QA in the recent past, i.e. LEP-subset

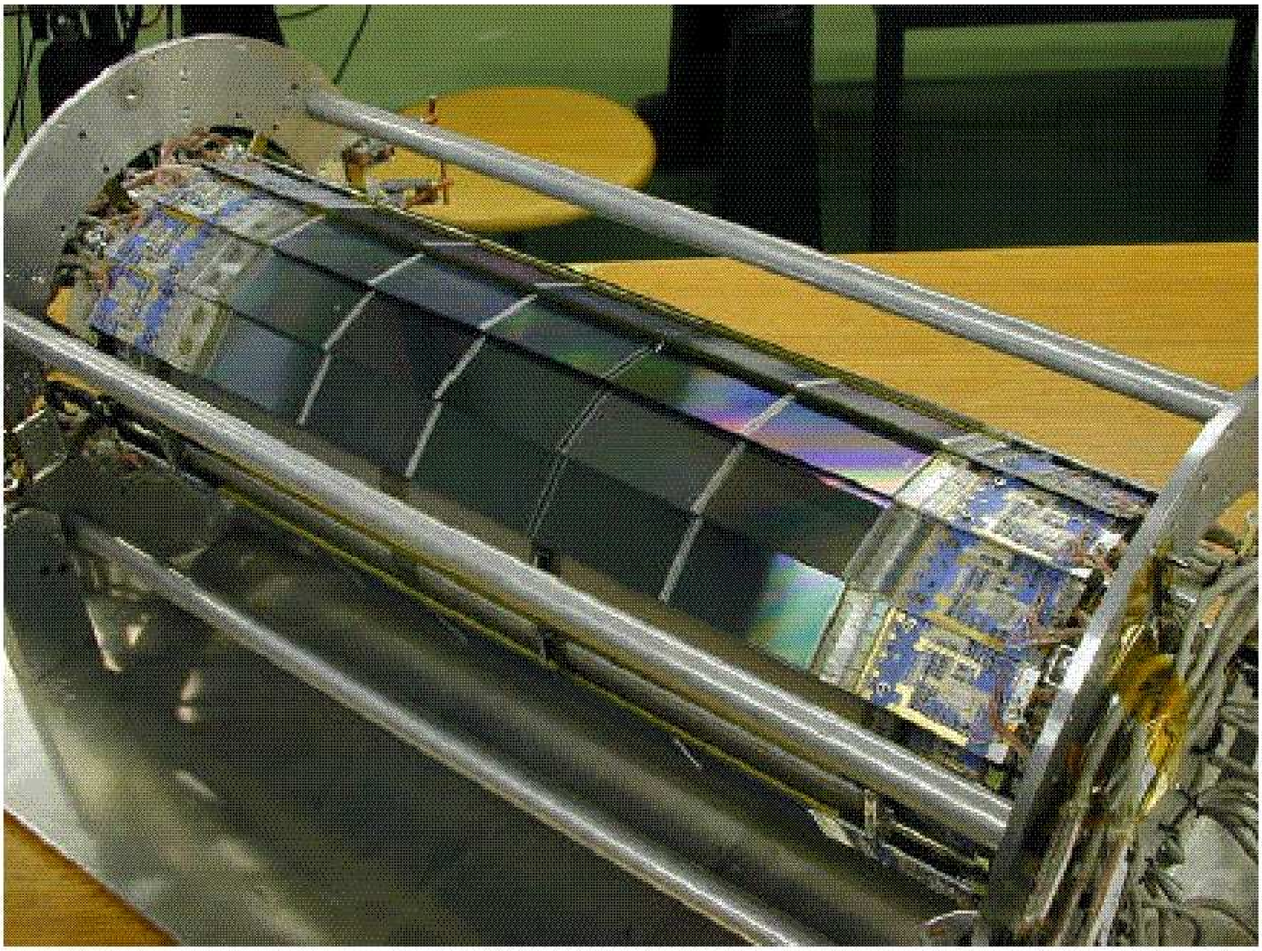
Workshop on QA Issues in Silicon Detectors, May 17-18, 2001

- OPAL experience (info from Alan Honma).
- DELPHI anecdotes.

Of course: no (max few krad/year) radiation!

OPAL

Detector really exists (existed..), hence QA ...



Basic parameters of system (as it was in 1996-2000):

- Two types of modules, either 2 or 3 daisy chained pairs of back-to-back glued r-phi and z type silicon sensors.
- 2×27 modules, total 270 sensors, ordered $\cong 500$
- p-on-n, high resistivity (>3kOhm*cm), 250μm thick, 33mm x 60mm made in pairs on 4" wafer, 25/50μm pitch implant/readout (r-phi), 25/100 μm pitch implant/readout (z), FoxFET biasing, AC coupled, produced by Micron Semiconductor (UK).

OPAL, cont.

Important specification parameters:

- Thickness tolerance: +-15 μm
- Max depletion voltage: 39V
- Inter-strip resistance: >10MOhm
- Leakage current at full depletion + 20V : $< 1\ \mu$A
- Number of defective strips(opens, shorts, pinholes): $< 1\%$

Quality assurance tests performed by OPAL:

- On all sensors prior to module construction:
  - Complete visual inspection of top surface under microscope for metal opens, shorts and implant defects (typ. 20 minutes per sensor)
  - Short term leakage current test (typ. 5 minutes per sensor)
  - Long term leakage current test (8 hours minimum)
- On small samples:
  - Measurement of FoxFET biasing properties
  - Check of pinholes
  - Bonding quality tests
- On all sensors made into modules:
  - Leakage current (sum of 4 or 6 sensors)
  - Number of bad (daisy chained) strips (noisy or open circuit)

About 20% failed above tests, and were replaced by MICRON

Another 7% were damaged during testing(1%), assembly(1%), bonding(5%), rest had $< 0.5\%$ bad channels(=daisy chained strips).

OPAL: QA issues related to silicon sensors

- Concerning wire bonding damage: New broken capacitors and increased leakage currents after bonding (0.1→few% level). Cure: switch from 25 μm to 17.5 μm diameter wire. This presumably meant that the increased power, time or force used for the larger wire may have caused the damage. After the change this problem was reduced to the 0.01% level.
- "radiation" and current in LEP:
  - 10% of modules (1993) slowly increasing current (guard).
  - Beam loss in the OPAL area, currents jumped up by as much as 50%, and continue to increase. Bias was always ON.
  - Cure: No-LEP→OFF (60% of time). Normal after ON.
  - correlation found with sensors sensitive to humidity (30-50%). The leakage current test with 40% humidity was implemented for the future purchases of sensors
  - Never reproduced in lab (sources, an x-ray machine, or the LEP injector test facility irradiation). Suspect surface charge build-up between the guard ring and the edge of the sensors. Note: less than 5% relative humidity in experiment.
- Large number bought (500) vs needed (270):
  - Losses of sensors in testing: about 2%
  - $\sim 5\%$ of modules were damaged→unusable.
  - $\sim 5\%$ in overheating accident in 1994.
  - $\sim 10\%$ of modules had $> 1\%$ bad channels→spares.
  - $\sim 15\%$ with high or unstable leakage current, most not due to any damage.
  - $\sim 20\%$ spares, because the installation into LEP was extremely delicate and the possibility of losses during installation was high.

OPAL: QA issues related to silicon sensors

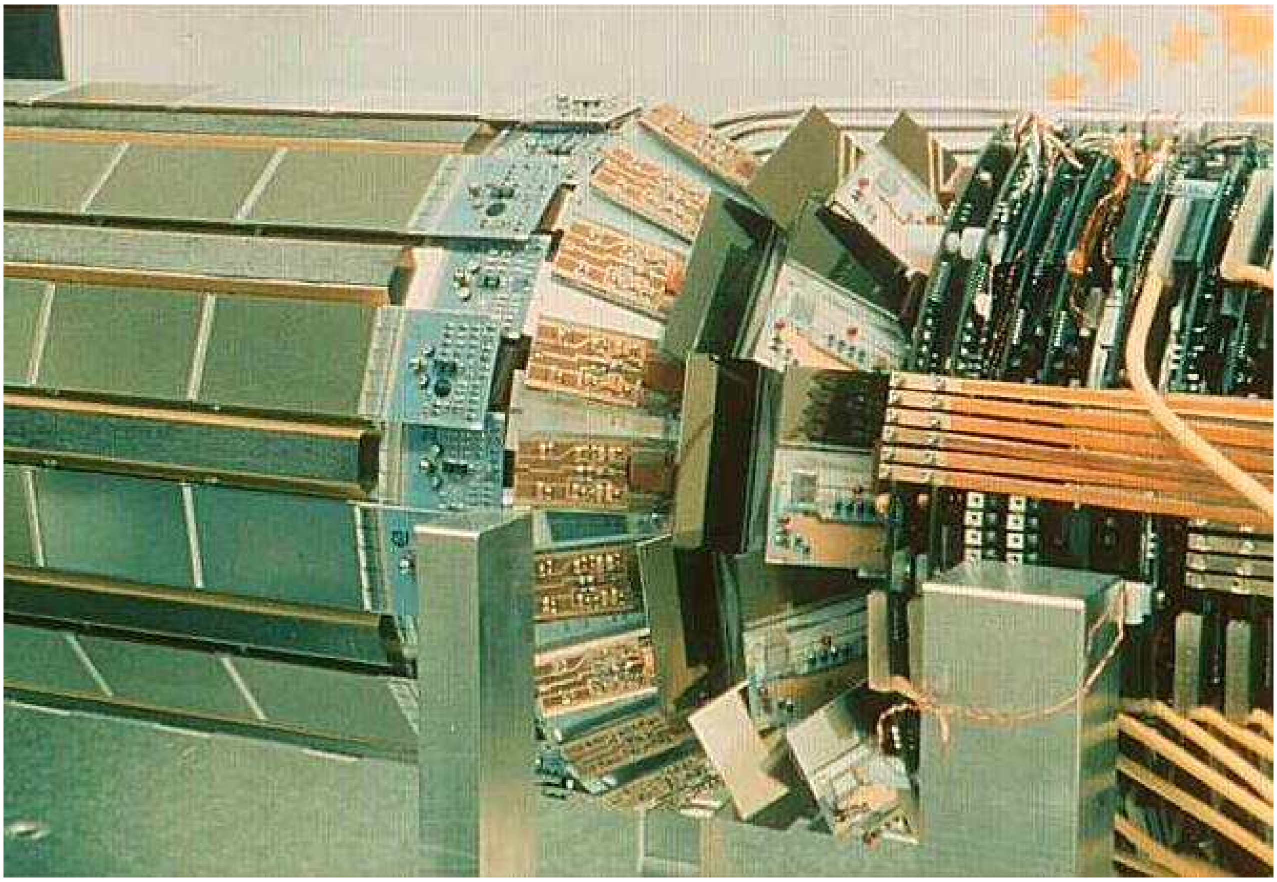
- Inspected after removal in 2000:
  - 2 of 54 modules not working, not sensor, but connectivity.
  - Visual inspection of all 54 modules plus 32 spares:
    * check chemical attack on bonds at hybrids (1994): none.
    * bond failure or anomalies on the sensors: none
    * some bonding failure observed on the gold plated signal routing circuit board, but this had poorer bonding adherence from the beginning.
  - Spares worse than installed modules: in experiment nearly 100% nitrogen atmosphere with less than 5% relative humidity.

OPAL:QA conclusions

- The original QA procedure envisaged for the OPAL microvertex silicon sensors was adequate for assuring good working devices except for the humidity leakage current requirement which was added later. Note that the low radiation dose of LEP did not require any special QA tests for this problem.
- The high strip quality and low leakage current requirements assured good S/N and less than 1% bad channels in the read out modules.
- An unusual radiation related leakage current problem was observed at very low fluence levels which was never properly understood. However, it was avoided by ramping down the backplane bias between physics runs.
- A much larger number of sensors was ordered than was strictly required due to the large number of losses encountered for a variety of reasons. Many of the losses were due to the complexity and delicacy of the construction and installation.
- No significant failures of running modules was found to be due to problems with the sensors during the 8 years of running in LEP.

DELPHI

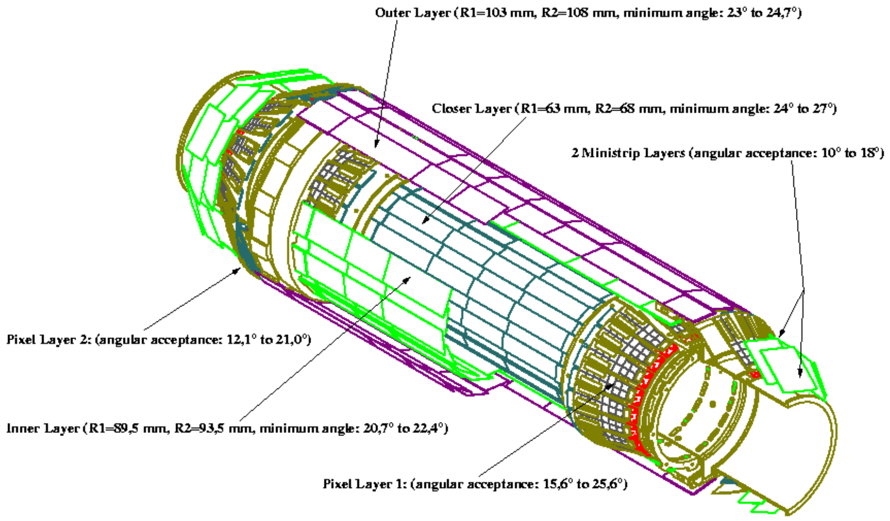
Again: detector really existed, hence..



DELPHI had "many" upgrades, from 2-layer single sided start in 1990 to 3 layer and end-caps detector in 1996-2000.

Total number of sensors installed: 888, (among which 192 SingleSidedDoubleMetal and 176 DSDM).

DELPHI: some barrel numbers...



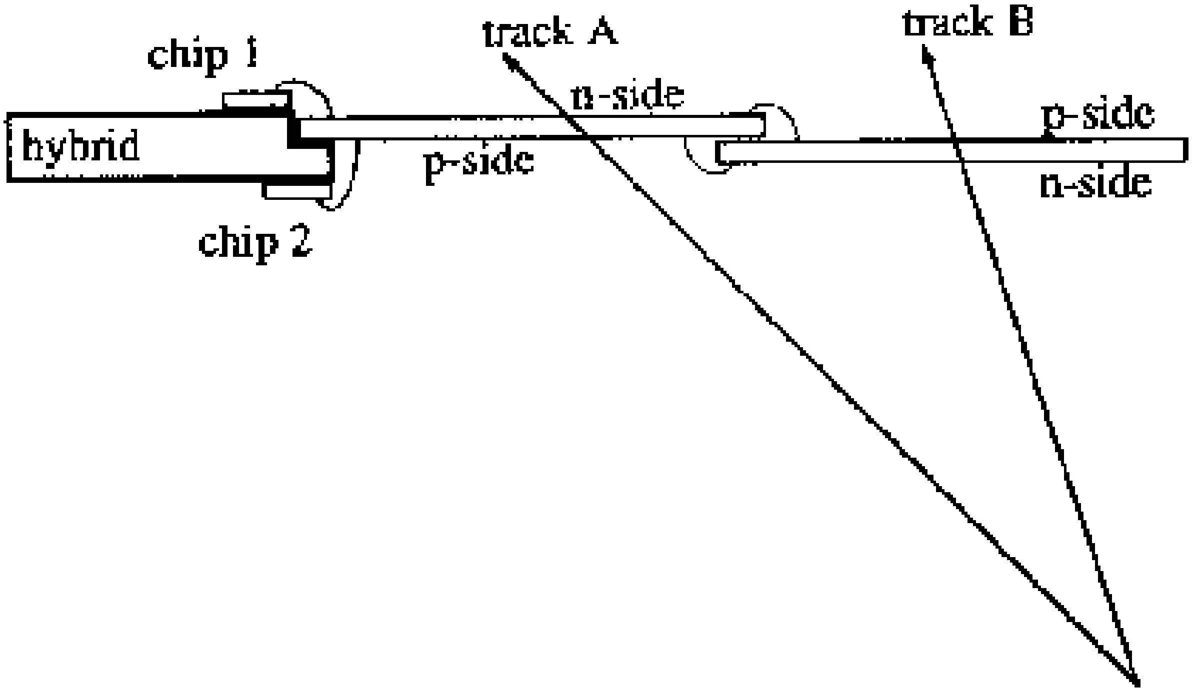
Characteristics of silicon plaquettes		Barrel			
		a	**b**	**c**	**d**
supplier		Hamamatsu	SINTEF	Hamamatsu	SINTEF
single/double-sided		ss	ss	ds	ds
double-metal	p-side	no	yes	no	no
	n-side	-	-	yes	yes
length (cm)		5.99	5.99	5.75	6.07,7.91
width (cm)		3.35	3.35	3.35	2.08
sensitive area (cm^2)		18.6	17.9	34.2	22.2,29.4
pitch (μm)	p-side	25	44	25	25
	n-side	-	-	42	49.5,99,150
readout pitch	p-side	50	44,88,176	50	50
(μm)	n-side	-	-	42,84	49.5,99,150
blocking strip (n-side)		-	-	p^+	field plate
# readout channels		640	640	640×2	384×2
wafer thickness (μm)		290	310	320	310
implant width (μm)		8	8	12,14	6,8
biasing		FOXFET	Polysilicon resistors	Polysilicon resistors	Polysilicon resistors
readout coupling		AC	AC	AC	AC
resistivity ($k\Omega$cm)		3 – 6	3 – 6	3 – 6	3 – 6
operating voltage (V)		60	60	65	60 – 95

DELPHI, concentrate on the barrel

All detector from two vendors: SINTEF and Hamamatsu

- Ordered typically 20% spares, exception was "very first" double-sided, double-metal with field-plate separation detectors, for which we ordered an extra 50% to replace noisy detectors.
- Flipped design: depletion voltage over coupling capacitance: Electronics=GND, p+=GND and n+ at V$_{depletion}$. $SiO_2+Si_2N_3$ layer can stand >150V. "flipped" design: Noise equalising, solve ambiguity using sign of charge.

  But: stringent requirement on coupling-C, vendors had to test at 100V, all channels on n-side.



DELPHI: barrel checks

Apart from usual check (IV, bias-R, interstrip-R), vendors had to check all strips individually, and provide checklist with the bad-strips. They measured capacitance of bond-pad to "rest-of-the world".

SINTEF

Read-out channel test results

Type:	Batch:	Date:
RZ-320	S-3	1994-12-21

Detector	Broken read-out lines (layer 2)	Shorted read-out lines*	Pin-holes	Metal-2-to-Metal-1 contact failure**	Broken read-out lines (layer 1)
S3-a-125					
S3-a-126					
S3-a-127					
S3-a-128	239				
S3-b-128					
S3-a-129	23				
S3-b-129					
S3-a-130		186 187			
S3-b-130	169				
S3-a-131		1 2			

FINAL TESTED SHEET

Customer's name CERN DELPHI DATE 1994.7.18.

TYPE No. RPHI-SSSD 3632
QUANTITY 63

HAMAMATSU PHOTONICS K.K.
SOLID STATE DIVISION
JAPAN

1. We checked short channels of AC coupling capacitor at 100V.
2. We checked open readout line channels and short with anothier strips channels by comparin capacitance of pads of one edge with capacitance of pads of another edge.
3. We checked dark current at Vr=100V.

The list of NG channels. (channel No. --- see DRG. No. 3S0487)

chip No.	1. AC short channel No.	2. Open channel No.	2. Short channel No.	3. dark current at Vr=100V
SPL6202-1	Nothing	Nothing	Nothing	160.3 nA
SPL6202-2	Nothing	Nothing	Nothing	281.6 nA
SPL6202-3	Nothing	Nothing	Nothing	133.9 nA
SPL6202-4	Nothing	Nothing	Nothing	156.0 nA
SPL6202-5	Nothing	Nothing	Nothing	258.6 nA
SPL6202-6	Nothing	Nothing	Nothing	132.8 nA
SPL6202-7	Nothing	Nothing	Nothing	170.5 nA
SPL6202-8	Nothing	Nothing	Nothing	173.9 nA
SPL6202-9	Nothing	Nothing	Nothing	174.0 nA
SPL6202-10	Nothing	Nothing	Nothing	159.5 nA

DELPHI barrel

DELPHI did the following:

- 4 labs for testing and assembly into modules.
- Each sensor (and later module) had its own collection of test sheets, which traveled with it. Hence all scribbling/sketching was available with the device. The test result sheets looked different per lab, allowing for "cultural" differences.
- Sensor test: x-checked vendor measurements (first all sensors, later partially depending on sensor (close to limit), or vendor). Automatic (and also manual) probe stations. For n-side we ramped all channels to 100V over the coupling capacitor.
- After module movement: receiving lab first checks the "claimed" performance on their own test-setup, and compares to file.
- Burn-in of n-sides: kept detector in a dark box at 100V for at least a month. Checked every day for punch-through, removed bond-wire, etc.. 99.4% of tracks at at least 2 hits in the 3 layers.

DELPHI anecdotes

Most striking things that happened, biased by memory, in increasing severity:

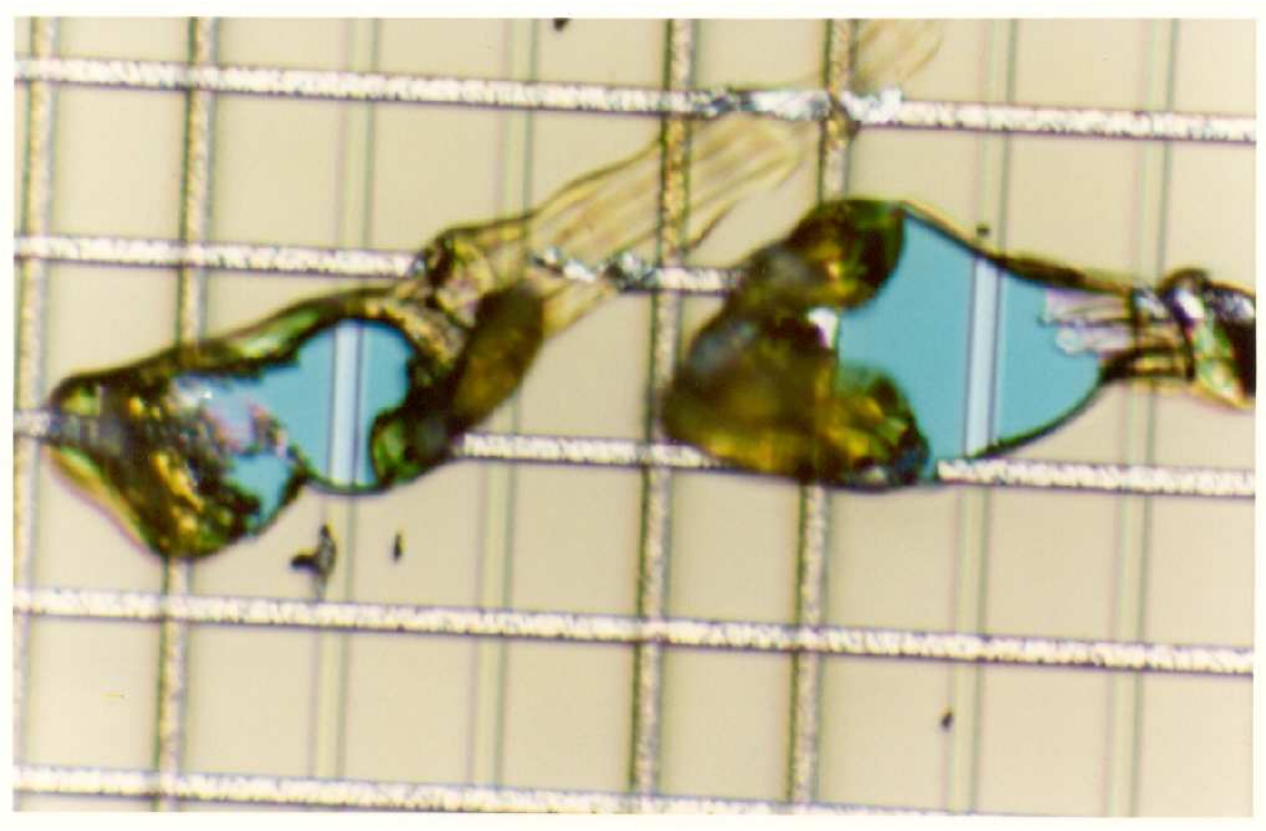
- Increase in current and bad channels after bonding (same story as OPAL, but only in one lab). Took a lot of adjustment, test bonding to get it right.
- Handling of double metal (or back-to-back) sensors in assembly. Noticed small (few $^{\circ}/_{\infty}$) loss in every step. Tried Teflon coating, Teflon jigs, very careful cleaning etc.. But: solved with thin tissue on jigs.
- Wrong length modules. Drawing made in one place, then all labs had to produce half-modules. Final assembly into full-modules at CERN. Lab which made the final technical drawing, produced modules which were too long by 1 mm.
- Two complete deliveries had unusable sensors. Vendors checked with C-measurements per channel, but looked for "flat-line", not absolute value..
  - One vendor had "forgotten" the implant step.
  - Other vendor had over-etched the 2nd-metal of 130 sensors, hence "all" strips disconnected, only the good looked bad.
- The anti-static-plastic saga.

DELPHI: the anti-static-plastic saga

Sequence of events:

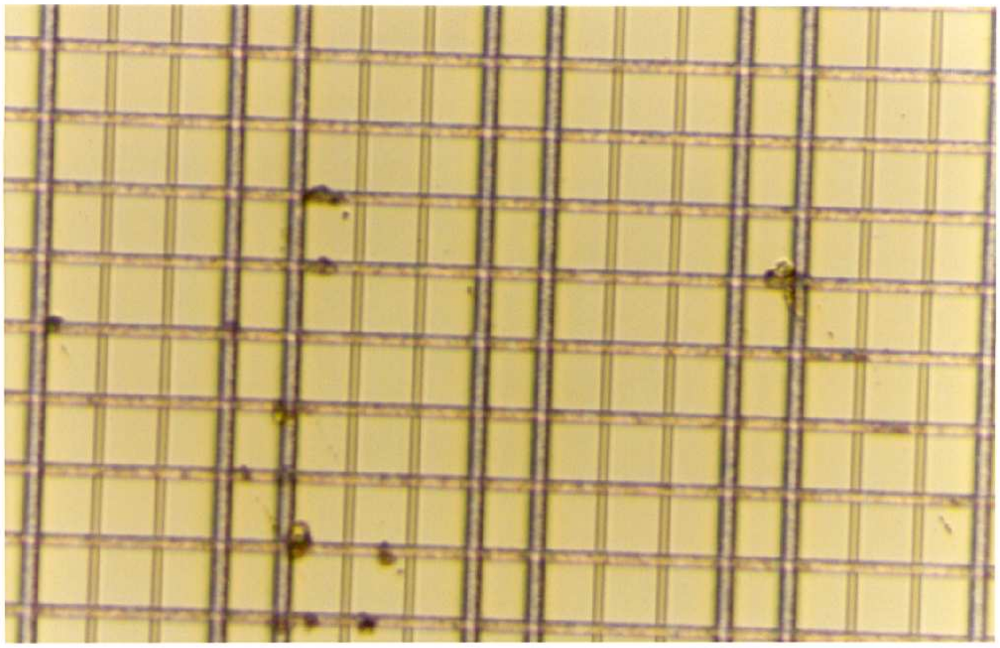
- CERN received a batch of double-metal sensors.
- Probed part of them to check quality, rest mailed to other labs. Nice agreement between what vendor found and what was found at CERN.
- CERN also mailed checked sensors to other labs.
- One lab x-checked sensors checked by CERN, and found they were not as good as claimed.
- Verified on a few sensors, but also some which were still OK.
- Contacted vendor: your sensors age. Response: you guys are ruining them.

And of course, accidents do happen:



The anti-static-plastic saga

Noticed that on "bad-sensors" some flakes appeared (not seen on "normal" sensors:



Zoom in on broken channel, and probe on 2nd-metal routing line till position of break was established: always at a "flake"

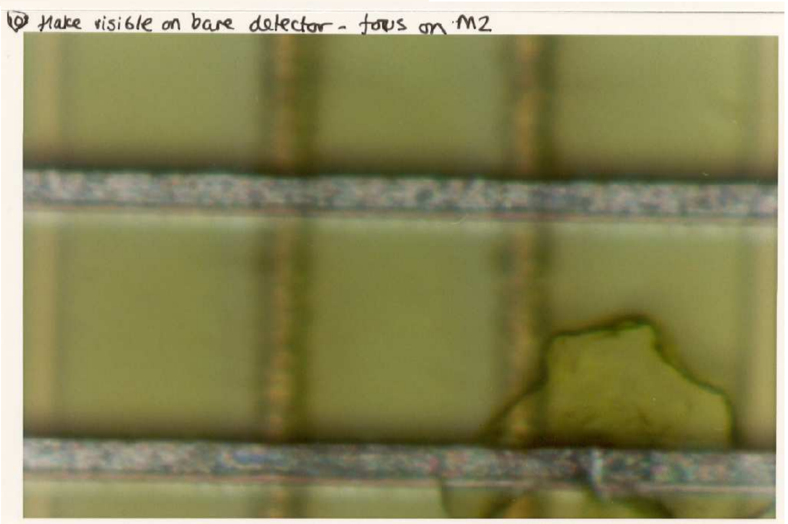
The anti-static-plastic saga

Still had a few "unpacked" sensors. Sensors were all sandwiched between transparent anti-static sheets.

Photo of "flake" through anti-static-plastic.

Photo of plastic only.

Photo of sensor only.



The anti-static-plastic saga

Managed to convince vendor:

- Vendor only did final wrapping in anti-static-plastic just before shipment.
- Vendor had changed supplier, new anti-static-plastic. Stuff is chemically treated to make it anti-static.
- Apparently these chemicals attacked the 2nd-metal layer Aluminium.
- All 60 affected sensors were replaced (+delay..).

DELPHI summary

- Quite happy with paper files: also allows "non-computer" personnel to add info. Have quick and fast info next to oscilloscope, allows scribbling, etc..
- Generally checking worked well for all "normal" cases, i.e. rejecting sensors, picking the best half-modules to make a full module etc.. DELPHI (barrel+forward) processed roughly 1000 sensors with about 10 labs in a period of less than two years.
- Frequent "low-level" encounters of people who really look at the sensors.
- Most problems finding triggered by a single sensor/module, not by making statistics over the last 100.
- Beware of the improbable.
- Time pressure: If you notice something, do you stop all labs before you find out what is going on, or...