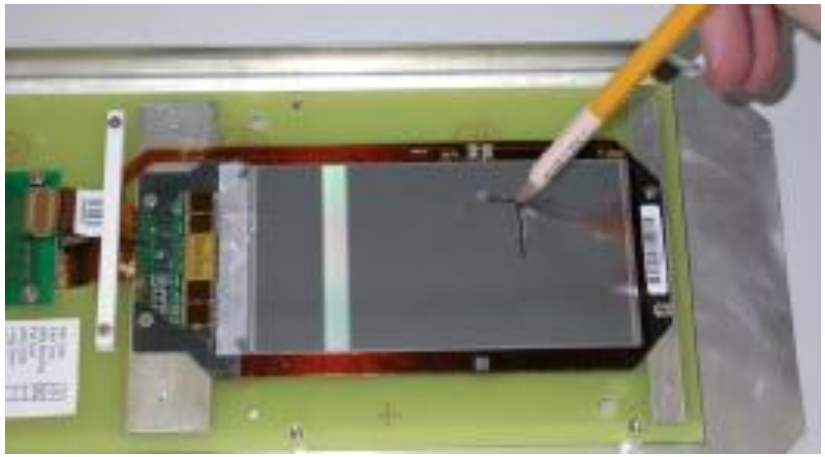


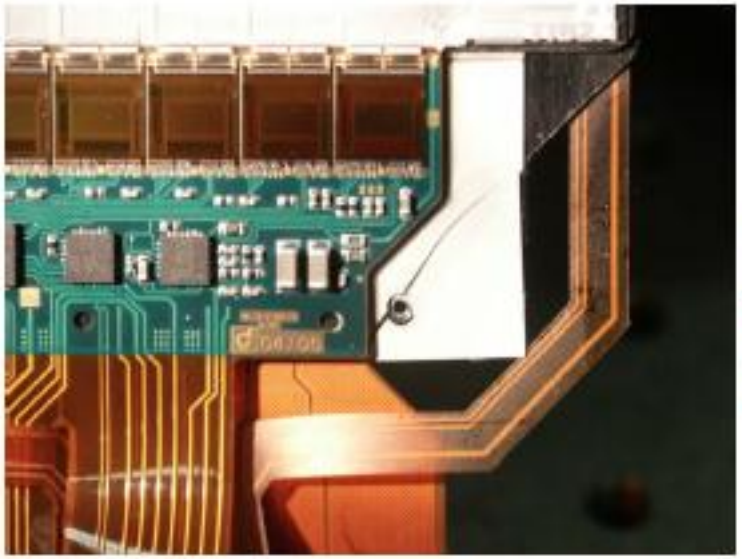
Shorted Strip:

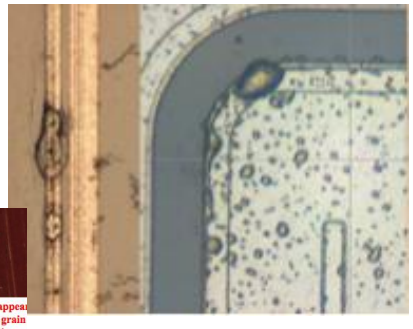


Two pictures here
from 2001 – which ones?

And some nice shockers!

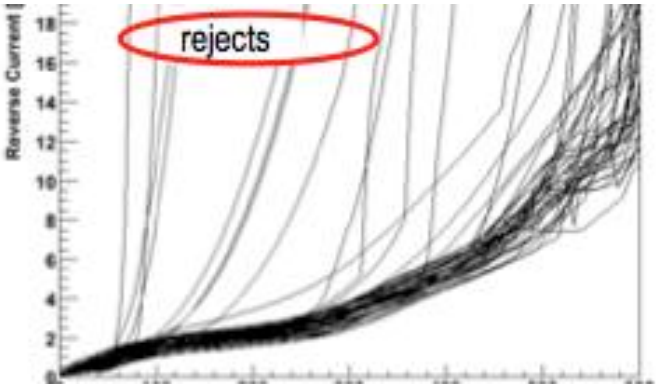




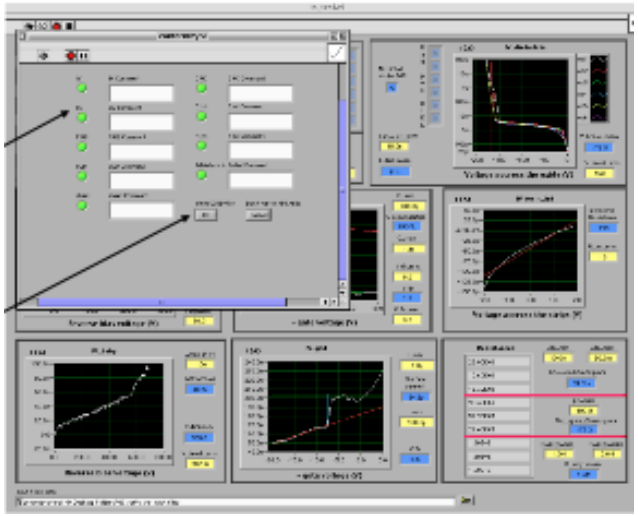


Kapton cracks
In CMS and ATLAS,
Use of stiffeners

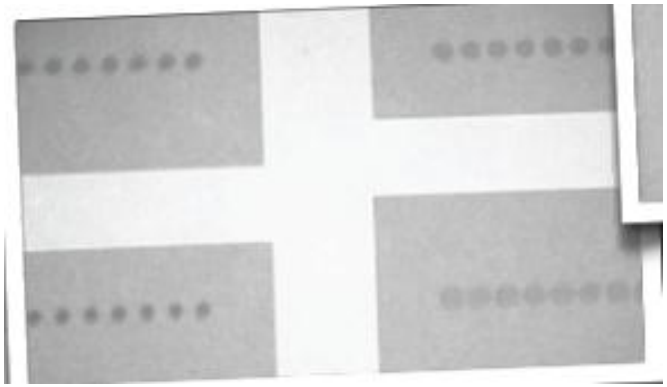
Beautiful test results



Classic signpost: IV behaviour



Highly automated CMS strip testing

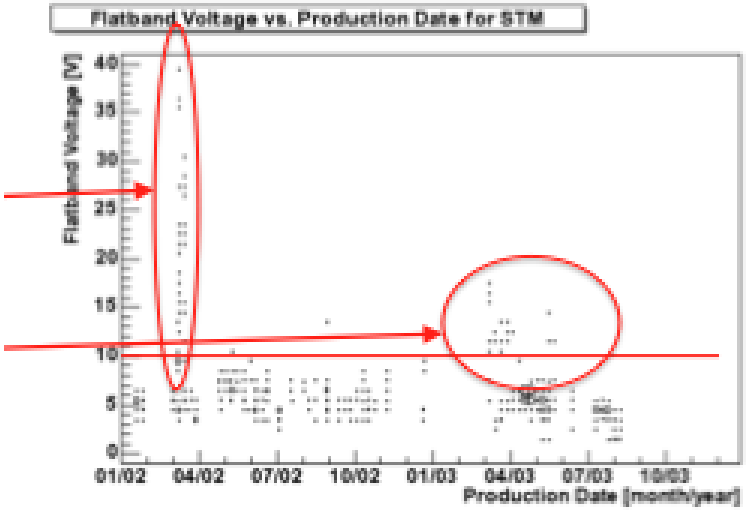


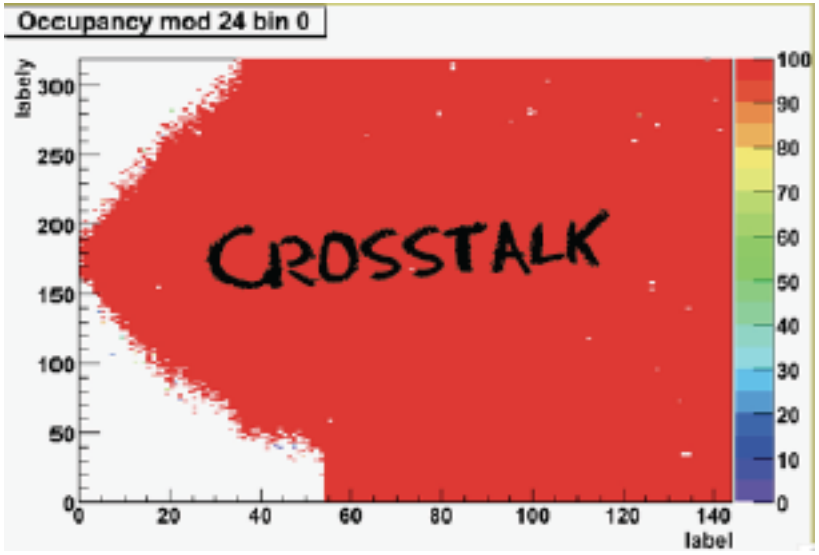
X ray images of bumps

Detection of metal shorts & breaks for ATLAS

Many special insights

- Crucial importance of databases
- High flat band voltage
- Cross talk – beautiful technique used extensively for ATLAS pixel testing
- Bump resistance turned out to be a critical check also (just like the LHC splices…)



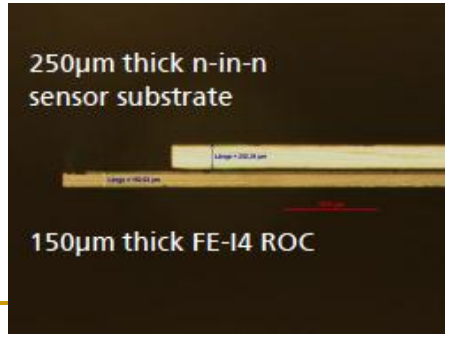


- Issues here have been cross-

Special thanks to our external contributors

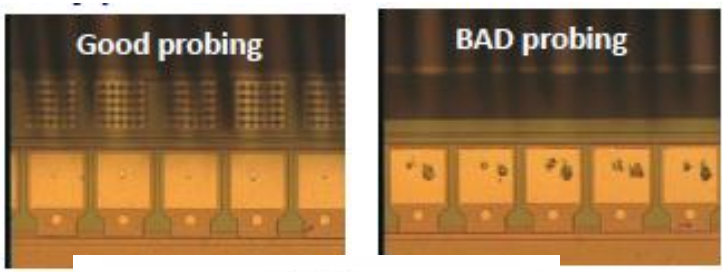
- NASA
  - Independently funded QA authority
  - Risk assessment feedback to management in order to make informed choices
  - Parts control board (EEE) established such that a certain component used in environment A is not shifted to an inappropriate application
  - Parts from resistors/capacitors (=sensors) -> space shuttle engines (=silicon trackers) considered
- Our own vendors: VTT, IZM, Hamamatsu, are active R&D partners
  - Special insight into process flow and quality control
  - New techniques
    - Stealth dicing, slim edge
    - Automated pick and place
    - Carrier wafers for thin/small items
    - …

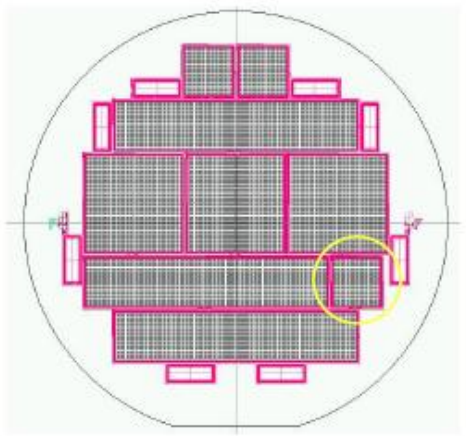
Good communication after solving some video QA issues…



Bump bonding : industry feedback

- Highlights enormous jump in contamination demands; scratches and particles which are fine for strips are not now acceptable
- Fast feedback loop desirable
- Some heartfelt appeals for interface between designers, packaging houses: passivation of both sides helps with bowing issues, recommendations for dicing lanes, pay attention to layout for dicing! alignment marks, simplified “traffic light” testing software…
- Bump bonding has been expensive, challenges become tougher with chips thinned to 100 um;





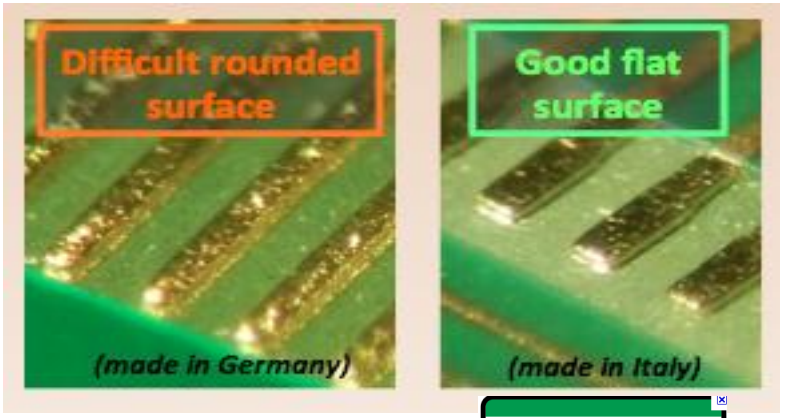
Echoed in the experiment talks

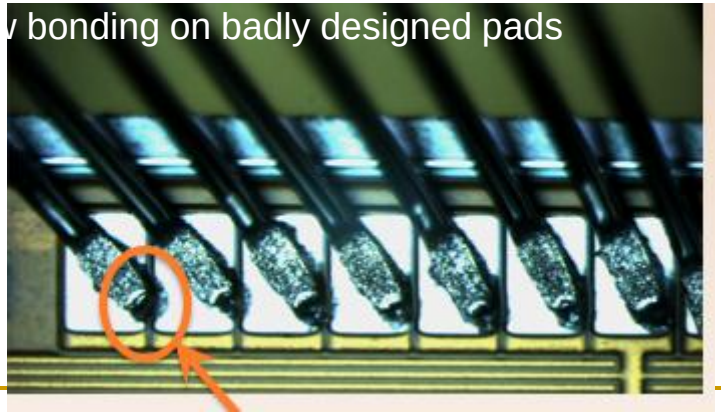
- ATLAS
  - Extensive campaign to protect against oscillating wirebond issues, *provoke* breakage to assure quality
  - Disconnected bumps main reason for dead pixels, disconected areas grow with thermal cycling, especially for indium bonds and FE edges
- CMS : advantages of internal production and testing; fast feedback saves money
  - Reusing gelpacks caused failures quick feedback
  - Possible to do things in small teams; CMS 7 people for ~1000 modules

Wire bonding

- Masterclass from Alan + Ian
- Far from being safe in spite of wide experience – QA should be expanded if anything – thickness measurements, chemical analyses, spectroscopic analyses, bond pull testing, ageing + stress tests – interesting to note that oscillation tests are now widely taken up
- Recipes
  - Bond pad size, surface geometry and aspect
  - Cleaning (e.g. chlorine+water)
  - Metallisation issues;
    - black pad, “purple plague”, metal migration
  - Good jig designs

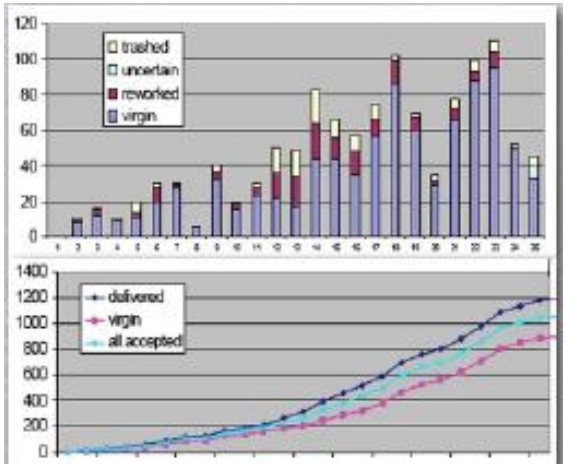
Nothing to be taken for granted!





Reactions to QA control issues along the way

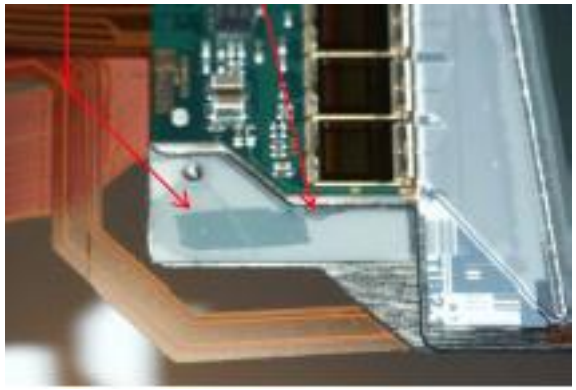
- Reworking – described by ATLAS and CMS “reworking is possible but painful, try to avoid”
- Common mode – noisy strips – breakdown deterioration…. Order new sensors!(Meschini)
- Pragmatic, creative
  - ATLAS: CIS sensors showing breakdown: choose the best and hope for improvement after inversion
  - ATLAS: Low R_int: Rejected 1000 sensors, in other cases changed process parameters at vendor
  - ALICE: pre-irradiation (not possible to change biasing scheme)
  - CMS: conductive glue saga: retrofitting of large number of module backplane contacts
  - (According to preagremeent)– CMS install sensors with high resistitivity in outer layers
  - ATLAS: Correlation between inter-strip capacitance and flat-band voltage: new limit for flat band voltage



Less good reactions

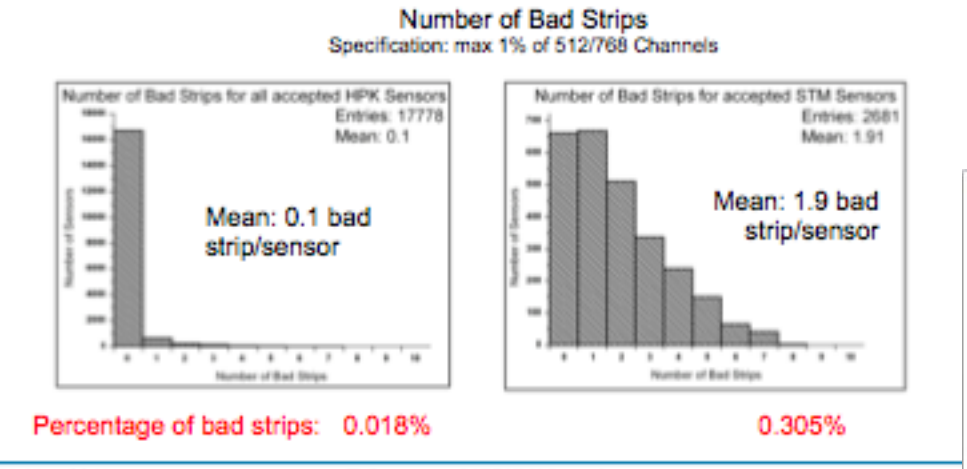
- Repair with solder….

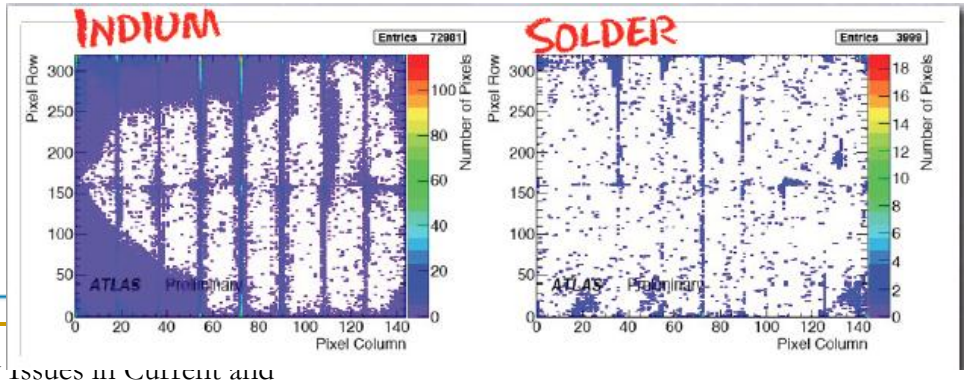
- Repair with scotch tape….



Comparisons…

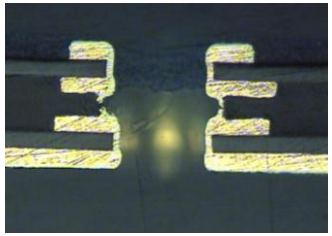
- Enthusiasm for Hamamatsu
  - Reliance on manufacturer in house testing
  - Variation seen in use of test structures and baby detector
    - Tend to focus on the “real item”
    - CMS were pretty rigorous
- ATLAS pixels: QA based comparison of bump bonding techniques

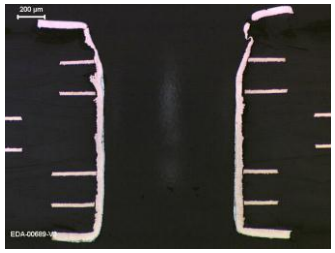


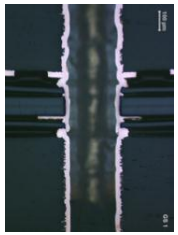


PCB issues

- First master class of the morning from Rui de Oliveira on PCBs *and* on quality control concepts
  - Focus on PTH problems: “most vulnerable problem on PCBs to damage from thermal cycling and most frequent cause of PCB failures in service ”
  - Usually first signs are skipped and alert only comes after 1000’s of boards installed in experiments
  - How to do a full, non-destructive, QA? Clear guidelines



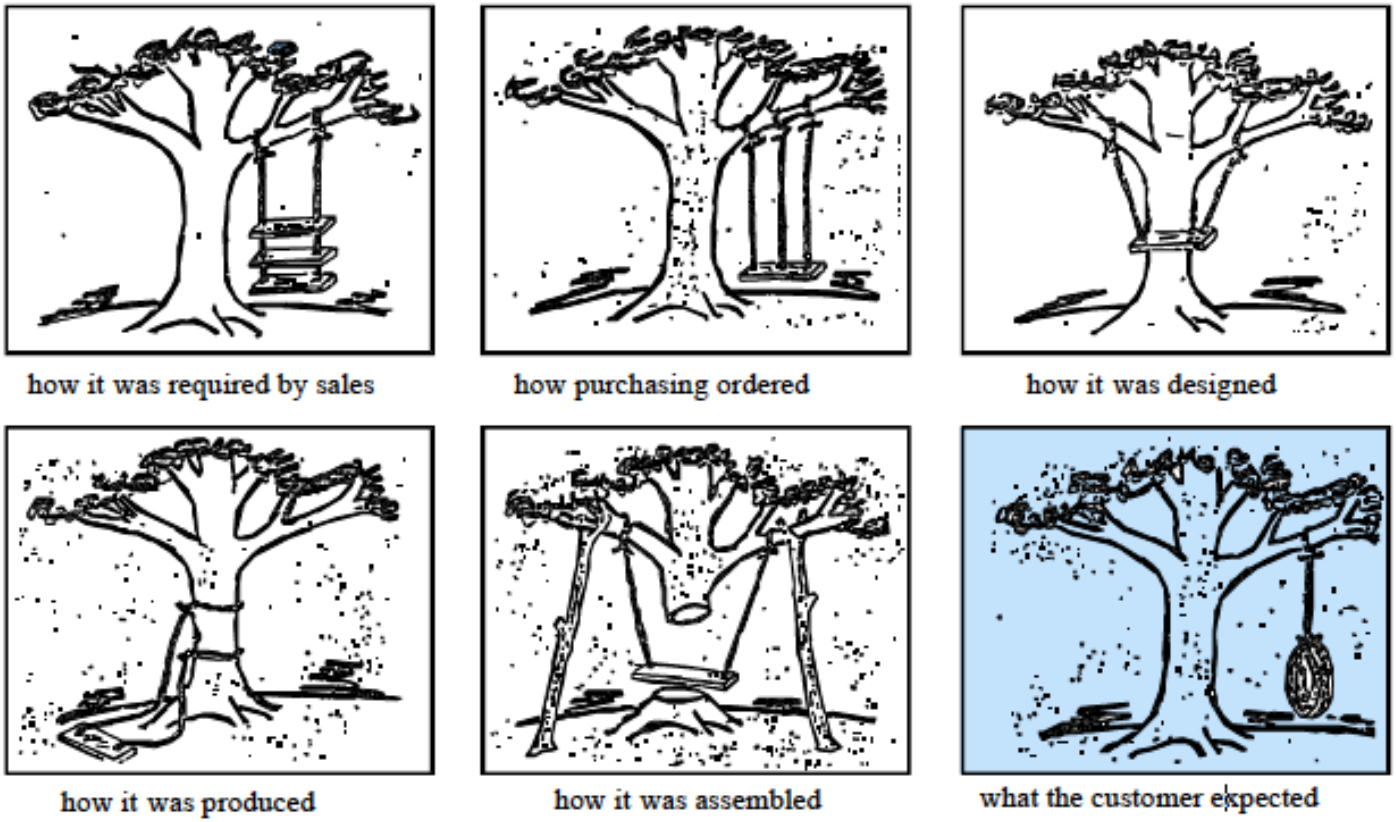




100% electrically tested!
IPC-600 Class 3 control!
ISO 9001 certified!

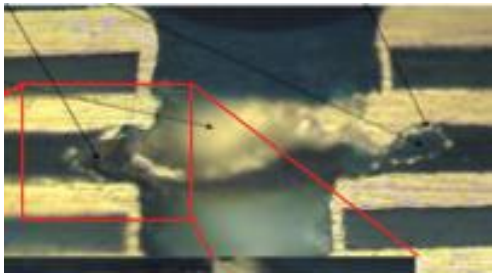
Electronic Assembly challenges

- Second masterclass from Sylvain Kaufmann, outsourcing, design, procurements, packaging, design rules for pads, delamination, vias, mechanical mounts, counterfeit parts… Lots of information!

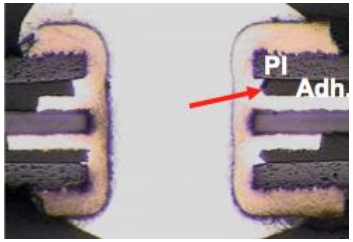


Assembly in experiments – the real deal at the coal face

Marcello Manelli



Before



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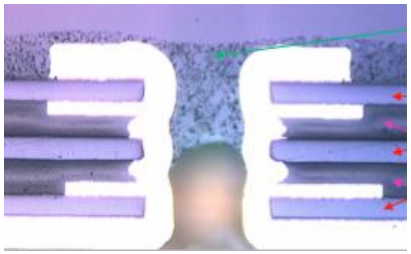
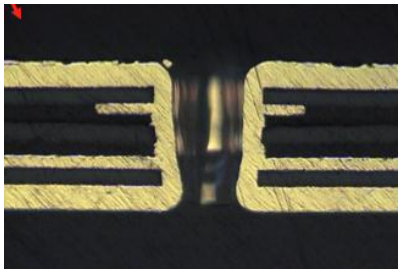
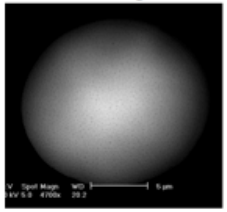


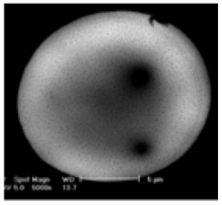


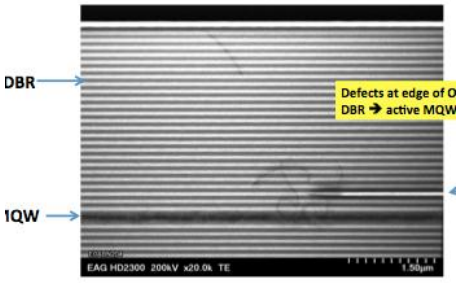
Tony Weidberg – focus on VCSELs and failure analysis

VCSELS can be very reliable commercially

Environmental factors can destroy this reliability

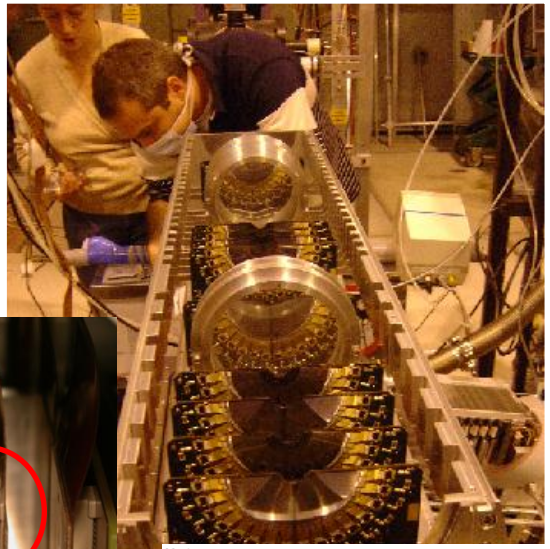


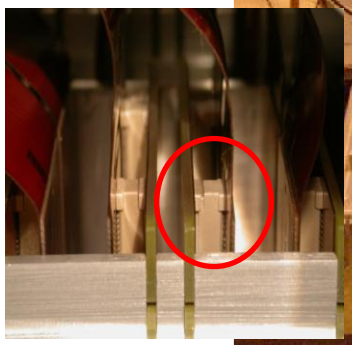


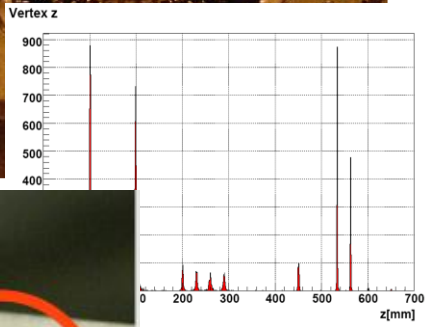


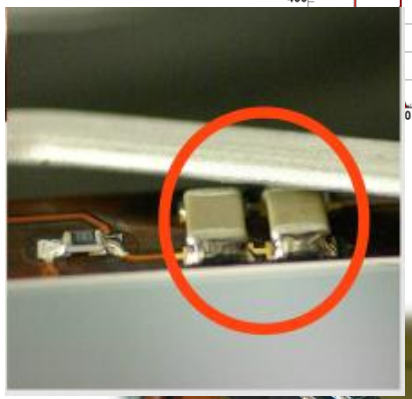
System Integration

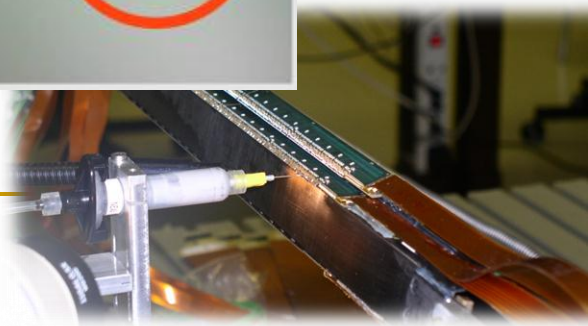
- Issues which creep through the best QA and basic functional tests
  - Connectors, PCBs, I^2C lines…
  - Mechanical + Electrical integration
  - CMS faced additional problems of scale
  - Do not forget QA for the software also!
    - LHCb reconstructed targets in testbeam
    - ALICE: QA tools pre-preparation
    - Survey: risk vs benefit?
      - ALICE achieved full software alignment
- Operational of full slice/detector (lab, testbeam..)
  - work + some risk: worthwhile benefits
  - Must be factored into the planning
  - Use of final versions of HW & SW allows for significant pre-development





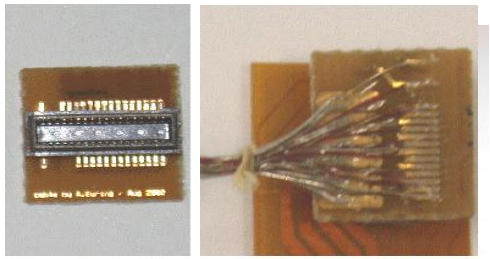


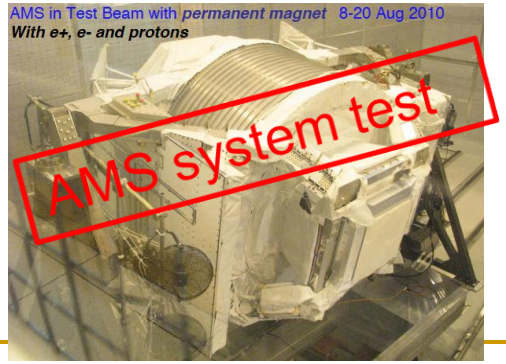




System Integration (ATLAS, AMS)

- ATLAS pixels
  - New issues + Imaginative investigations
    - Optoboards, VCSELS,
    - Connectors (again)
- AMS
  - Real inaccessibility (as opposed to perceived)
  - Cooling in vacuum
  - Vibrations
  - Large variations in P and T
  - Power and weight are expensive
  - Change of magnet mid-operation (!)





Is there a constant for silicon detector efficiency

ATLAS pixels 97.2% working
ATLAS strips 99.0% ON

Cms pixels 98% working
Cms strips 98.1 (96.3/98.3/99.1/98.8)

ALICE SSD 92.5% working (99% in good modules)
ALICE SSD 90% channels working
ALICE pixel 85-92% working

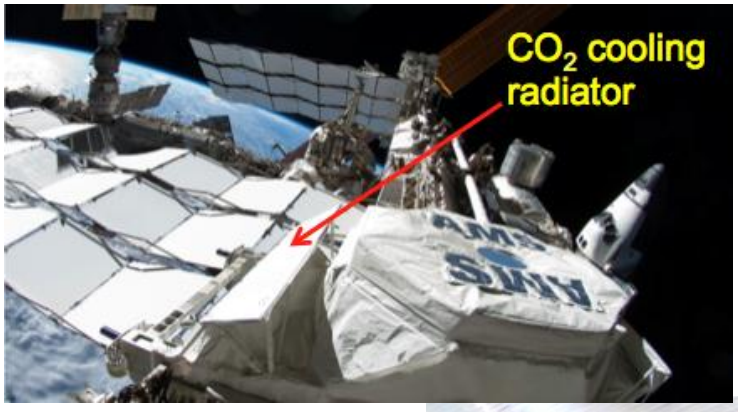
LHCb silicon 99.2% (700k channels)
LHCb TT 99.8%
LHCb ST 99.2%

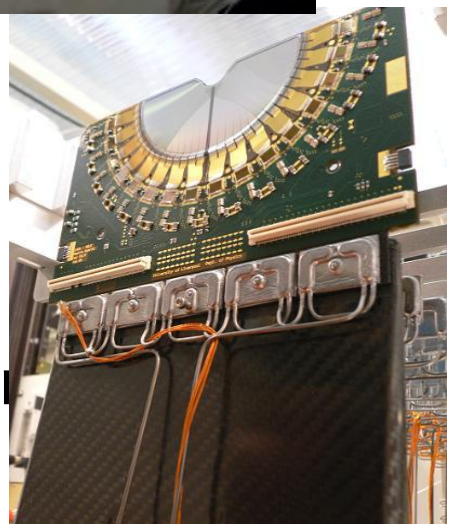
CDF (after 9 years) 90% (but started out much lower)

AMS: ~99% working (p side)
~98% working (n side)

Cooling: Major progress in last 10 years

- CO_2 systems operational in two rather inaccessible places
  - LHCb VELO vacuum tank
  - Outer space
- QA issues
  - No leak within system
  - Isolation hard to apply to complex shapes
- Titanium tubing exciting new possibility
  - Joining technologies needed!
  - CTE, corrosion, material
- Investigating orbital welding close to componer





Cooling – the coal face again

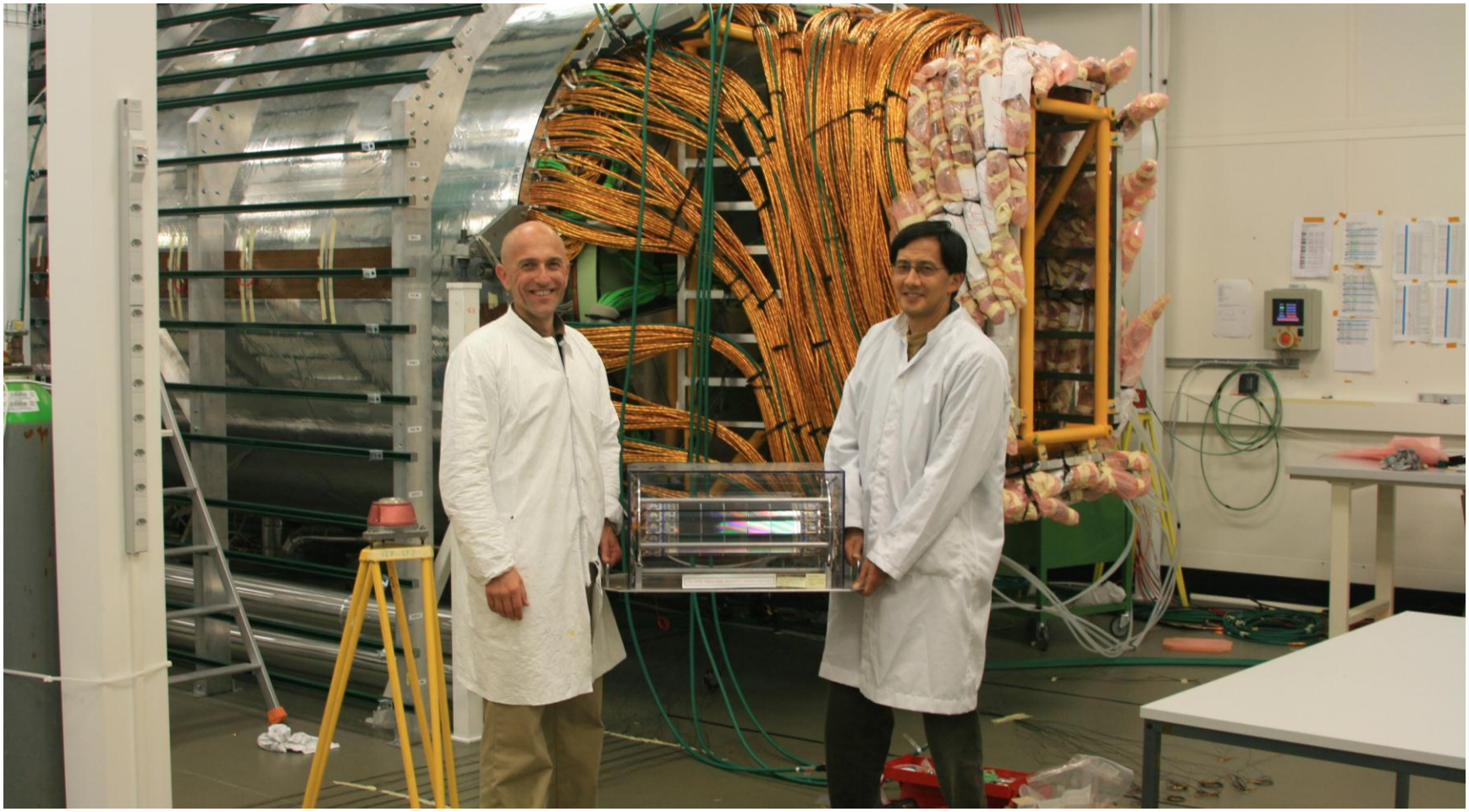
- Last masterclasses of the day
  - How to design a cooling system
  - Connections, leaks, pressure tests, leaks, cleanliness, commissioning
  - A reminder that a lot of investment is at stake!

- Beautiful presentation from Rosario
  - Thanks for sharing….
  - Hope you don't have to do it again ☺

Quotes & questions

- Test structures only used if there "was a reason"
- Very often It is the less "sexy" things that fail most
- Do not expect that once you made it through the learning curve you will only produce good bare modules
- What's the best die size? (design choices = quality/reliablility = money)
- How to bring the test procedures *to* the clean room
- How to find a balance between paranoid search for every single possible unknown defect and time slot allowed for production?
- Quality is conformance to customer expectation: Reliability is quality over time
- Know what you are doing, if not get someone who does
- Different parts of the design team cannot "guess" what they don't know
- Only the Paranoid Survive
- What we say in the conference – what REALLY happened
- Lots of people think that "space" means exotic technologies; the opposite is true

Many thanks to Alan and the bond lab team



= the organising committee

Statistics, statisics, statistics

- 2000 wafers per month for LHC mass production; 7310 SSSDs for CMS
- 95% of detectors no bad channels; 0.01% *in house* tests
- ATLAS numbers: also count number of acceptance criteria
- 35000 sensors delivered for CMS
- Connection density of 4800 cm-2 atlas, 80.3 M bumpbonds ATLAS pixels
- 2582+2380 ATLAS SCT modules
- 15148 CMS modules