Thoughts on Large Collaborative Wire Bonding Projects

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Outline

- Intro
- Direct Experience: CMS Strip Tracker 2000-2007
  - Organisation
  - Requirements/specifications
  - Other QA measures
- Areas of improvement from experience

Introduction: Why me?

Why am I giving this (and this afternoon's) talk?

Some background:

CERN Senior Physicist in the Detector Technologies department (since 1999). Previous HEP hardware experience: SLAC fixed target (tracking chambers), UA1 (trigger), SLD (calorimeter), OPAL (Si µVtx), ATLAS (LAr calo), CMS (Si Str. Trk), CMS upgrade (Si Str. Trk).

Also, head of CERN wire bonding lab (1999-2001, 2009-present), head of CERN QART (quality assurance and reliability testing) lab (2008-present).

More specifically, for this topic:

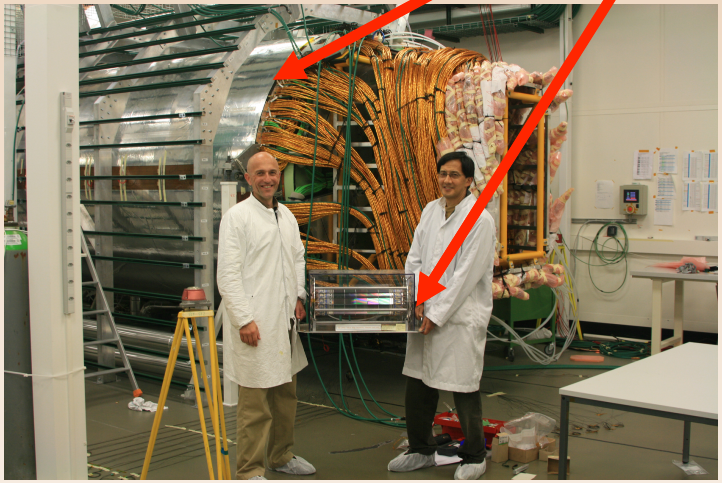
CMS silicon strip tracker wire bonding working group coordinator (2000-2003) and then working group technical advisor (2004-2006).

First learned about wire bonding in 1991 for the OPAL silicon microvertex detector. Took over responsibility for the CERN wire bonding lab in 1999 and been in charge or closely associated since then.

Direct Experience: CMS SST production

First (and only) experience with a large collaborative wire bonding project: the CMS Silicon Strip Tracker production (2004-2007, but organisation started in 2000).

Silicon detectors: CMS vs OPAL



The project in numbers:

A 2.4m diameter 5.4m long cylinder filled with:

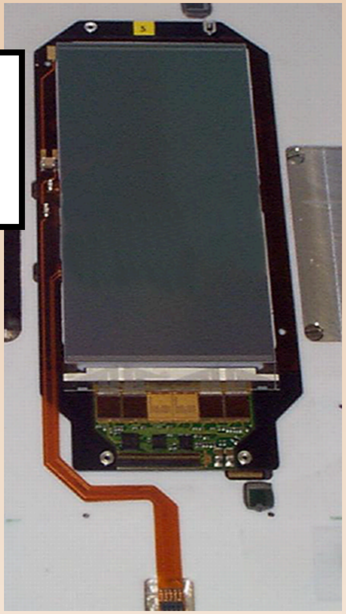
- 210 m^2 of silicon sensors
- 24328 sensors
- 15232 modules
- 9,648,128 strips (electronics channels)
- 75,376 read-out chips
- About 26,000,000 wire bonds to be made by the collaboration bonding centres (and about 6,000,000 by the hybrid producer)
- 15 collaboration wire bonding centres in 6 countries

The next slide shows the CMS tracker module design and details of the wire bonding:

Module design (but 24 different module types!)

Common design elements: carbon fibre or graphite frame, 1 or 2 single-sided silicon strip sensors, glass pitch adapter and read-out hybrid. 512 or 768 strips (read-out channels).

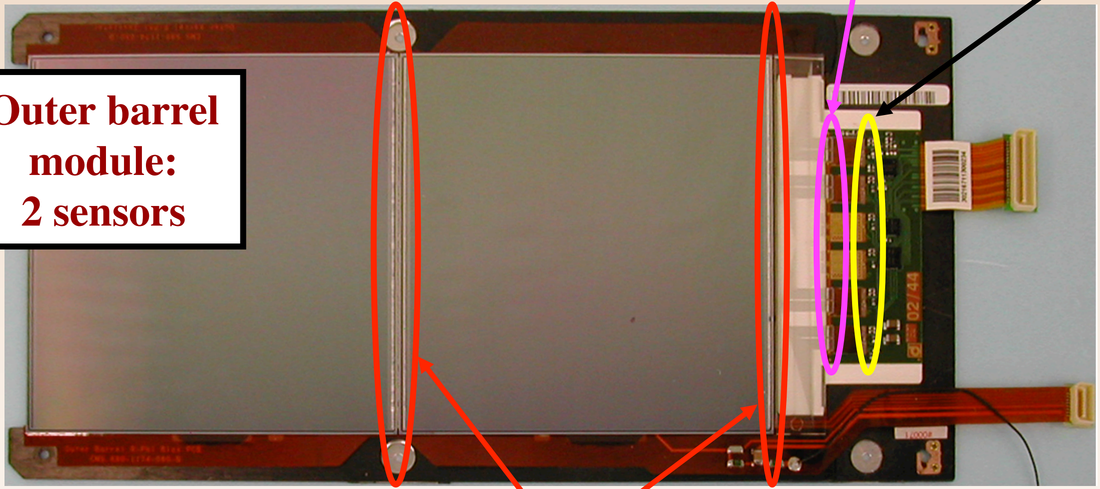
Inner barrel module: 1 sensor



Bonded by hybrid producer: readout chip

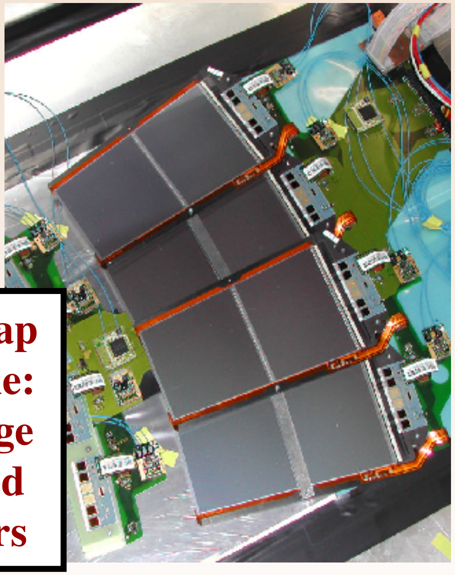
Bonded at CERN and Santa Barbara: pitch adapter - readout chip

Outer barrel module: 2 sensors



Bonded by 14 bonding centres:
Sensor-sensor and sensor-pitch adapter

End-cap module: 2 wedge shaped sensors



(From a talk given at the Bonding and Die Attach Technologies Workshop, CERN, 11-12 June, 2003)

CMS SST production: organisational issues

What I consider to be the important bonding issues learned from the CMS tracker project that are relevant to similar future projects.

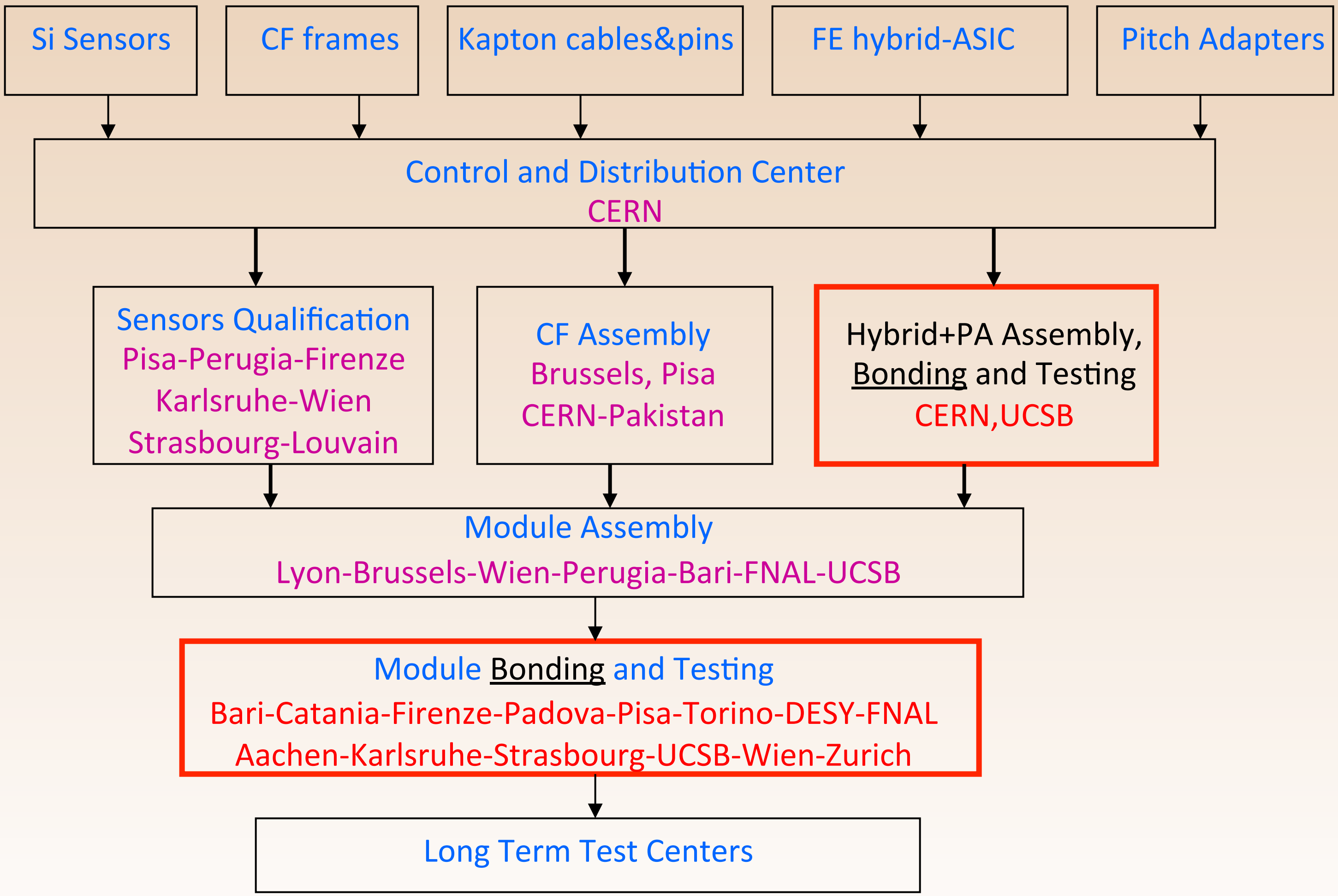
Organisational issues:

Although working groups were formed for the sensors and module assembly at the start of the CMS tracker project, there was none for wire bonding. I suggested to the project manager to allow me to create the wire bonding working group in order to best coordinate the activity and (hopefully) maintain a uniform and good quality over the many participating centres.

The wire bonding centres had to fit into the overall module assembly organisation. As the tracker had 3 fairly distinct module types (inner barrel, outer barrel and endcap) it made sense that there be 3 sub-groups of institutes working on those parts. The wire bonding centres were thus attached to one of the 3 sub-groups. Usually the institutes that were wire bonding centres were also centres for other module assembly activites (sensor testing, robotic module assembly, integration centre, …). In any case, the fact that the activities were spread out geographically made for a logistical nightmare.

CMS SST production: organisational issues

Module production logistics



CMS SST production: organisational issues

Organisational issues:

At this point each wire bonding centres needed to have a person made responsible for that activity and be able to report to the Working Group (WG). Within the overall module production organisation and schedule, we needed to work out the number of modules to be produced at each centre and to evaluate the equipment at each centre. Here is a 2003 summary table of the 15 wire bonding centres:

	Institution	Bonding Responsible	Required peak prod rate mod/day	Bonding machine
Inner	Bari	P. Tempesta	3	Delvotec 6400
	Catania	S. Costa	reserve	Hughes 2740-V
	Firenze	E. Scarlini	2	Delvotec 6400
	Padova	A. Kaminski	3	K&S 8090
	Pisa	F. Bosi	4	K&S 8090
	Torino	L. Demaria	2	Delvotec 6400
Endcap	Aachen 1	W. Braunschweig	6	Hesse&Knipps 710M
	DESY		not determined yet	Delvotec 6400 ?
	Karlsruhe	H.J. Simionis	6	Hesse&Knipps 710M
	Strasbourg	F. Didierjean	6	Delvotec 6400
	Wien	T. Bergauer	2	K&S 4123
	Zurich	K. Freudenreich	4	2 x Delvotec 6319
Outer	FNAL	W. Kahl	14	2 x K&S 8090
	UCSantaBarbara	J. Incadela	7+21 hyb/day	K&S 8060
Hyb-PA	CERN	A. Honma	38 hyb/day	2 x Delvotec 6400

At this point, no production modules had yet to be bonded.

CMS SST production: requirements/specifications

So now we knew who was to do what and with what equipment, but how do we manage to keep the quality uniform and high? That is where the requirements for the centres and the bonding specifications comes in…

Requirements/specifications:

All centres must meet qualification standards

- Minimum clean room, ESD protection and equipment requirements
- Standardized pull test structures (Al on glass, silicon)
- Test of absence of damage on silicon "baby" sensor
- Successful bonding of dummy and prototype modules

Written specifications and procedures, common to all centres

Module quality goal: <2% non-working channels (for whatever reason) ⇒ bonding faults <0.5%

The specifications and procedures document is (in my opinion) a key element to obtaining a uniform result. It was relatively easy to get agreement from the CMS centres to go this way as many centres were brand new and had little other guidance. In the case of already established centres with previous experience, it could be more problematic as they may prefer their own methods. I would suggest trying to find a common basic procedure with some freedom for each centre to modify as needed.

CMS SST production: requirements/specifications

I started writing the bonding specifications in 2000, well before the production started (2004). It evolved with time as module details emerged. Having such a document well in advance made it easier for the bonding centres to know what would be expected from them. Here is a 2001 version:

Preliminary Bonding Specifications and QA Criteria

Bonding Specifications:

1) wire thickness and type (Al, 1% Si, 25μm diameter, medium hardness)

2) loop height and form (depends on relative heights, separation and structures on components, but in general about 300 to 700 μm with shape such that wire is clear of any nearby metal

3) tail length (visible but short , <50μm)

4) accuracy of placement in X and Y(fully on bondpad)

5) pull strength (>5g, avg)

6) break on pull failure (wire should break leaving bond foot = heelbreak)

7) failure rate (sum of all failures should be less than 1%, depends on required throughput)

- wire fails strength test
- missing wire
- broken wire
- failed weld
- bond pad failure (tear off)
- uncut wire
- damage to substrate
- bad shape of loop

8) tests 5,6,7 must be passed after thermal cycling

Specifications on Bonding Jigs:

1) height differentials between CF surface support (under PA) and sensor surface support (within 50μm of nominal)

2) flatness of critical surfaces (<20μm)

3) teflon surfaces for sensors, soft vacuum pads allowed

4) vacuum needed only in area of bonding

Specifications on Module Components and Assembly Relating to Bonding:

1) height differential between sensors (<50μm)

2) height differential between sensor and pitch adapter (not yet determined)

3) parallelism of PA surface to CF surface (<5mrad?)

4) quality of PA gluing (no vertical motion of PA during bonding)

5) size of bond pads (>50μm width and >200μm length)

6) reference marks (sufficient for pattern recognition)

7) quality of metal surfaces (adherence, cleanliness)

Quality Assurance Tests:

1) bond pull tests on test bonds

2) air jet test on real bonds (not yet certain)

3) bond physical presence test by pattern recognition (optional)

4) visual inspection:

- placement accuracy
- physical presence
- loop shape and height

5) read-out test (with thermal cycling if possible)

- IV curve to check for proper sensor connection and possible sensor damage
- APV single channel noise to check bond connections and proper sensor bias
- backplane pulsing for most sensitive check of bond connections
- thermal measurements to check thermistor connections and module thermal contacts

to do:

more detail on bond pull tests (where, when)

QA prep (reception, inspection, what to enter in DB, what actions to take for problems /failures)

CMS SST production: requirements/specifications

Let's go back a bit and look in more detail at one of the bonding centre qualification standards. It will serve as an example of the environmental requirements needed for a bonding centre:

- All centres must meet qualification standards: Minimum clean room, ESD (electro-static discharge) protection and equipment requirements.

The clean room standards should be adapted to the job.

- In our (the CERN bond lab) experience, a clean room class of 100,000 is sufficient although 10,000 is preferred so that one can leave bonding surfaces exposed for longer periods without having to worry about particulate accumulation.
- Temperature stability is usually very important although the exact value of the temperature is usually less critical. The CERN bond lab is set at 21 ± 1 °C.
- Humidity control is important for ESD protection. We use 50 ± 15 % RH. We find it is high enough to avoid high levels of ESD charge up but low enough to avoid condensation on cold material brought in from the outside.
- Other typical ESD measures: slightly conductive floor; specialized ESD material - floor and table mats, wrist straps, clean room shoes, clean room coats, furniture (tables, chairs), tools (tweezers, screwdrivers, vacuum pens), ionisiers.

Note: We often don't use wrist straps but because we have implemented most of the other abovementioned measures we do not observe ESD caused failures.

CMS SST production: other QA measures

The requirements/specifications are the first step in the overall QA planning.

- **One can (and should) build in much of the QA into the requirements and specification documents. Examples:**
  - **Component reception visual inspection**
  - **Pull test requirements**
  - **Post bonding visual inspection**
  - **Post bonding electrical tests**

- **Not yet mentioned is the data base (DB). A good DB is essential for a large multi-centre project. I believe all LHC experiments had fairly extensive and sophisticated databases for their construction.**
- **However, each sub-system will have specialised needs and it is not always clear if the "standard" DB for the whole experiment or subdetector will meet the needs for the production bonding task. In CMS, the strip tracker project had its own DB and the bonding working group built a custom interface that used the main DB but allowed for separate storing of other bonding specific data that was not easily incorporated in the main DB.**

CMS SST production: other QA measures

Good communication between the bonding centres and feedback to the bonding coordinator was helped by the (approximately) quarterly working group meetings. We eventually went to having a coordinator and a technical advisor because of the heavy logistical load of coordination.

Another element that was a key to the coordination of the production as well as a QA tool was the bonding working group website. It is fortunate that the person that took over from me as bonding working group coordinator also built the bonding DB and managed the group website. This person was Salvatore Costa (Catania) and he has kept the website on-line so you can see much of the details of the bonding working group even now, 7 years after the production was completed:

http://cms.ct.infn.it/bonding/

Much of what I have just described is given there more detail and updated as of 2005-6.

On the next slide is a screenshot of the website front page:

CMS SST production: other QA measures

CMS Tracker
Bonding Working Group

Coordinator: Salvatore Costa

NEWS

WG Meetings
Next | Last | All

Official Procedures
- Module Bonding
- Strips to leave unbonded
- 50th wire Pull Tests
- Bonding Repairs
- Test Structure Bond Testing
- TEC Hybrid Test Bonds Removal

Technical Info
- Module Bonding Specs
- Tool care & change
- Pinholes-by-Bonding Study
- Pull force correction
- Pull Testers
- Loop documentation
- ESD Equipment
- Wire handling

Center Facilities
- View facilities
- Update info
- Add bonding machine
- Remove bonding machine
- Status on 28 Jan 2005

DB Interface
- Install latest upgrade
- User's Manual
- DB Tables & variables

WG Members
- L3 Responsibles
- DB Responsibles
- All Members

Link to Hybrid Assembly page
Link to Bond Workshop page

Welcome to the Bonding Working Group web site.

NEWS

1. **01 Feb 2006**
   Alessandro Profeti from Pisa is the new Bonding Working Group Technical Advisor. Many thanks to Alan Honma who stayed on as Technical Advisor to the Bonding WG for almost 3 years after stepping down as WG Coordinator.
2. **31 Oct 2005**
   Following decisions at the 25 Oct 2005 Bonding WG Meeting, the 'Module Bonding Procedures' document has been modified to include procedures to bond the HV in the module backplane for TEC modules. The 'Module Bonding Specs' document has been modified to add number and height of HV bonds for TEC modules.
3. **09 Oct 2005**
   The document 'Bonding Repairs' has been revised as mentioned during the 20 Sep 2005 Bonding WG Meeting, so it is now official. It includes all changes proposed by Alan Honma on 04 Aug 2005. Please be aware that this document is not a Tutorial, it is a Reference Guide. Module failures are grouped into categories depending on their nature and on the production phase of the Module, then they are listed one by one within each category. Each Failure item in this document is self-contained, as it is normally found in a Reference Guide, such as a dictionary or an encyclopedia. That is, for each failure item the full procedure to repair and to enter the appropriate info into the Database is given. Thus, you are not supposed to read the entire document but, rather, to search for the failure you are facing and read only the table rows concerned with that particular failure. If you read the entire document, you will find certain procedures and certain DB actions repeated many times, because certain operations apply to sever failure types or to similar failures occurring at different production phases of the Module.
4. **29 Sep 2005**
   A new document 'TEC Hybrid Test Bonds Removal' Procedure is now posted on this site. It has been prepared by Martin Weber and distributed to everybody in the TEC Community. It illustrates a quick procedure to remove the test bonds present in Hybrids used for TEC Modules. This removal is necessary because the Brussels Gantry pickup tool picks up the Hybrid right in the area where those bonds are placed, thus smashing them. At this time in production it is too late to redesign that pickup tool. Other Tracker subdetectors are not affected by this issue, so they do not need to remove those test bonds.
5. **03 Aug 2005**
   A new document 'Bonding Repairs' is now posted on this site. I've put it together collecting information from many Bonding WG Members, from our own Meetings and also attending some of the Module Test Meetings. It is not yet approved by the WG. I'll put its discussion up on the agenda of the next Bonding WG Meeting. In the mean time, please have a look at it and get back to me with your suggestions, corrections, additions,...
6. **11 Feb 2005**
   I've updated the 'Module Bonding Specs' document and the 'Pull force correction' document to better specify pull tester hook placement and correction formulas, respectively.

CMS SST production: other QA measures

A key bonding specification is the pull test. The pull test criteria used was as follows:

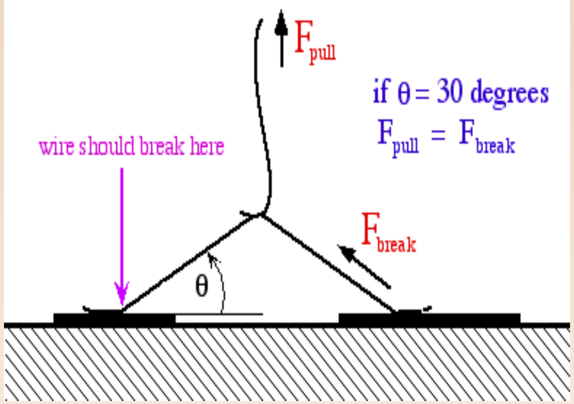
Wire loop should be such that one gets a 30° angle at each bond foot when pulling at the midspan. If a different angle is obtained, the pull strength should be corrected for the angle effect. (Note: wire used is 99% Al, 1% Si, 25 µm diameter, medium hardness)

Number of wires: at least 10

Mean pull strength: 5g

RMS of pull strength: <1g

Number of lifts allowed: <20%



We would have specified 8g mean pull strength but we had to keep it to 5g because one machine (a Hughes deep-access bonder) could not make 8g strength bonds. In reality, all other centres usually did better than 8g anyways.

The 3 page module bonding procedure (can be found on website) was agreed on by all centres and (hopefully) followed by them. The official procedure evolved as needed and there was quite a lot of feedback from the centres. However, this did not mean that everything went smoothly. There were plenty of problems but the wire bonding never became the bottleneck of the production.

Areas of improvements

What did we learn that we should have done differently? Did we miss things that could have improved the production?

1. Although costly, a personal visit by the coordinator to each centre prior to production would have helped to see if some centres needed more assistance or guidance.
2. Except for the test structure bond test used to qualify the bonding centres prior to production, there was no further "blind" bond testing, we trusted the centres to self-test and report honestly. I learned later that a few centres had un-reported problems and may have made some or many modules with a quality inferior to the specifications.
3. We did not anticipate the large number of repairs coming from damage during installation but unfortunately this did occur. However, this problem is not really the responsibility of the bonding centres (but rather of the integration centres and the detector design). Still, a stronger role for the input to the integration centres and detector design from the wire bonding experts could have helped reduce this high level of damage. This is easily said in retrospect but given the schedule pressure at that time, decisions are often made hastily and can lead to high risk of damage, in this case the decision <u>not</u> to encapsulated bonds.
4. Did we really need 15 bonding centres? Roughly ½ of the bonds were made by only 2 centres (CERN and UCSB) using a total of 4 machines. Clearly only 2 more centres like CERN or UCSB would have sufficed but the number of centres was driven by "political" constraints not technical ones. It would have been much less difficult on the QA, organisational and logistical levels to have had only 4 bonding centres rather than 15.

Conclusions

- The CMS tracker bonding task benefitted greatly from the working group organisation and a coordinator. I don't believe such a large number of collaborating centres could have reached the required level of quality and throughput by just working on their own.
- Large collaborative projects require extra overheads such as complex logistics and an efficient database. Wire bonding is no exception. Also, be prepared to provide for contingency for repairs during installation.
- A well planned QA strategy can avoid a number of problems. It should start with a comprehensive specifications and procedures document that is agreed by all participants.
- Compliance can be an issue but I suspect an "everyone knows what they are doing" policy could end up with bad surprises. Certainly a set of qualification criteria to become a bonding centre should be agreed to and compliance should be mandatory.
- Reasonably frequent meetings, an updated working group website, and information sharing (especially about problems!) are recommended.