Experience with services for the CMS Tracker endcap

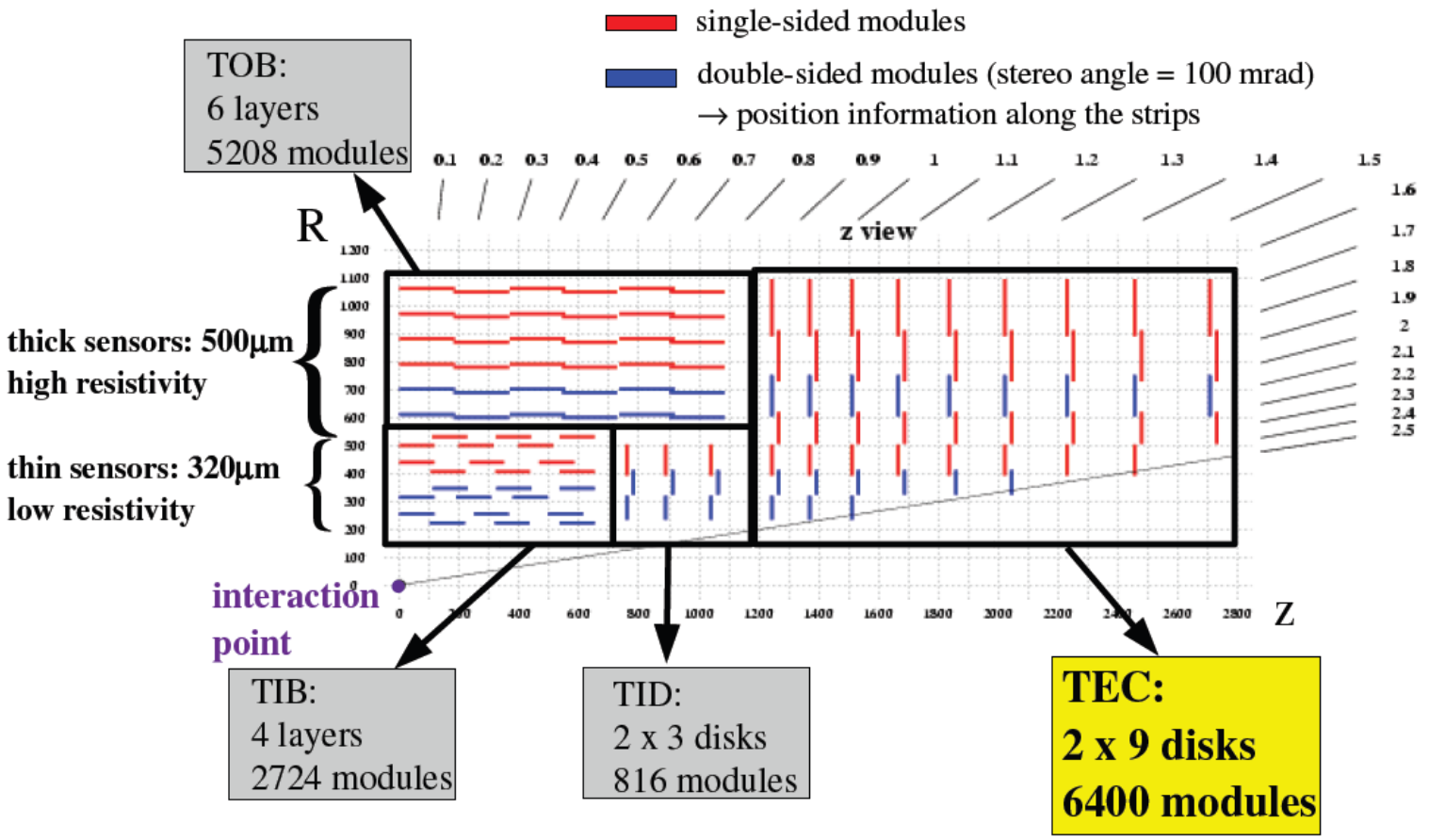
The Good, The Bad and The Ugly

Nick Lumb

CERN, 3 July 2012

CMS Tracker Endcap: Overview (1)

Cross section of one quarter of the tracker:



⇒ TEC comprises 42% of the modules of the tracker = 82 m² active silicon area

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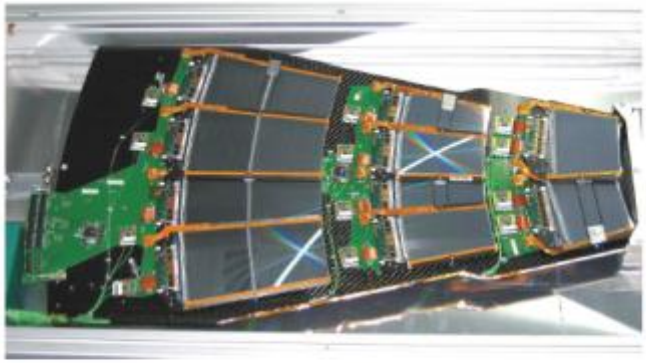
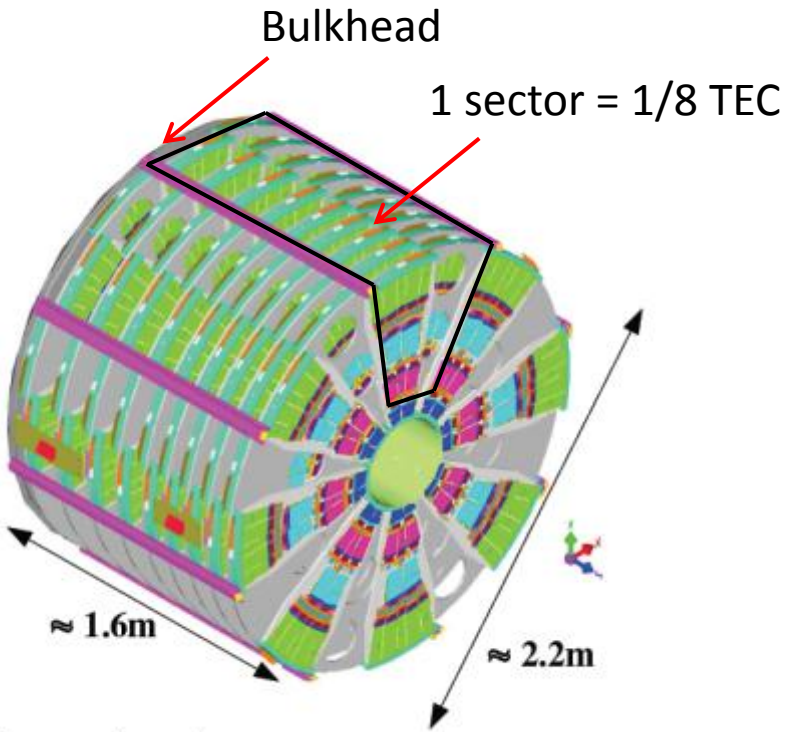
CMS Tracker Endcap: Overview (2)

The TEC features a modular design:

Silicon modules are mounted onto both sides of carbon fiber (CF) support plates: "petals"



≈ 80cm



End cap structure:

- Populated petals installed into TEC structure
- 16 petals per disk
- 9 disks and 144 petals per TEC

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CMS Tracker Endcap Services

The goal of this forum is the exchange of experience obtained during the design, construction and installation of the current LHC tracking detectors.
We aim to evaluate where ample or insufficient emphasis was put.
We wish to highlight the problems encountered and the excellent solutions found, in order to improve performances and reliability of future tracking detectors.

This talk will try to achieve the goal of the forum
by highlighting 3 case studies key to the delivery of the CMS tracker endcap services:

- Optical fibers
- Cooling circuits
- Power cables

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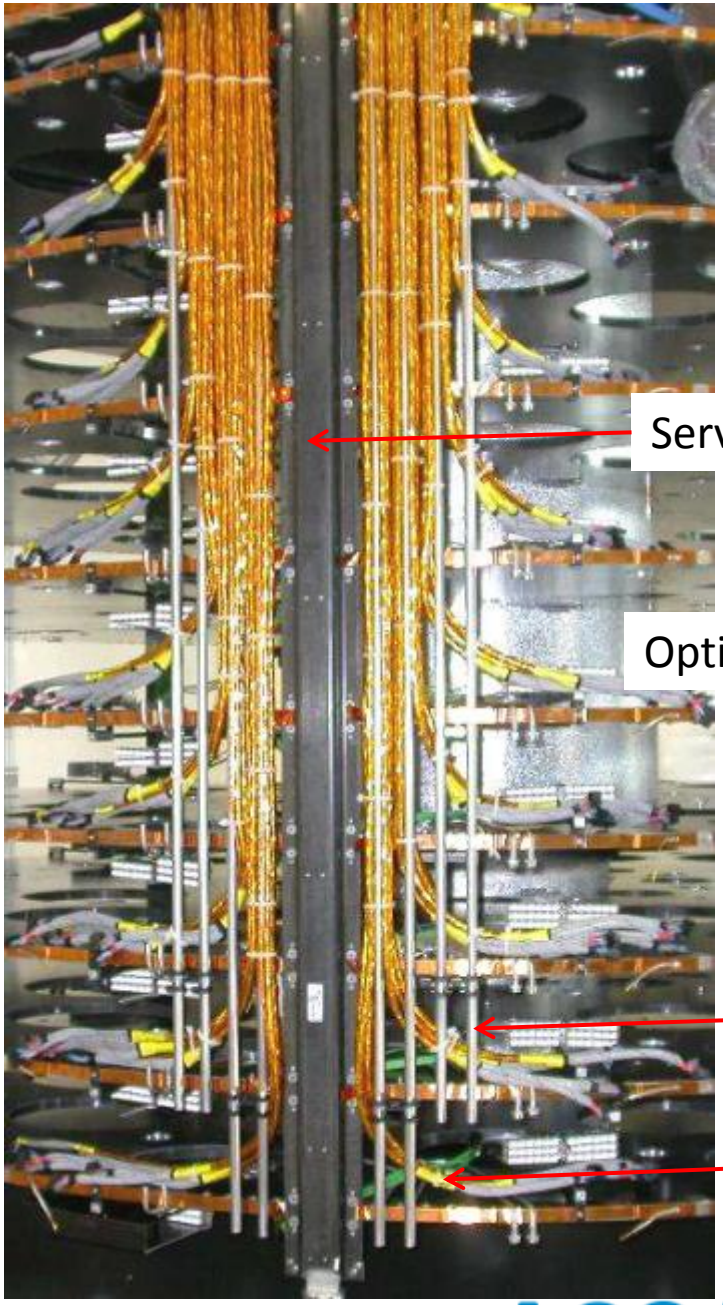

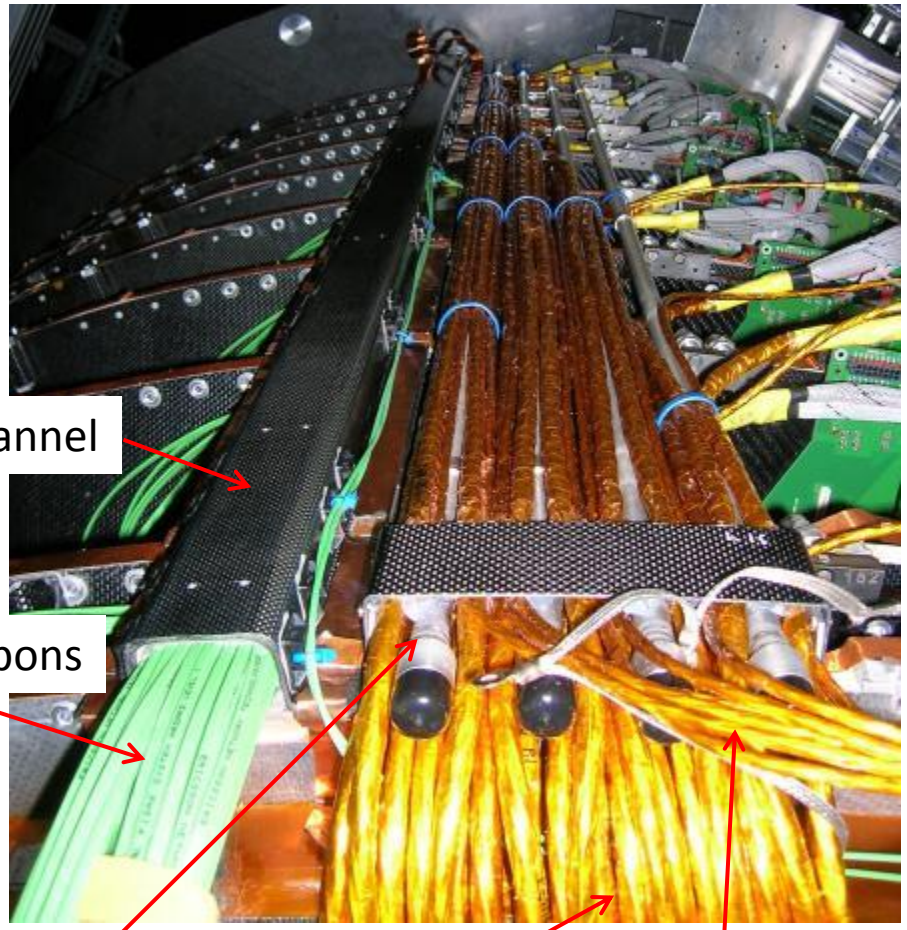

Service channel

Optical ribbons

Cooling pipes

Digital power

Power cables (HV, LV)

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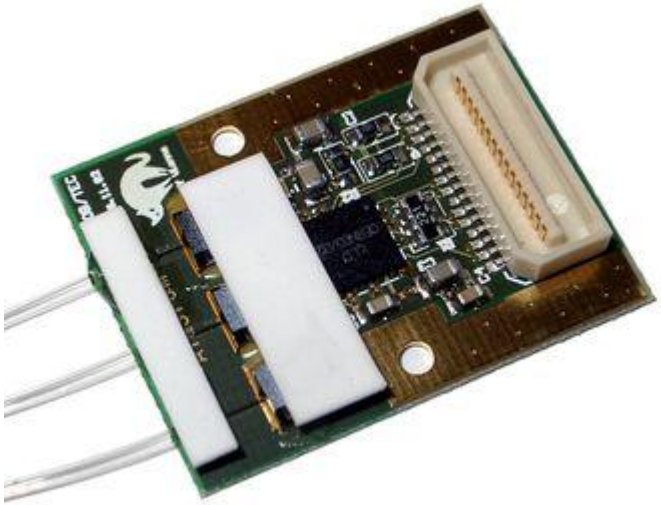
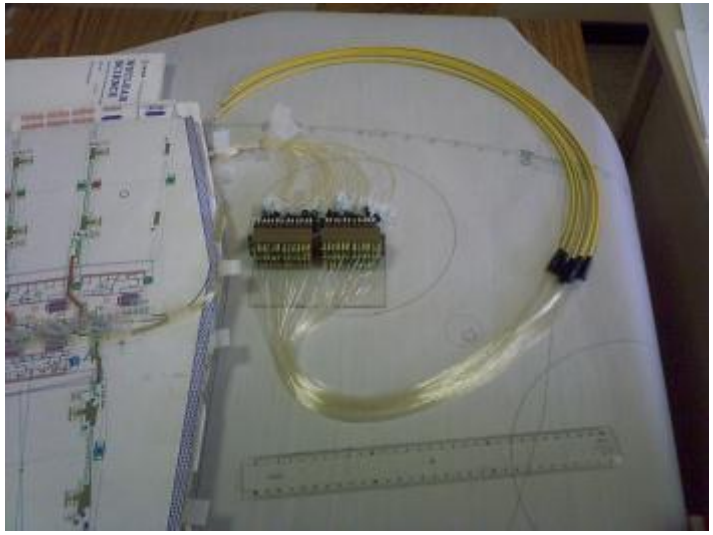
Optical fiber mechanics



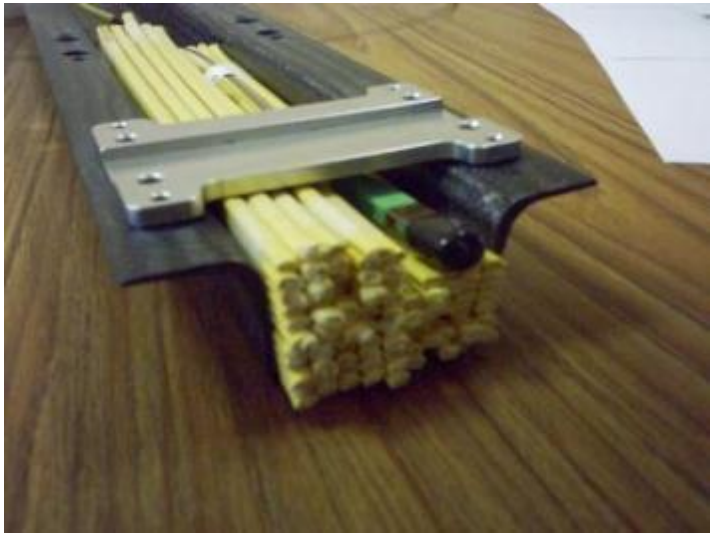
- Opto hybrids manage data transmission / receipt from petals
- Three individual fibers per analogue opto hybrid
- Up to 64 fibers per petal
- Fibers fanned into ribbons via connectors at disk edge
- Need mechanics to manage connectors and spaghetti of fibers

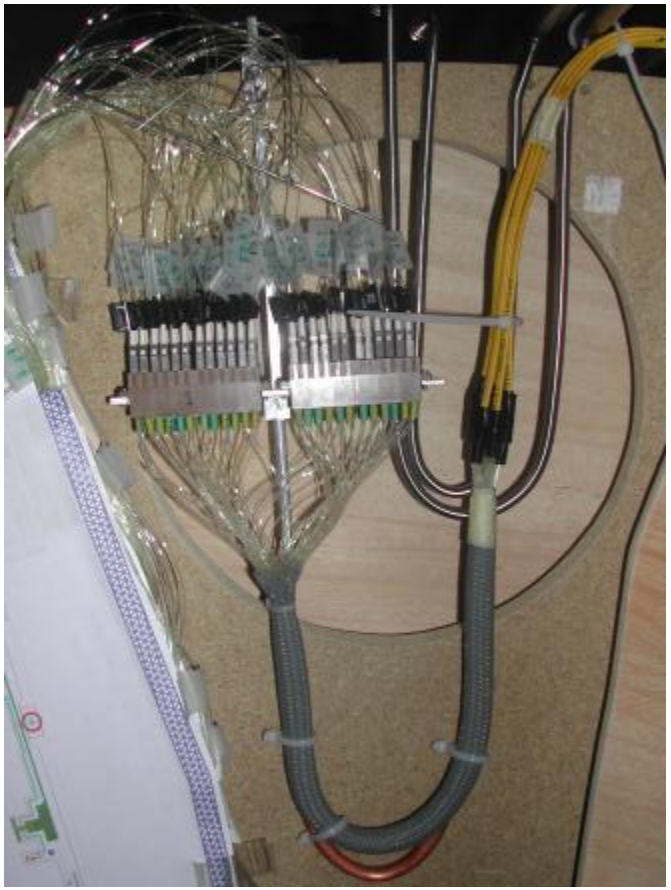
Optical fibers: mock-ups



Routing individual fibers from petal to connectors

Order of ribbons within service channels





Routing of ribbons into service channels from ‘fiber mechanics’: mechanics must move radially to allow plugging of connectors

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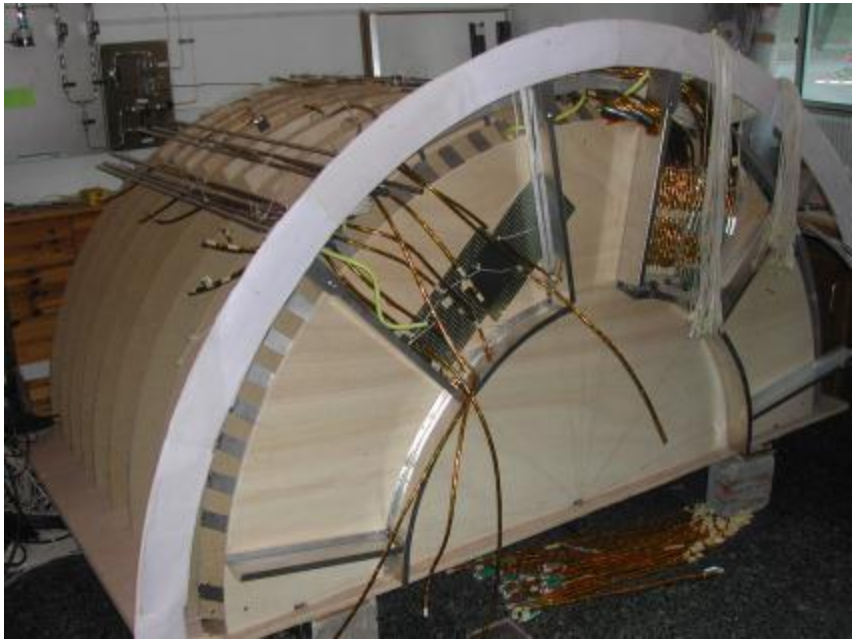
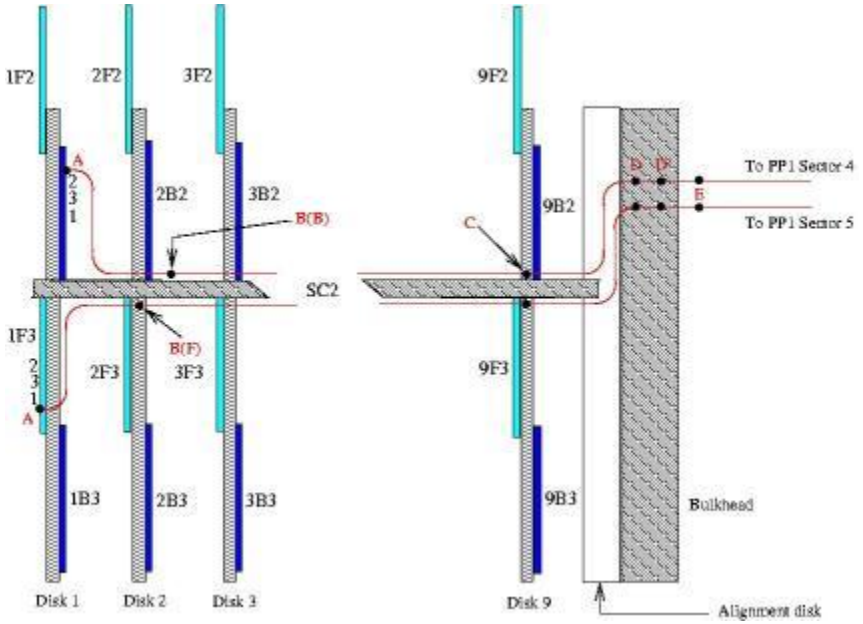
Full-scale mock-up





- Allows ribbon lengths from petals to bulkhead to be estimated
- Determines routing at bulkhead

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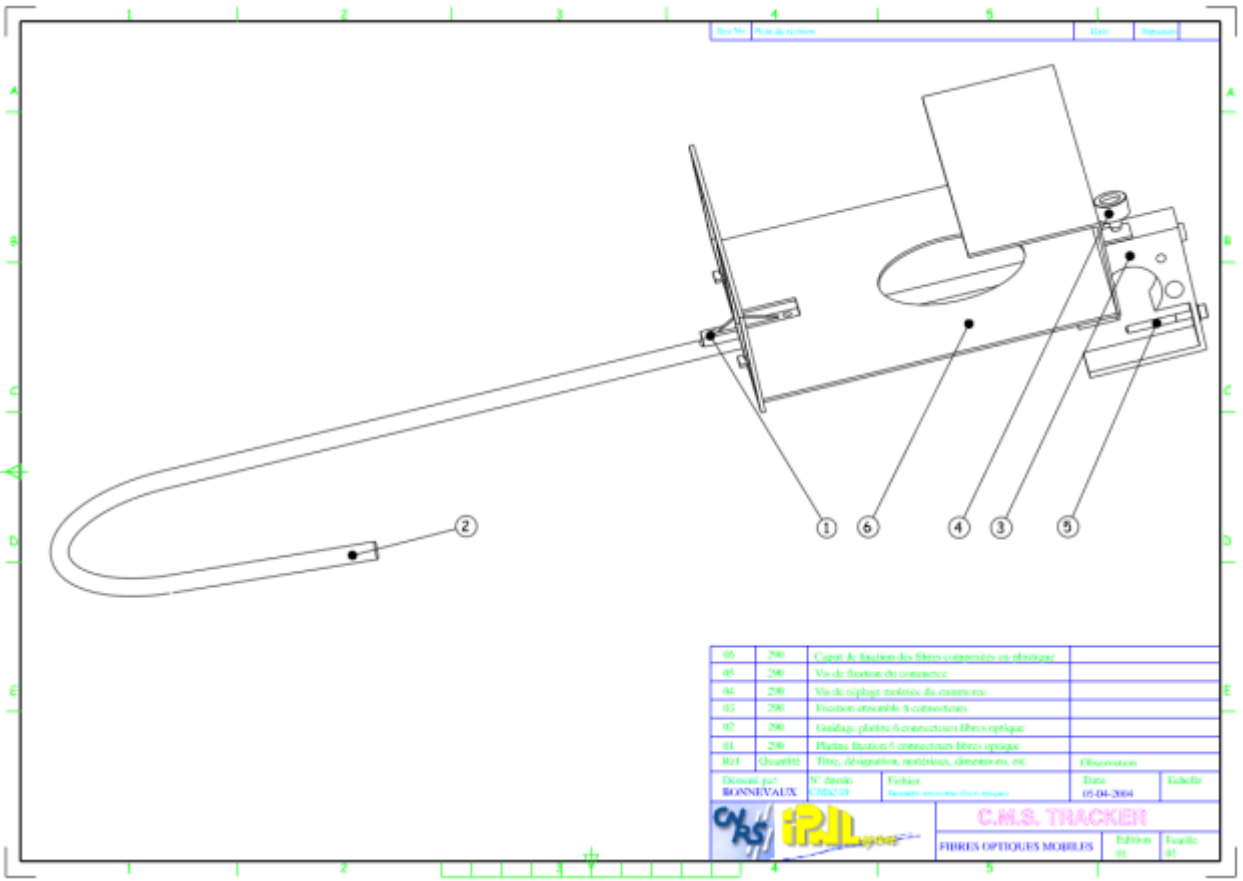
Fiber mechanics: original design



Whole mechanics within TK volume (needs to be light!)
Original design foreseen in aluminium, and quite bulky

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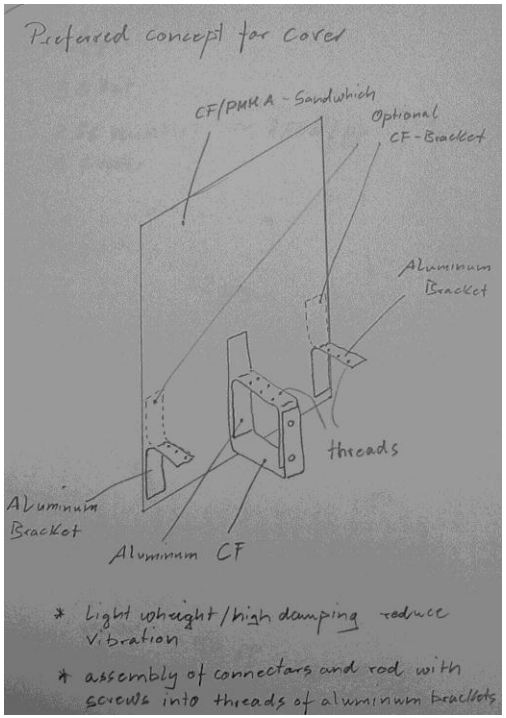
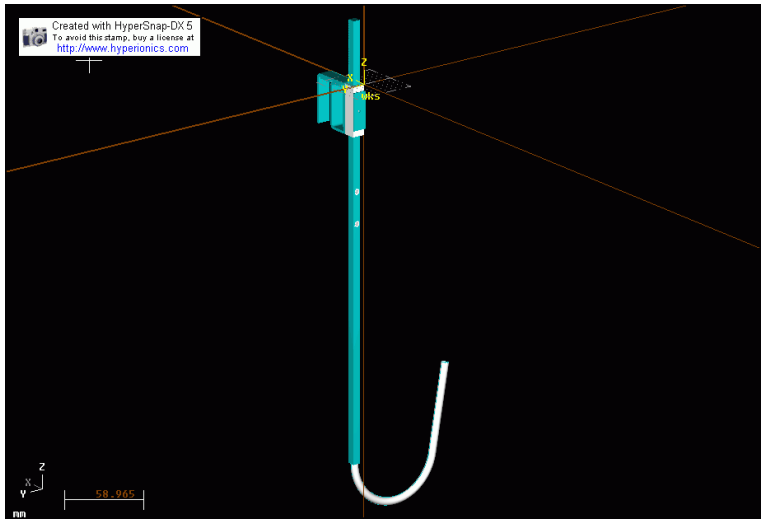
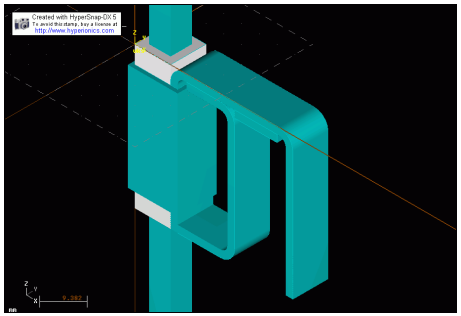
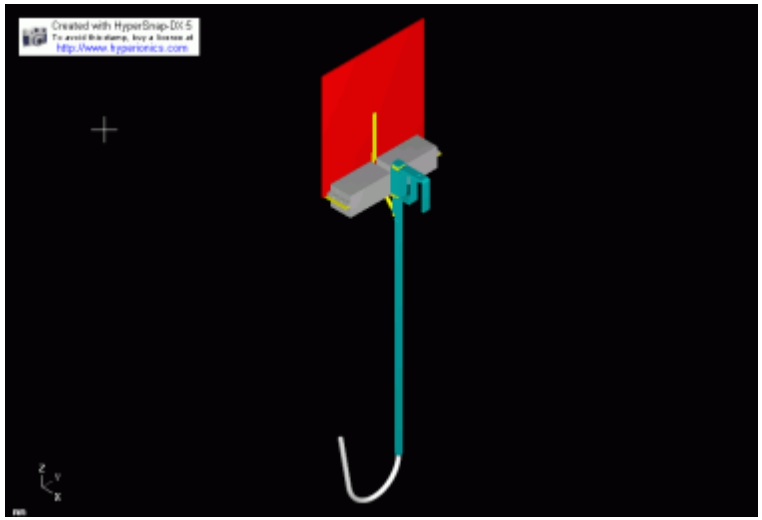
Fiber mechanics: production









- Contact made with ADCO company
- Aim to construct in carbon fiber, based on original design
- ADCO take charge of new design, working out many of the small details

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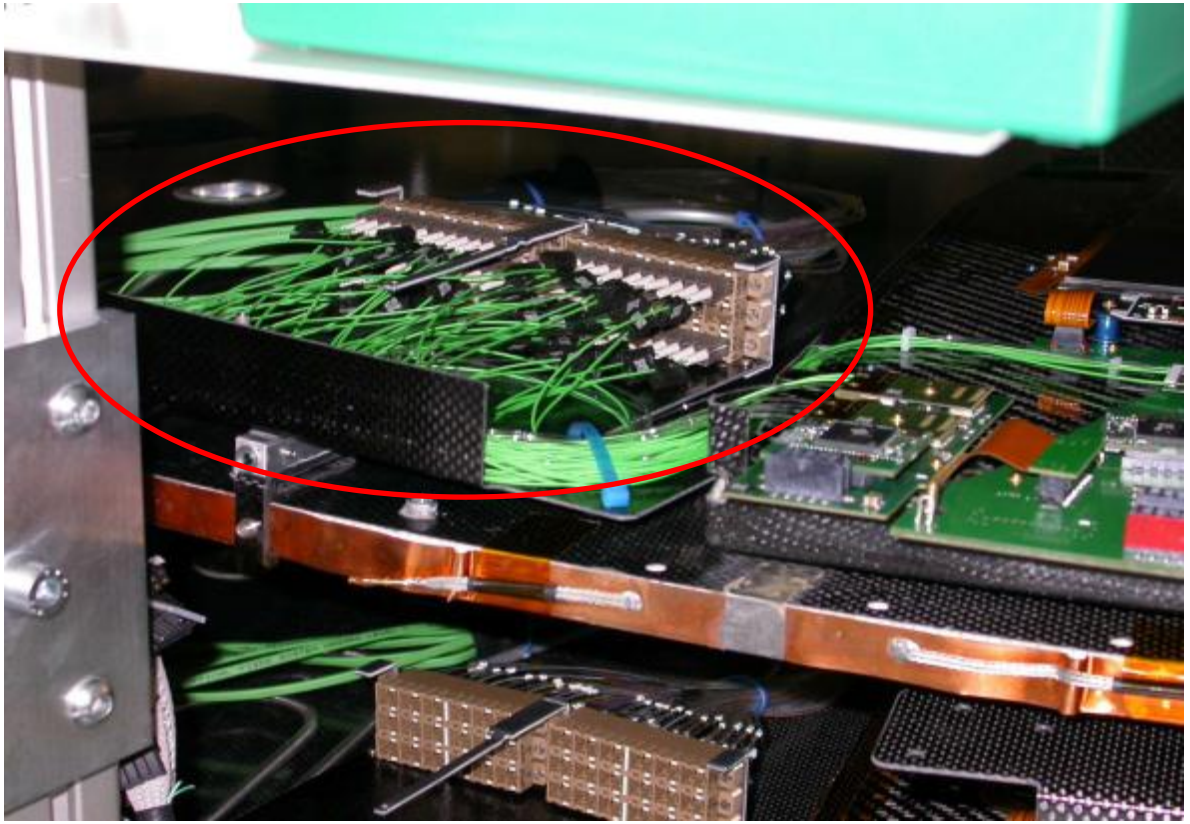
Final product



Final product is lightweight solution which does the job

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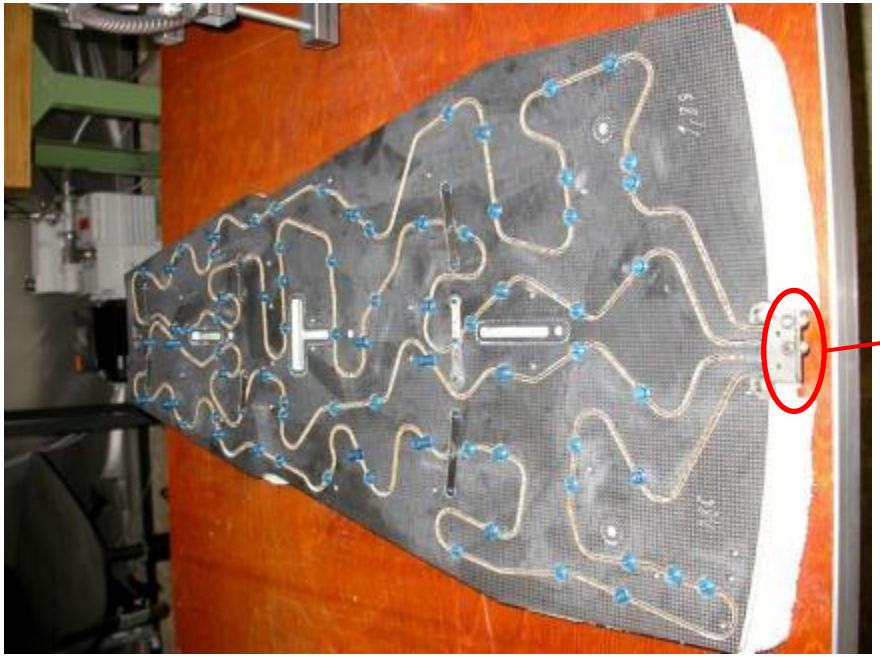
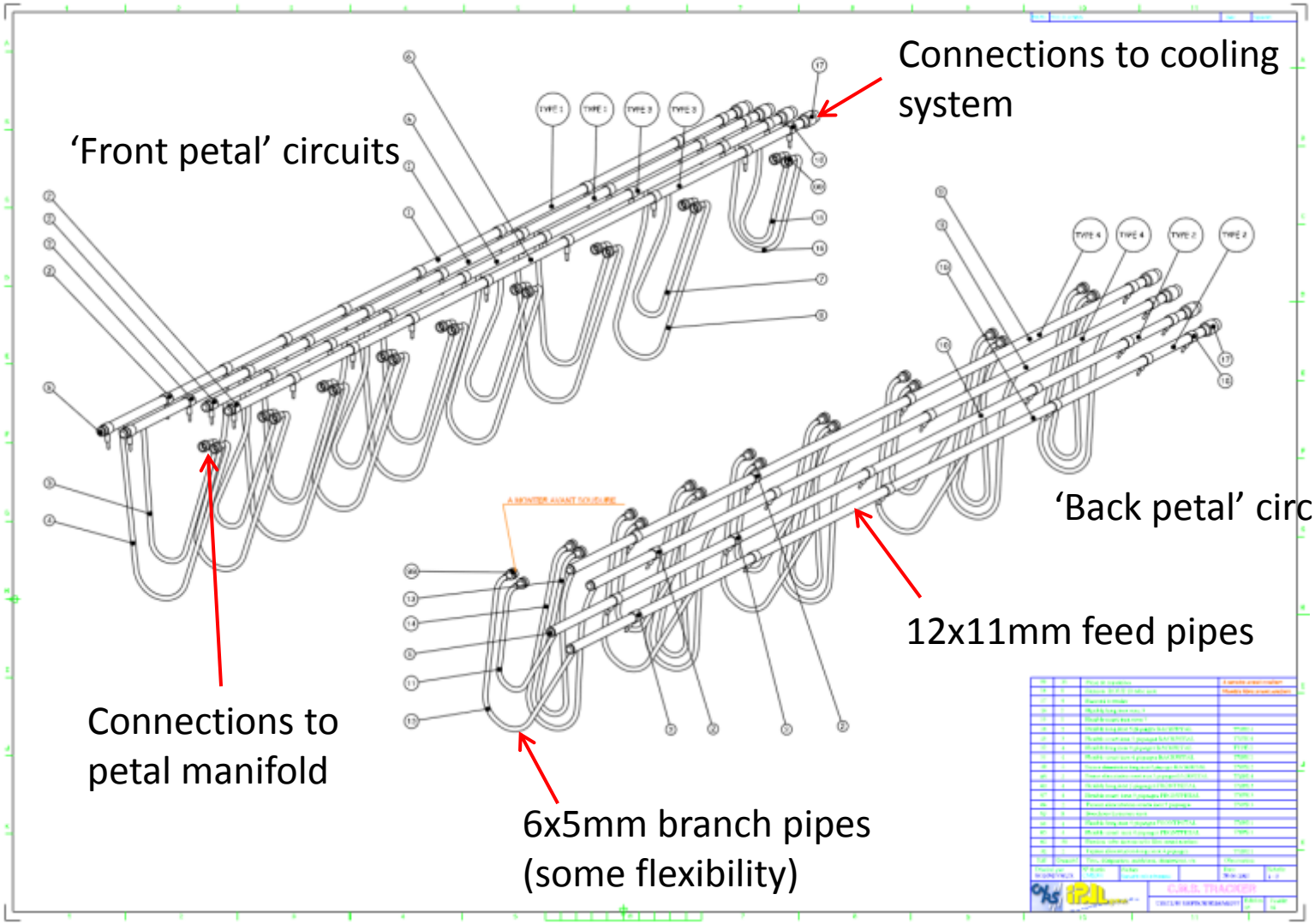
Cooling circuits: inside petals



- Titanium pipes, 3.4 mm inner diam., 7 m long
- Very complicated path, special jigs required
- Laser welding of pipe to manifold requires specialist techniques

Longitudinal cooling pipes: 4 circuits / sector



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Longitudinal cooling pipes: constraints

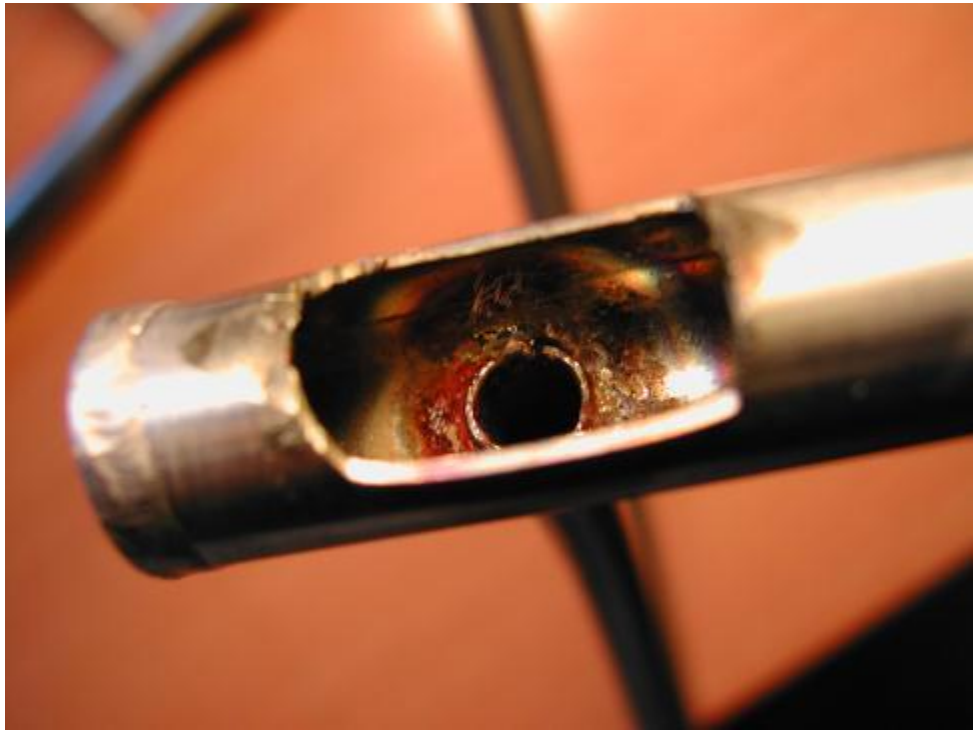
- Lightweight within tracker volume
- Leak tight!
- Mechanically precise enough to mate with petal manifolds
- Cost
- Time pressure

Routing of branch pipes within TK volume is non-trivial. After many corrections, production drawings are finalized and a call for tender is launched. Contract awarded to UK company Lancashire Fittings.

Quality control

- All pipes pressure tested at 20 bar at Lancashire Fittings
- Visual inspection upon receipt
- All pipes re-tested at 20 bar (nitrogen) at IPN-Lyon (15 minutes)
- Mechanical tolerances tested on purpose-built jig
- Flow tests:
  - Flowmeters installed between each petal in / out connector (max. 5 per circuit)
  - C6F14 circulated in circuits
  - Require flow variations between petals < 5%

Prototypes: oxydation problem



- Windows cut in prototypes to examine weld quality
- Rusty condition indicates lack of inert gas flow during welding
- Problem reported to Lancashire Fittings and second series produced
- Problem is solved
- All other parameters within spec: production launched

Mechanical tolerence problem

Good mechanical tolerance seen in prototypes
begins to drift
Not a problem for single connection, but constraints become too big if many mis-aligned on same feed pipe

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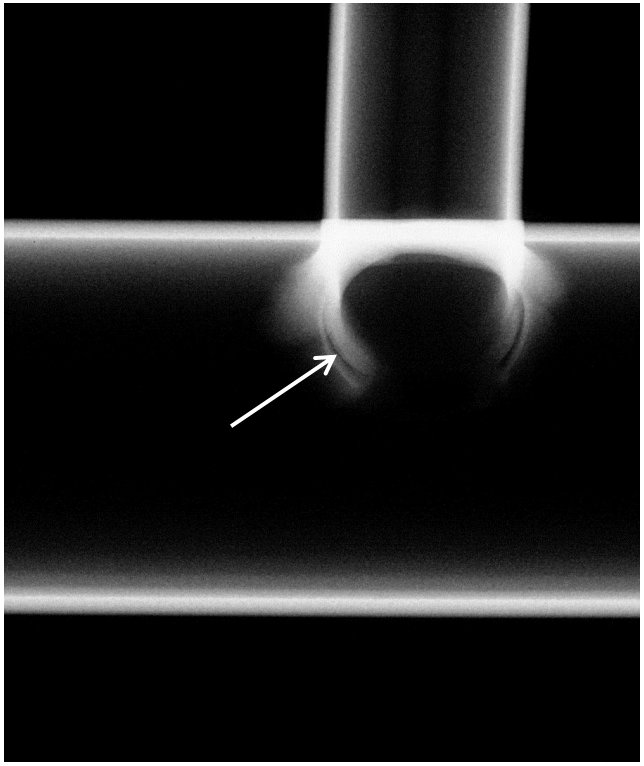
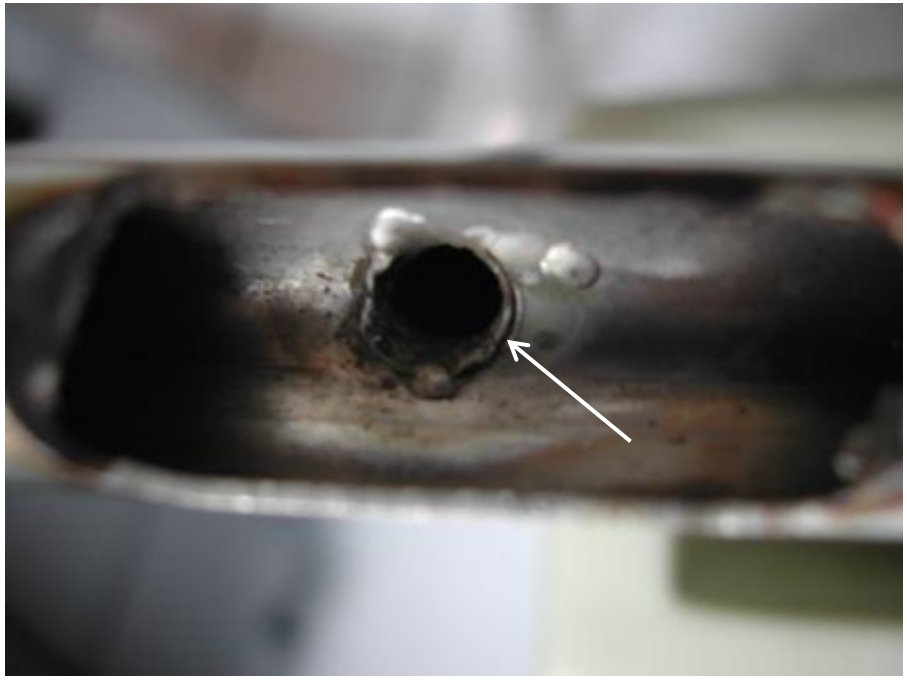
New constraint: X-ray inspections

- Previous problem with welds still at the back of our minds
- After discussion with CERN colleagues, decide to X-ray test first batch of production circuits
- Not in original specification!
- Cutting and bending of pipes continues at Lancashire Fittings

Weld defect: ‘lack of penetration’





Welding stopped at Lancashire Fittings and company asked to resolve the problem
Search for alternative companies launched in parallel

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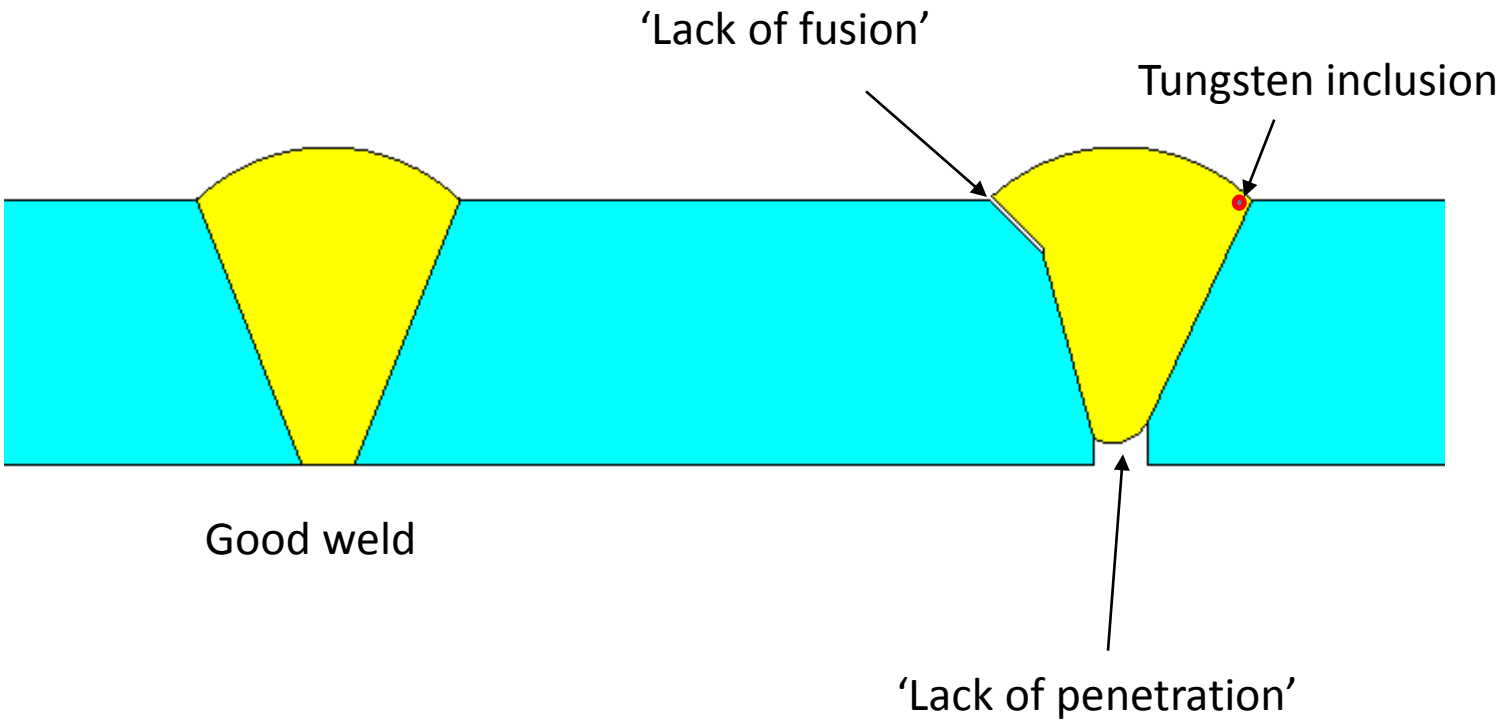
Common weld defects



Slide from talk of 14/03/2005

X-ray inspection - Summary

- Tests performed at Norisko (France)
- Standard: ISO 5817, class C; 2 X-rays per weld
- Results:
  - Lancashire second protos (4 welds tested) – FAILED (lack of penetration)
  - Lancashire production set (5 welds) – FAILED (lack of penetration)
  - ACC, Paris, 0.5 mm (1 weld) – FAILED (lack of penetration)
  - ACC, Paris, 1.0 mm (1 weld) – FAILED (lack of fusion)
  - Microsoude, Lyon (3 welds) – FAILED (tungsten inclusions)

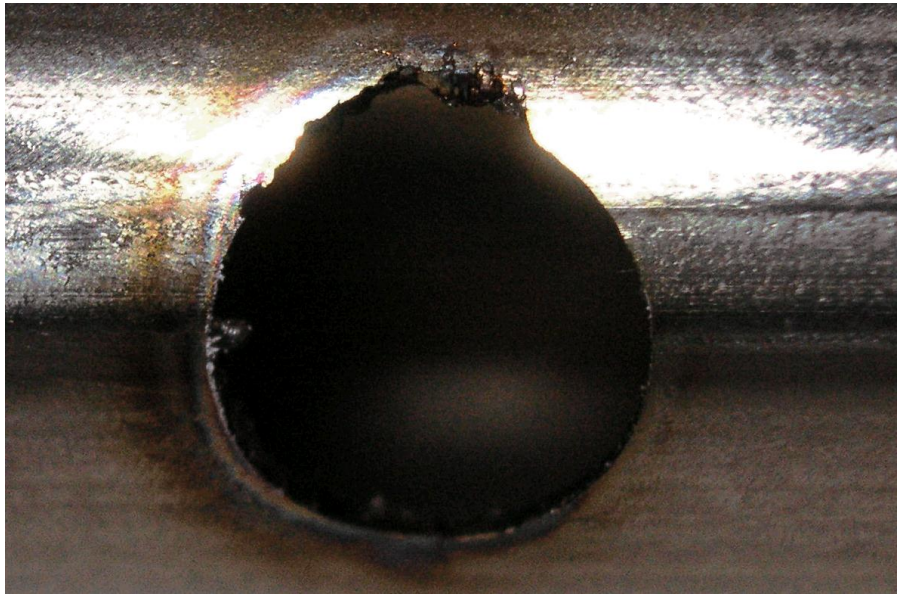
At this point, very much on the critical path for integration of both TECs!

Resolution

- Finally a company (Fraunhofer Institute / IPT, DE) is found
- Back-up company also found (Process Fluides, FR)
- Both capable of passing X-ray tests and providing needed mechanical precision
- Lancashire Fittings to provide cut and bent pipework but to cease welding
- Branch pipes compared to drawings by IPT and adjusted when necessary
- Process Fluides produces spares
- 100% X-ray testing of welds (704 welds)

As if that wasn’t enough…

Other problems

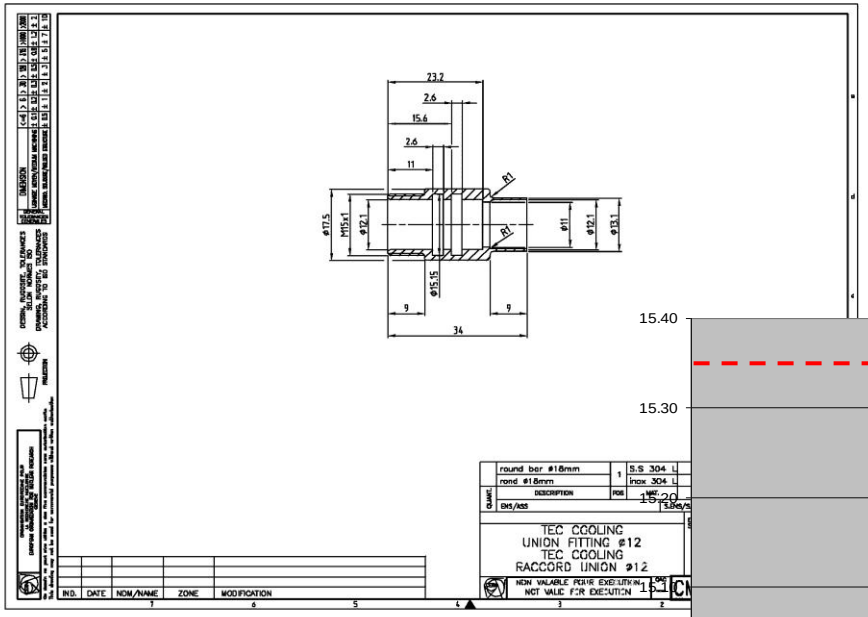


- Holes laser cut into feed pipes prior to welding branch pipes
- Sub-contracted to another company by Lancashire Fittings
- The holes are not round!
- All affected feed pipes need to be re-done

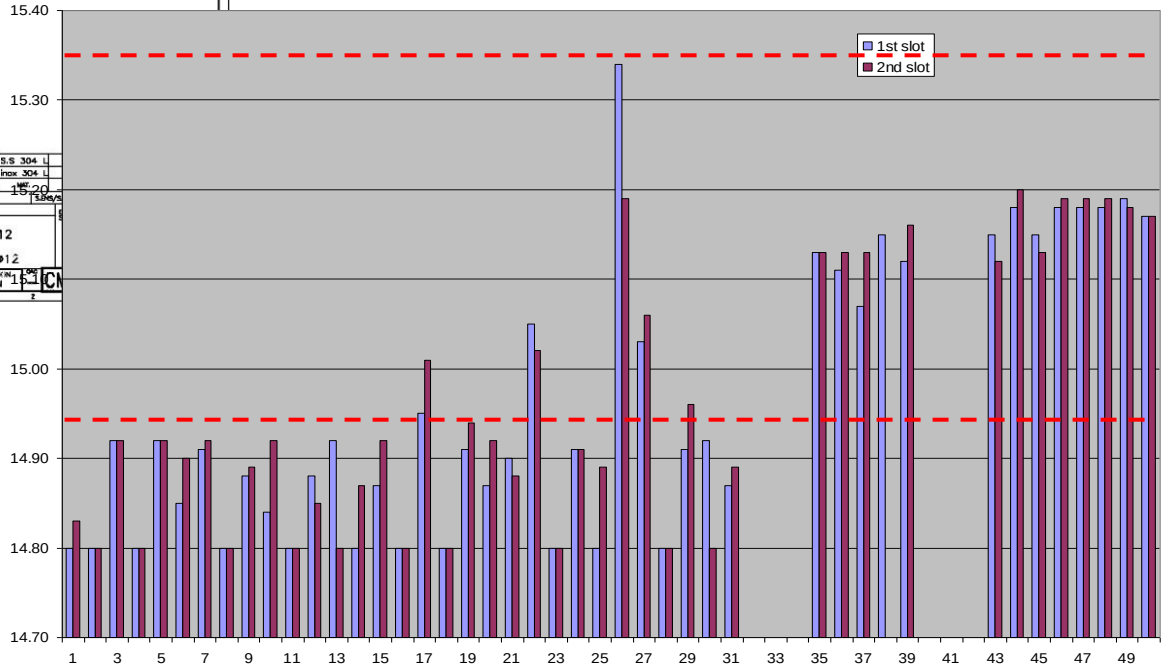
… and finally…

Some branch pipes completely blocked with sand on arrival at IPT!
(sand is used during bending)

Feed pipe connector at bulkhead



- Also produced by Lancashire Fittings
- Separate contract (CERN) for TIB, TOB, TEC
- Grooves for o-rings not deep enough
- Had to be re-machined at CERN



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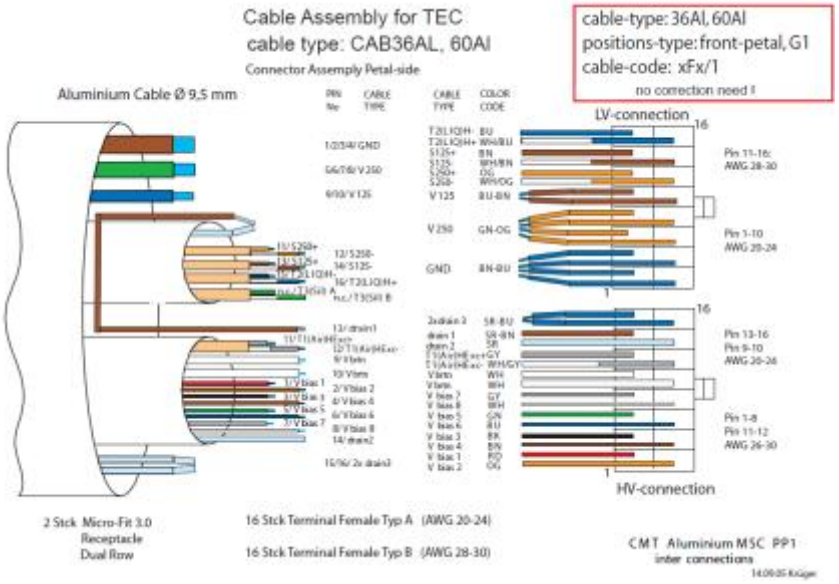
Power cables



- Fairly complex multi-wire cable with aluminium conductors
- Full-scale mock-up again invaluable for length determination and routing

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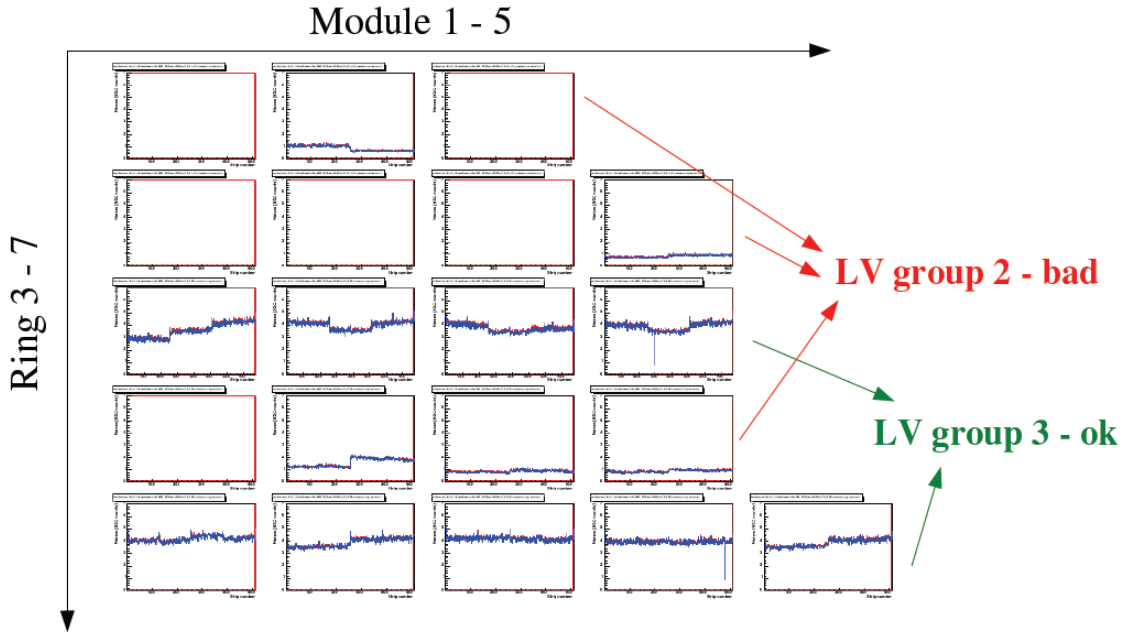
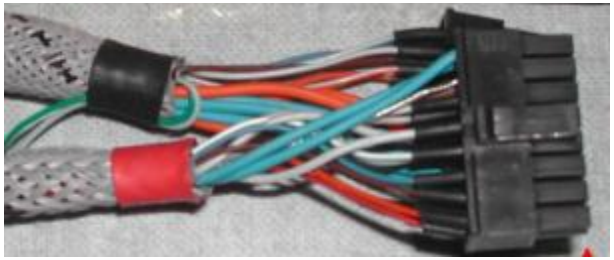
Cable connector problem





- Symptom: Very low or very high noise on a power group
- Could be temporarily fixed by unplugging and re-plugging Molex connector on petal
- All cables had passed electrical tests before installation on endcap!
- At this stage, all cables were already installed

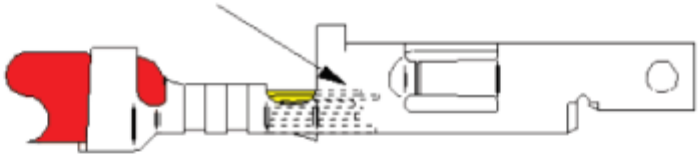
Bad crimping

- Problem finally identified as bad crimp contacts within connector
- Visual inspection shows only a few cases where insulation is fully below crimp contact
- But many ‘non-standard’ crimps

molex

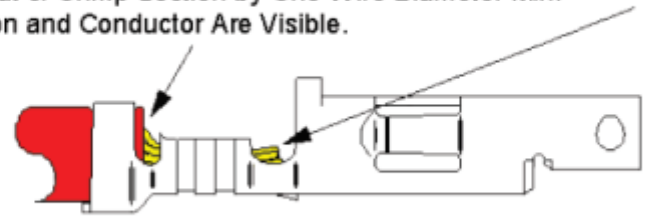
WIRE INSERTED TOO FAR

Wire Conductor Extends Into Transition Section of Terminal and Insulation is Into Crimp Section

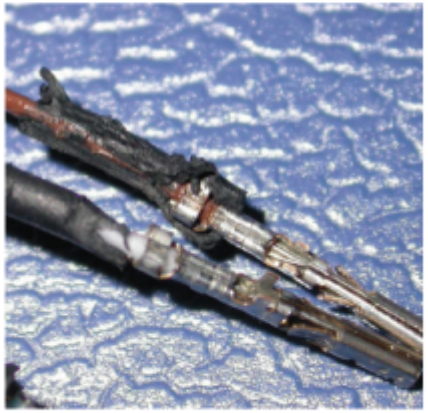


Wire Protrudes Out of Crimp Section by One Wire Diameter Min. and Both Insulation and Conductor Are Visible.

Good Crimp



Solution: Strip Length Too Long or Wire Inserted Too Far Into Crimp Section Before Crimping. Check Wire Stop Location on Press.

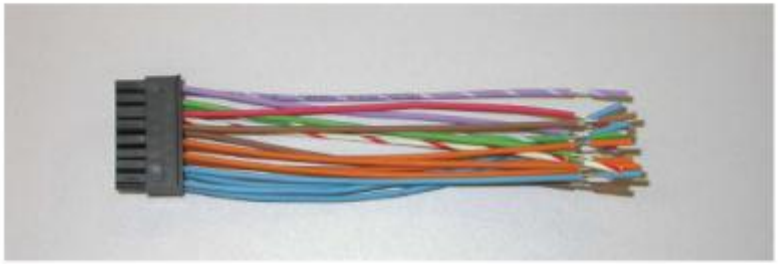


Company response

- Company producing cables (ADAPT) admits liability
- Declares whole production as unreliable
- Proposes solution
- Accepts all additional costs and provides manpower to manage repair at Aachen (TEC+) and CERN (TEC-)

Technical solution

Decision to **repair ALL connectors** (LV, HV, control) in following way:



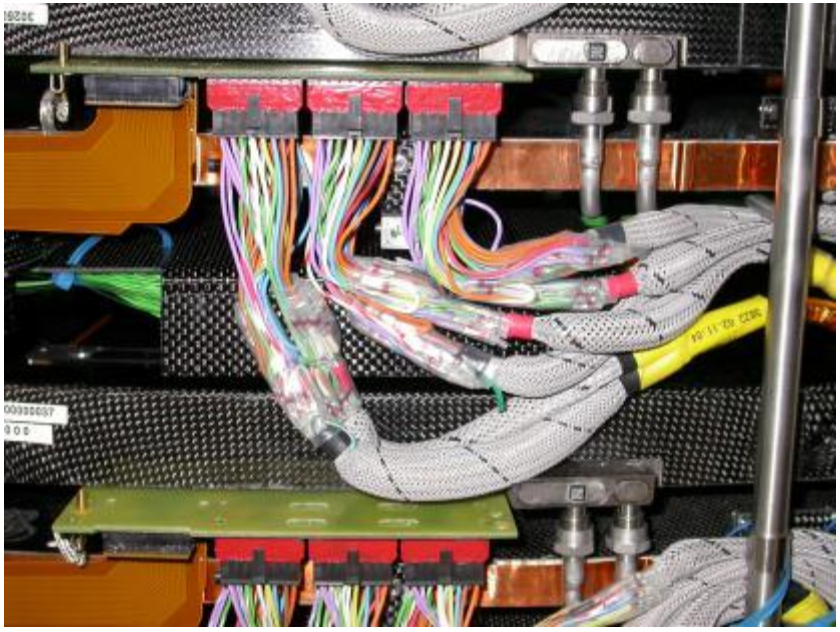
pigtails as delivered by Adapt:
stripped, crimped and inserted into connector

crimps of type Tyco D-609-03

cables after Y-type crimping

repaired cables with shrinkage tube

Cable re-work



- Very labour intensive
- Puts schedule back by about 1 month
- Result isn't too pretty, but does the job (validated by noise profiles)

Summary of experience with external companies (1)

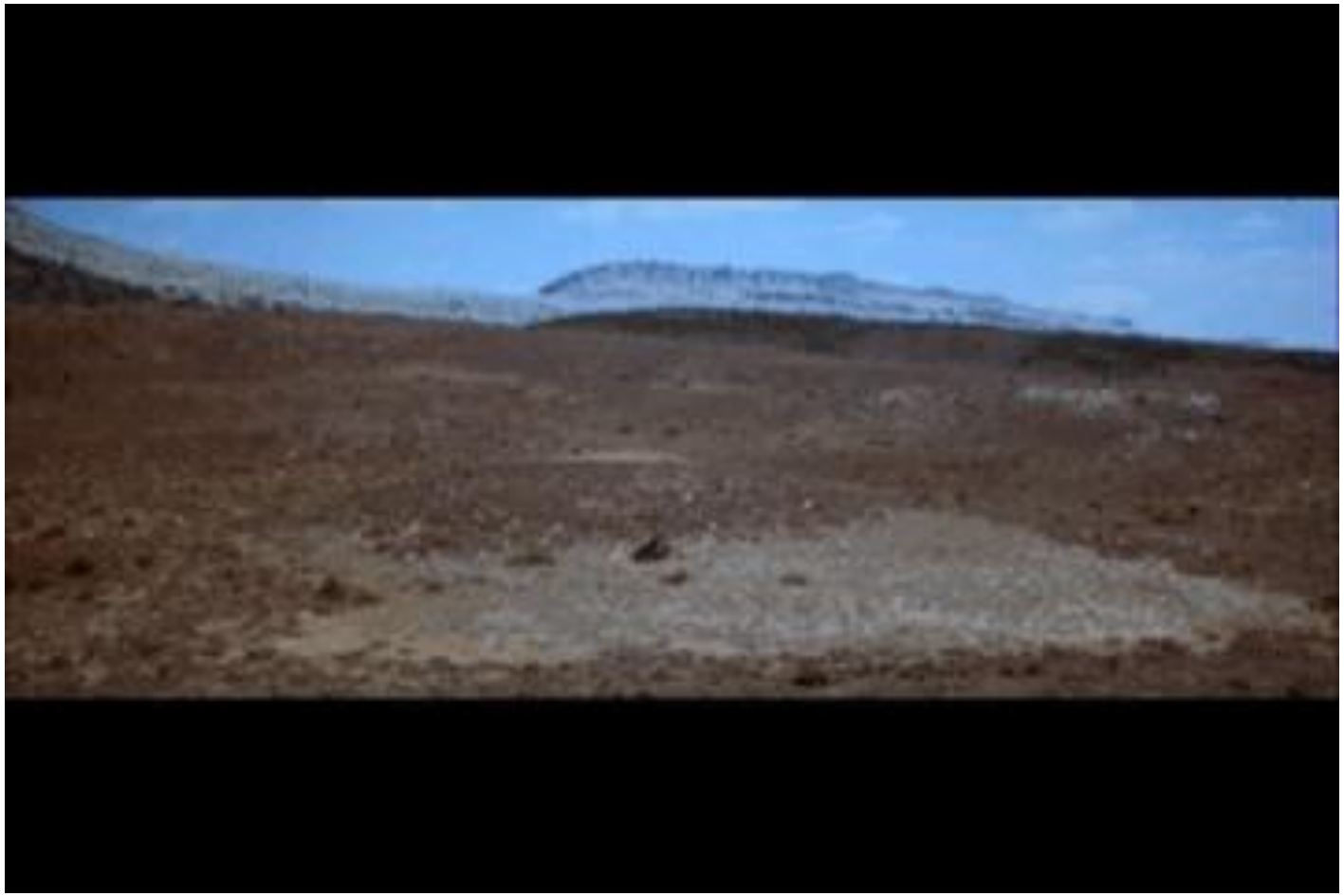
- ADCO (Optical fiber mechanics)
  - Company very much R&D based
  - Very pro-active, lots of good suggestions
  - Very good working relationship (many face-to-face meetings)
  - No real specification (just drawings and oral / e-mail descriptions)
  - No back-up solution
  - (CMS gold award)
- Lancashire Fittings (Longitudinal cooling pipes)
  - 'Production' company
  - Phone / e-mail contact only
  - Fairly detailed formal specification (but, critically, X-ray testing missing)
  - Even not considering the welding issue, this company delivered a long catalogue of sloppy, sub-standard work outside of the technical spec.
  - Back-up companies were in place, but not sufficiently involved

Summary of experience with external companies (2)

- ADAPT (Power cables)
  - Very good working relationship
  - Detailed specification
  - Quality control did not catch unforeseen problem
  - Company accepted responsibility for mistake
  - Extremely professional and well-organised implementation of acceptable solution
  - (CMS gold award)

Conclusion (lessons)

- Working with external companies is an essential part of detector construction
- A sound technical specification is an important tool…
- … but keys to success are less tangible:
  - Choosing the ‘right’ company in the first place
  - Preferably a local company
  - Building good working relationship with company contacts (including regular face-to-face meetings)
- A back-up company is always a good idea
  - Preferably involved from the beginning
  - Preferably constructing some fraction of the final product
- Mock-ups extremely useful tools: build the best you can afford
- Despite the problems encountered, excellent solutions were finally implemented - on time - for the endcap services!



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