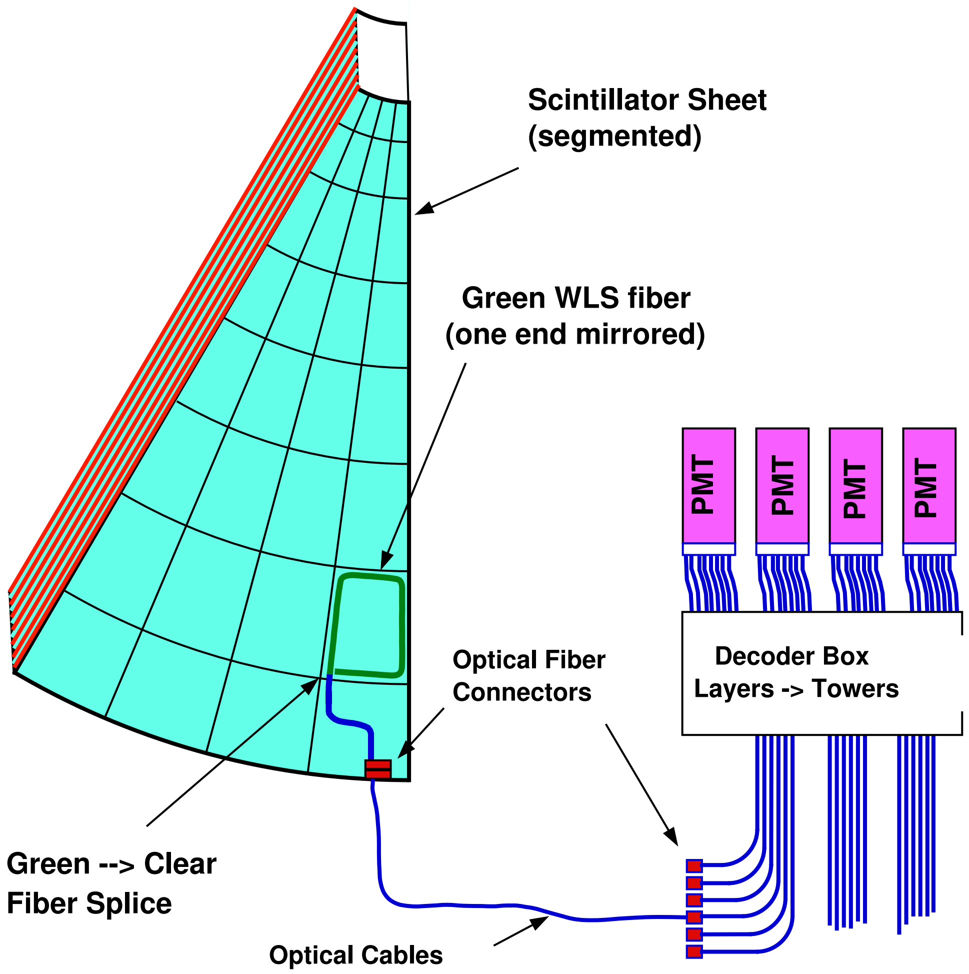
Large Scale Constuction: CDF, CMS, and CDF→CMS Experience

- Howard Budd - University of Rochester
- This is my view on quality control and production having worked on both these projects.
- Arie Bodek
- Pawel de Barbaro
- Yeon Sei Chung (CMS)
- Willis Sakumoto (CDF)
- Along with many other people from both experiments and Fermilab people.

Outline

- Tile - Fibers.
- My View of QC.
- The CDF & CMS QC procedures.
- CDF R&D and production.
- CDF$\rightarrow$CMS.
- QC Stories and Applying the QC Principles.
- CMS Production.
- Conclusion.



- Scintillating tile arranged in projective towers.
- Readout = Wavelength Shifting fiber $\longrightarrow$ clear fiber $\longrightarrow$ clear cable $\longrightarrow$ Decoder Box arranges layer geometry into tower geometry $\longrightarrow$ PMT.
- A design philosophy
  - Seperate the components for production.
  - The scintillator tiles and fiber pigtails were made seperately. The fiber pigtails were inserted later. This enables the production to be broken up into groups. It enabled the production to go easier and enabled the package to be repaired easier.
- Discuss scintillator pans, fiber pigtails & optical cables.

Size of Project

- CDF - 480 megatiles
- CDF - 1900 fiber pigtails
- CDF - 17000 tiles

- CMS - 2300 megatiles
- CMS - 2450 fiber pigtails
- CMS - 38000 tiles
- CMS - 8000 Optical cables

My View of Quality Control

Note, unlike electronics where once you make the solder connection the transmission is 1, everything in fibers and tiles is analogue.
You do something wrong, you lose light!

- Quality Control has 2 purposes:
  - Easy one - It should test the each final component to be sure it works in the final apparatus.
    Rejecting parts based on a cut from QC.
  - Hard One - The QC should determine if production is going OK.
    Final QC should closely follow production in time to ensure all components are OK.
    - The final QC should check the first prototype before the rest are built, preferably before the rest of all the components are built.
    - All elements of production should be ready, before one goes into production on the parts.
    - This means the design and building of the QC takes place at the same time as the design and building of the prototypes.
    - All this may seem obvious, but is not necessarily what happens.
    - You are paying techs $$$/month, but some production task cannot be completed. You don't want them sitting around.

    - And not all the QC is in place, but you are still paying techs $$$/month.
    - So, you go into production on certain components, even though you can't produce and test the final product.
- QC tests on the components should be as close as possible as to how the apparatus is used in the experiment.
  - If it is a simplified test, a study should be done to see how it addresses final preformance.
  - The QC should give simple, reliable answer.
    People, physicists and techs, can spend lots of time trying to understand non-reliable QC data.
  - The QC should be able to give you an overall view of the construction.
    You should be able to compare a part made in the beginning with a part made at the end.
- There should be some type of QC in place for testbeam. Again it is best if it can follow production in time.

Production Quality Comes from the Design and Production Procedures.

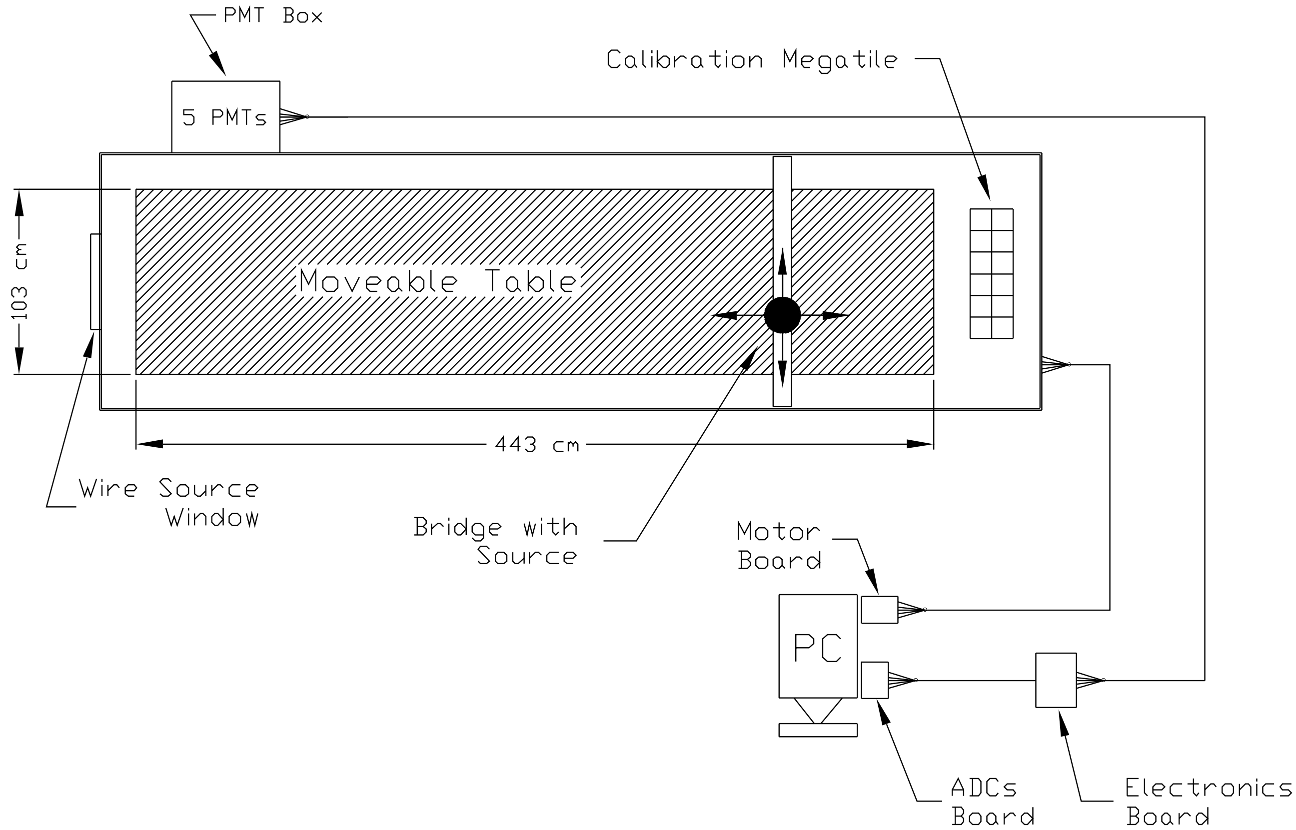
The detector design and the production procedures should be simple enough so that it is easy to build a quality device.

- Quality comes from the design and production procedures.
- This is done by trying to have assembly procedures which are simple and robust.
  - The CDF & CMS design enable seperation between the pan production, fiber production, cable production and descrambler production.
    This simplified all tasks.
    - This decision for CDF was the result of combining all components together in the testbeam module. A variety of broken fibers existed in that module.
  - In CMS the splice machine was very easy to use and didn't require user intervention.
    (unlike the CDF splicer.)
  - Ice polishing for CMS gave simple and good fiber polish for splicing and mirroring.
    (As opposed to the individual fiber polish of CDF which required the machine to be tuned just right.)

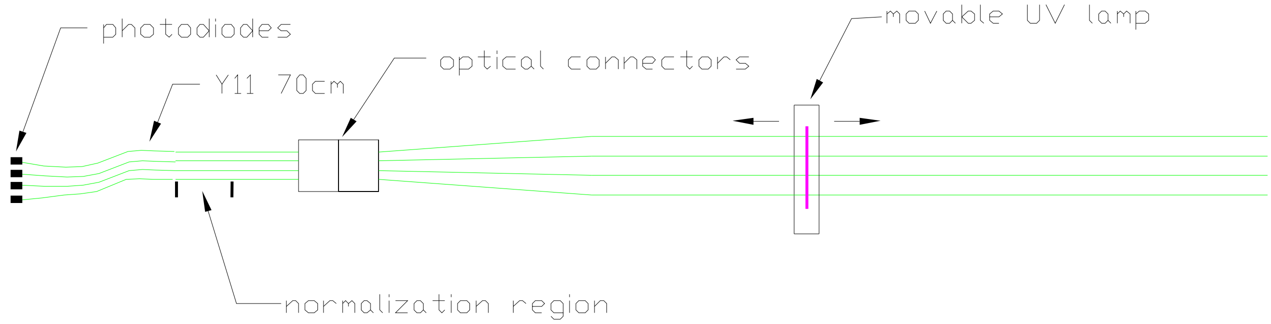
- The fiber had to say in the scintillator groove. Test were done to ensure that if the techs mishandled the megatiles they would still be OK. Procedures were setup to be sure they were handled OK, but if they made a mistake, it wasn't a disaster.
- In CMS, fiber insertion was designed to be easy. (It wasn't so easy in CDF.)

- Procedures were documented for the production process
- Check lists were made for production processes.
- Obviously, In the best QC situation, the design is so good that QC tests doesn't find problems.

QC Procedures (CDF and CMS very similar)



- The final QC on the scintillor pan was a scanner with a collimated Cs137 gamma source collimated with a lead cone. The tiles were read out with phototubes. In addition there were normalization tiles to understand the normalization.
  - The megatile scanner worked well. The decay of a source is well understood, and the PMTs were stable.
  - The wire source was run on the pans and the ratio of collimated to wire was compared.
  - The result was simple, reliable and we could compare the beginning of production to the end.



- The fiber pigtails were tested with UV scanner and read out by pin diodes.
  - But, we could not compare fiber pigtails from one layer to another, only within a layer.
- In CDF, Y-11 fibers were QC with the same UV scanner as the pigtails
- The splice transmission was tested for each layer with UV scanner.
  - Y-11 Fibers scanned.
  - The fiber cut and spliced.
  - The fiber scanned across the splice.
- Fiber mirrors were tested
  - Fiber scanned near end with pigtail UV scanner.
  - Mirror cut off and end painted black.
  - Fiber rescanned near end of fiber.
- In CDF, clear fiber was not QC, although it was studied during the R&D.
- In CMS, the clear fibers were QC with a cutback test which used a source and scintillator.

CDF R&D and Production

- R&D for tile-fiber production started in summer 89.
- R&D took about 4 years.
- R&D became more intense in winter 90.
- 2 testbeams - summer 90 and summer 91.
- After 2d testbeam, there was an intensive effort to finish the design for production.
- Production started about 2 years later, in spring 93.
- All the i's need to be dotted and t's crossed.
- Production finished fall 94.
- Production started with the scin pans in spring 93.
- Techs were hired and we were paying them $$$/month.
- Fiber pigtail production did not start till late fall 93.
- It took another 4 or so months before pigtail production got up to full speed.
- Hence, final assembly was 6-9 months after pan construction
- We put fibers in a couple of megatiles to be sure they were OK.
- But we could not QC each pan with fibers until much later after the pan was made.
- So, QC did not follow production and QC could not influence scintillator pan production.
- We did not run into a problem because of this.

Going From CDF $\rightarrow$ CMS

- After SSC was killed, Rochester joined CMS to build the megatiles for CMS HCAL.
- The CMS decision was to use tile-fiber technology for hadron calorimeter.
- The design of the absorber was fairly well worked out.
- There was a good understanding of how things would be done.
- We tried to do as much as possible the same for CMS as CDF.
- But there were differences.
  - The megatiles were difference size, barrel instead of endcap.
  - In CDF, alum structure supported the megatile, but this could not be done in CMS.
  - 16 fibers/megatile instead of 10 fibers - new optical connectors.
  - Megatiles were much longer.
  - etc...
- But it didn't seem the differences were that much, but there was 3 1/2 years of work before production started.
- Winter 95 - Summer 96: 2 testbeams to clarify the design.
- Summer 96 - Summer 97: Clarify the design, do the cost estimate, WBS, and the Lehman review.

- Summer 97 - Summer 98: Dot the i's and cross the t's. Make production procedures simpler and more robust.
- Summer 98 - Make the 1st megatile and test it with the megatile scanner.
- The QC we had at that point was the collimated source megatile scanner
  - But we did not have the fiber scanner.
- Summer 98 - Summer 99: Make 2 sets of megatiles for each layer.
  - The fiber scanner existed for the second set.
- Summer 99 - Winter 02: Production of megatiles
  2 1/2 years

QC Stories and Applying the QC principles.

Do You Need QC for a Testbeam Module? QC should closely follow production.

- For the 2d CDF testbeam a full module was built
- The fibers were glued into the tiles in a U shaped pattern in the hadron calorimeter.
- The epoxy CDF was using was Bicron BC-600 epoxy (We still use this epoxy)
- But BC-600 is not radiation hard.
- EPOTEK-305 is more radiation hard, but the CDF group hadn't used it.
- They asked a group which used it whether EPOTEK-305 damages fibers
- They answered, correctly, no.
- But that group only glued fibers in a straight grooves while the hadron calorimeter used curved grooves.
- In curved grooves EPOTEK-305 destroys the cladding and transmission of the fiber. It destroys the cladding fairly quickly.
- The production of the hadron testbeam module did not have adaquate QC in building it, and all the fibers in the tiles were glued in with EPOTEK-305.

- This badly damaged the testbeam hadron calorimeter.
- The fibers in the tiles were drilled through to make the transmission in the tiles the same for all the fibers. i.e. zero.
- This calorimeter was used for the testbeam, but it didn't get much light.
- The is a good illustration how you try to get QC to keep up with production. (If you have QC)
- Note, in CDF and CMS we did not glue fibers in the production module.
- Note, in CMS all testbeam devices were subject to QC.

QC Following Production Can Catch Problems

- In CMS, about 1/2 way through production, Kuraray starting shipping us bad scintillator.
- Note, their tests showed the scintillator was bad, but they sent it anyway. We do not know how high in the company they knew this.
- We were not monitoring scintillator at this point, We thought Kuraray was a good company.
- The problem was picked up in the final QC with the megatile scanner.
- By having the QC follow production, we were able to pick this up.
- The advantage of the source in picking this up was we were able to compare tiles made at various times and different layers.
- The fiber scanner data was not as useful to understanding whether the fibers were a problem. One could not compare fiber pigtails of different layers (essential different lengths). This is a problem with the light scanners.
- This stopped production for a couple of months.
- In CDF, final QC did not follow production and it is not clear we would have picked this up until very late in production if it would have happened in CDF.
- One should maintain all QC even if you think the company is reliable company.

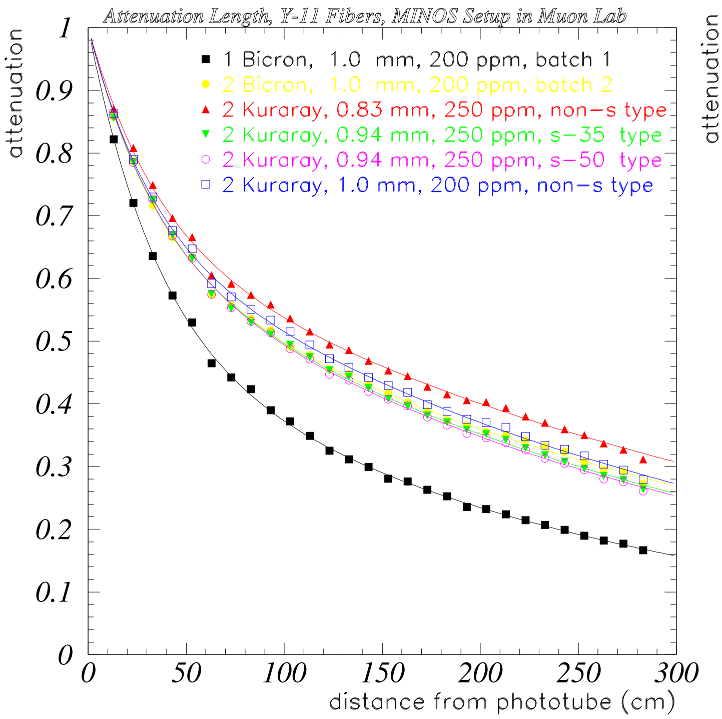
Information from Fiber QC and Final QC How They Can Work Together.

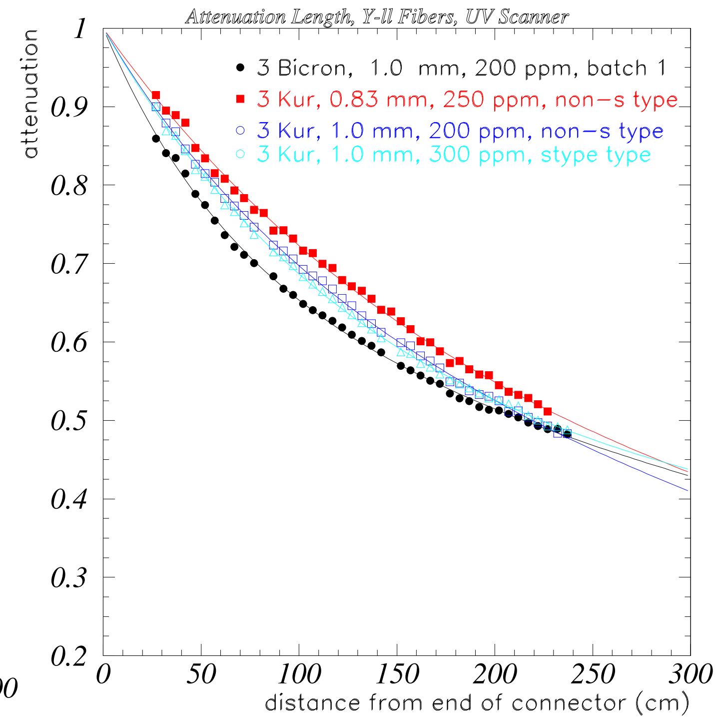
- In CDF, small % of the towers(I don't remember the exact number) failed the final QC.
- Some were understood, but a large % were not understood.
- It was said "its just a bad splice".
- But the fiber pigtails were tested in the UV scanner and were judged OK, what's happening?
- Well the % was small and so we just fixed the pigtails.
- About 1/2 the way through we decided to investigate.
- Reason was due to tiny cracks in the fiber cladding in curved portion of megatiles.
  - The Kuraray fibers in the megatiles are called nonS-type
  - They are not very flexiable, but according to our R&D they should not have failed.
  - These nonS-type fibers splice better than the flexible ones(S type)
  - Apparently high stresses in certain parts of the fiber caused it to crack when bent.
  - The problem was understood by working with the megatile scanner and the fiber scanner QC.

- Although nothing could be done about it for CDF, the problem was fixed for CMS,
  Another step in making the construction procedures for CMS robust.
- Kuraray made S-35 fibers, an i that needed to be dotted.

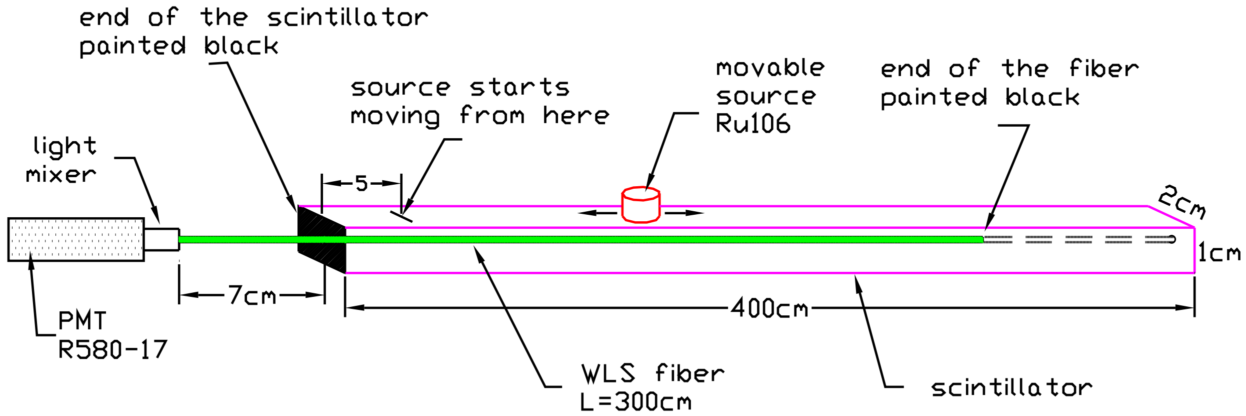
- In CMS the problem did not occur.

QC Tests Should Be To Close Actual Use





- Attenuation length of different WLS fibers.



- The left plot measured with the MINOS setup
  It uses source, scintillator and PMTs.
- The right hand plot uses with the CDF UV scanner
- The numbers after the symbols in the plots state the number of fibers measured.

- The CDF fiber scanner was used for the QC of the Y-11 fibers for CDF.
- However, the left plot indicates a bad batch of Bicron fiber as compared with the good Kuraray and Bicron fiber.
- However, the scanner test can't tell the difference between the bad Bicron and the good Kuraray fiber.
- The CDF Y-11 fiber QC was not reflecting the actual performance in the calorimeter and could not have picked out the problem with the Bicron fiber.

You should have some control of needed apparatus.

As previously stated the CDF Y-11 QC doesn't work.

- It can be shown that testing Y-11 fibers with MINOS setup is a reliable check of the QC of Y-11 fiber.
- (The apparatus still exists in the tunnel of Muon Lab.)
- We wanted to use the setup to QC our Y-11 fiber.
- Unfortunately, we didn't control the setup.
- There was a variety of times we couldn't use the setup.
- In addition, It kept being disassembled.
- Our scintillator was left out in the light and that destroyed the scintillator.
- There is a setup in Lab 6 which uses UV lamp and pindiodes, but it was down when we wanted to use it.
- Net result was the QC of the Y-11 fiber was barely done.

Design Criteria - Some Thought Need

The design criteria may include non physics criteria - These criteria may be obvious, (but unstated), but somehow it is missed by the people incharge of a part.

- In CMS, to repair any electronics in the pit, the all optical cables must be removed from the optical decoder unit (ODU).
- This means that the optical cables must be easy to connect and disconnect for an untrained person.
- For instance, a post-doc and grad student who join the experiment after it starts may have to exchange electronics in the pit. They do want to do their job and at the same time not bust a bunch of optical fibers.
- However, the optical cables were hard to connect for various reasons.
- A set of optical cables were brought to CERN to test the first barrel megatiles.
- The people at CERN there discovered cables were very hard to connect and they broke fibers in these cables.
- Infact, they were so hard to install that the megatile performance did not look good.
- All cables were already partly built.

- We spend 9 month of R&D to figure out how to make the cables easy to install, without badly effecting the performance.
- Fortunately, we found a solution.
- We traded off some performance for ease of installation.
- In retrospect, ease of installation should have been a top design criteria, but clearly, it was not there on the connector machine drawing.

QC Devices should give reliable answers.

- We QC optical decoder cables and optical cables.
- The QC device used LEDs to light the fibers.
- The light was read out by pin diodes.
- However, there was no normalization in the device.
- Therefore, one of the optical cables we were testing became the normaliztion - called the "Golden Cable".
- But the "Golden Cable" could and did become damaged.
- There were many cables which became "Golden" over their short lifespan.
- Therefore the normalization became suspect.
- THe RMS of the QC was probably larger than the RMS of the cables.
- This device was easy and fast for the techs to use.
- But it was very difficult to understand it data, and we spent a lot of time on this normalization question.
- One could not tell if a change in quality took place throughout production.
- QC devices should give simple, reliable answers.

- The problem with the pigtail fiber scanner was you couldn't compare one layer with another.
  But it could maintain its calibration well.

Dynamics of Manpower and QC, A Word of Caution

- Once the people are hired for the project, you are spending $$$/month on the project.
- The experiment tells you need to get the apparatus finished by a certain date for beam.
- There is very strong pressure to keep people busy on production, even if the final QC of the parts is not available or has to be delayed for some reason. All the production steps may not be there to make the final part.
- Management complains why your burning through all this money.
- There is no simple solution.
- For CMS, we produced the HB (barrel) ODU cables. and HE (endcap) ODU cables.
- After producing all the HB ODU cables, one would thing that you have a good handle on QC.
- In addition, why should gluing the fibers in the connector have any effect on their quality.
- As we had idle people, we gave them the job of gluing the optical fibers in the connectors.

- But fiber holes are larger for HE connectors than HB connectors
  - HB cables were 18 fiber
  - HE cables were 12 fiber
  - They were made by the same company.
  - The tolerances of the HB connectors were carefully studied.
  - But the HE connectors were not as well studied.
- It was the gluing of the fibers in the larger holes had the biggest effect on their quality.
- We found this out after all the HE ODUs cables were glued. and we were trying to understand the larger RMS.
- Just because one production step is well understood doesn't means that a nearly identical production step is also well understood.

The CMS Production

- Note that amidst all the problems stated above everything has been shipped to CERN and satisfies the criteria for performance.
- The CDF megatiles are taking data.
- Much more QC and measurements were done than described here.
- Although this may seem obvious, a crucial element was a talented work group, with a variety of talents. These included people outside our group.
- 2 techs were given responsibility for running production.
- The techs were given the responsibility for running the QC programs to get the final answer, so that any problem could be seen as soon as possible. This was a different philosophy than CDF where physicists ran the final QC programs which stated how a part or step was preforming.
- We delegated resposibility to techs in CMS which engineer and physicists had in CDF.
- Note, that physicist did run the QC programs, but the techs did it on the day to day basis.
- Any deviations from expected performance were reported to us.

Conclusion

- Building a detector requires a lot of work.
- Both CDF and CMS had roughly 3.5 years of R&D before production.
  Even though we had the CDF experience to draw on for CMS.
- It takes a while to dot the i's and cross the t's.
- Quality is built into the design, production procedures, and testing apparatus as the components and procedures should be simple and robust.
- All assemply procedures should be ready at the start of production.
- All QC devices should be ready at the start of production.
- While production is taking place the QC should be measuring the parts to ensure all parts are OK.
- This enables the QC to feed back into production.
- The QC devices should give relevant and robust information.