Quality Control of the CMS Tracker (and ECAL) installed optical cabling

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Outline

- Optical links for CMS Tracker and ECAL;
- Quality Control: program and objectives;
- Test tools;
- Experience & lessons learned:
  - practicing with tools;
  - practicing procedures;

Results here presented for Tracker (90% of the activities).

Authors acknowledge the University of Minnesota group for the activities on ECAL.

P5 and TIF activities

In UXC55 (experimental) cavern:

✓ECAL supermodules installation completed in July 2007;

❑ TK electrical cabling ongoing;

❑ ECAL and HCAL cabling (electrical + pipes + optical) is starting;

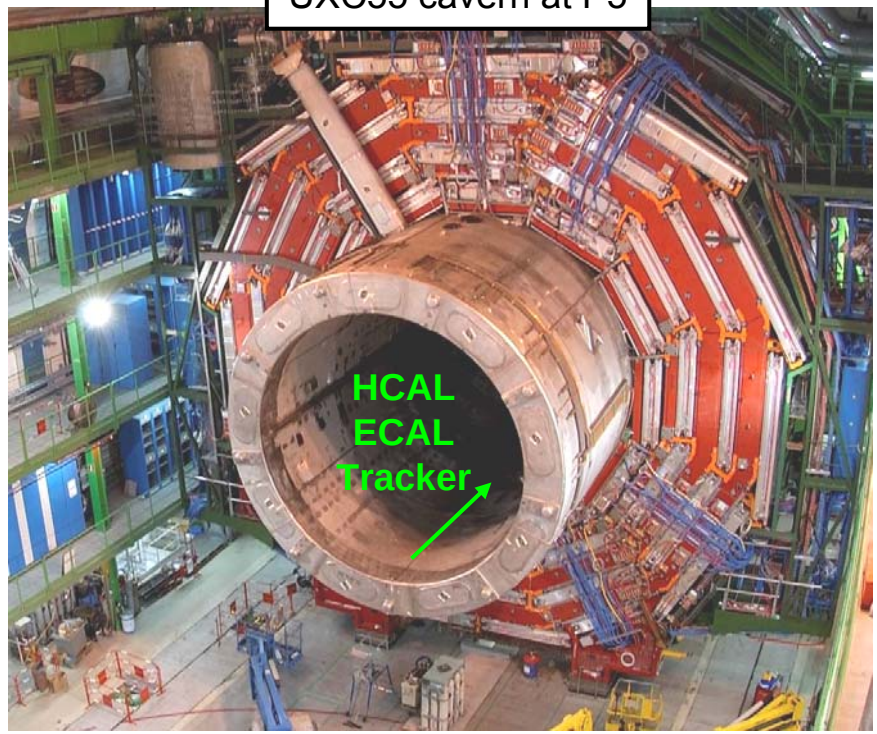
❑ TK optical cabling will follow (optical cassettes already installed in PP1);

❑ TK insertion: October 2007.

In USC55 (service) cavern:

✓ racks ready and equipped.

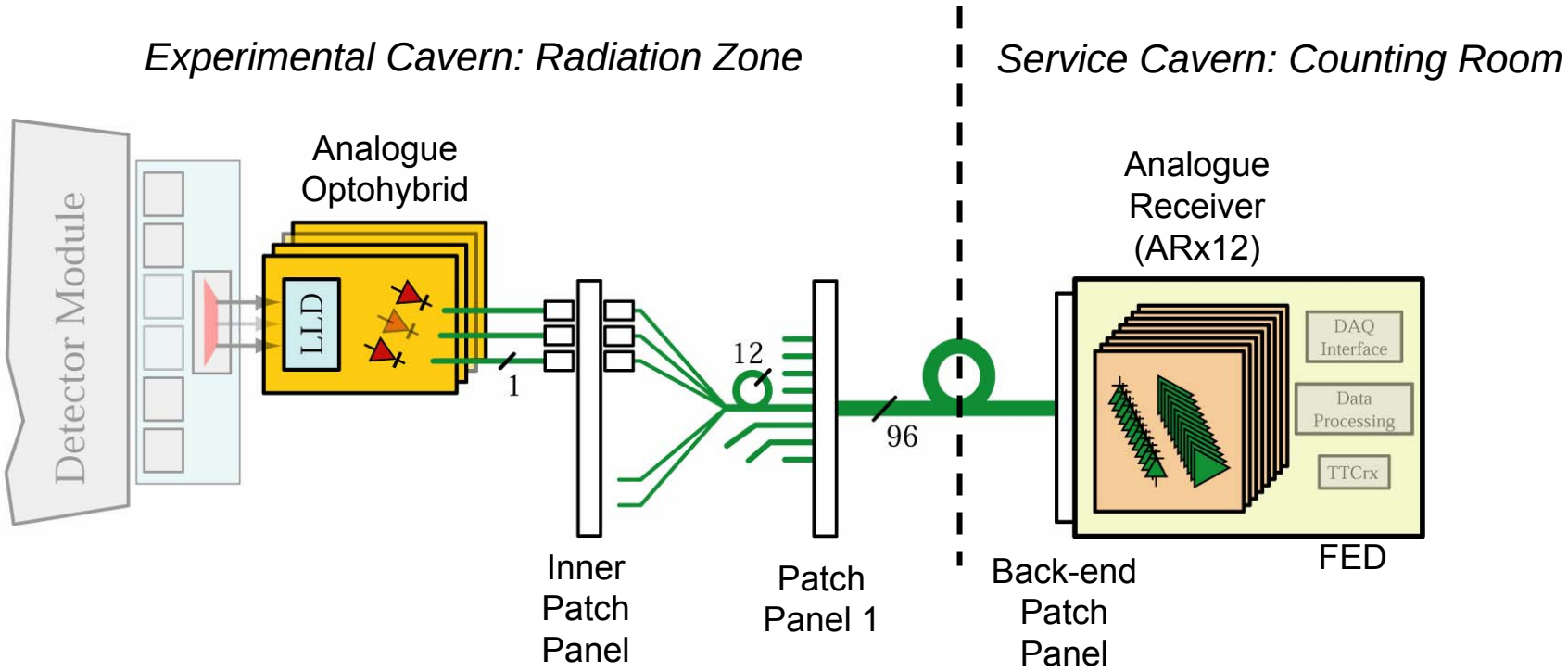
UXC55 cavern at P5



TIF: Tracker Integration Facility (Bld. 186 at CERN)

✓ TK sub-detector integration completion;
✓ TK assembly;
✓ Tests:
- on sub-detectors;
- on 20% of the whole TK;

Tracker Optical Links

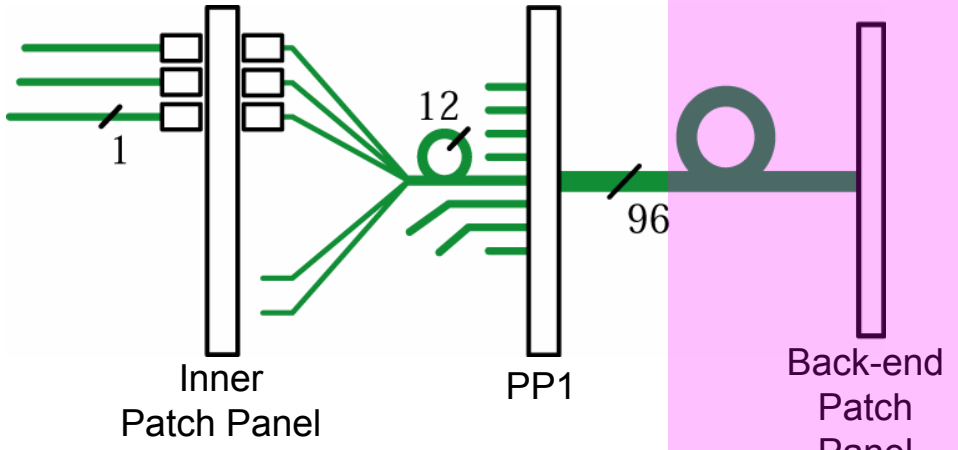


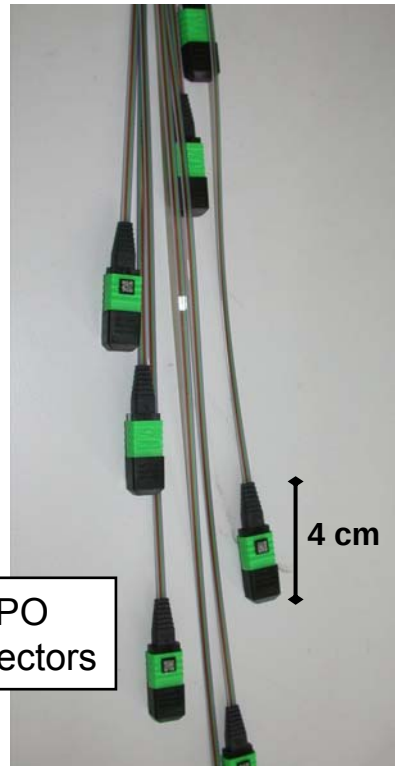
~36000 analogue fibre channels + ~3000 digital fibre channels

ECAL and Pixels have similar optical links.

Components: fibers and connectors

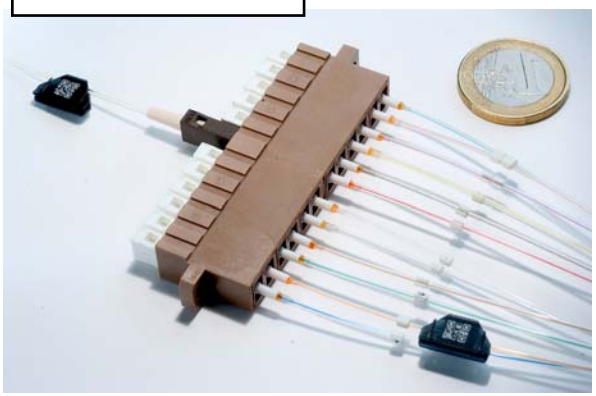
~39000 single pigtailed fibers

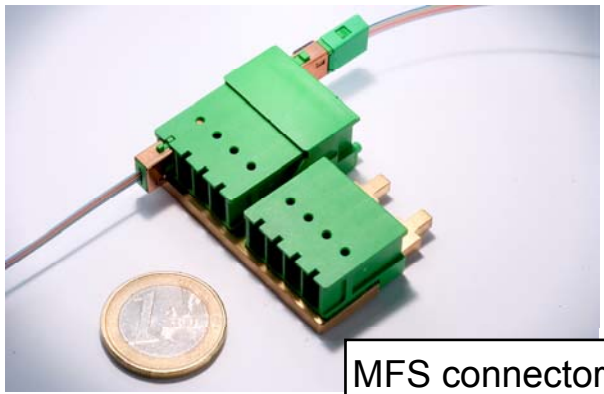




MPO connectors

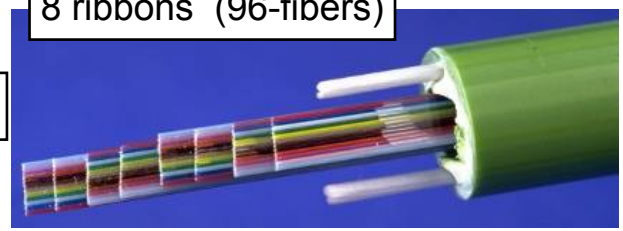
MU connectors





MFS connectors

8 ribbons (96-fibers)



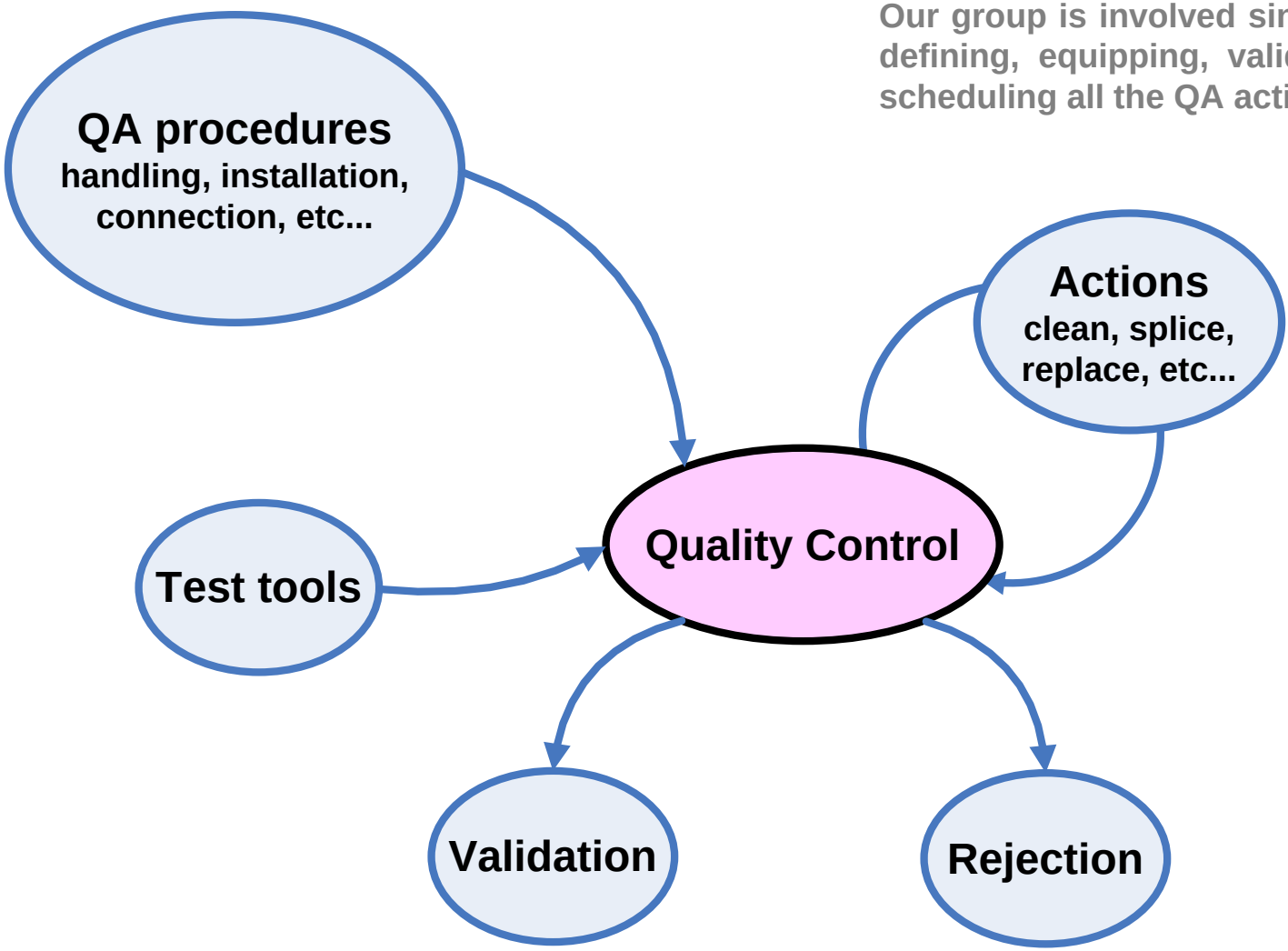
Inner Patch-Panel:
pigtails grouped in ~4000 **12-way fan-outs**

Patch-Panel 1 (PP1):
8 fan-outs grouped in a **96-way Multi-Ribbon cable**.
Very dense configuration!

Tracker: 530 MR cables
Pixels: 34
ECAL Barrel: 108

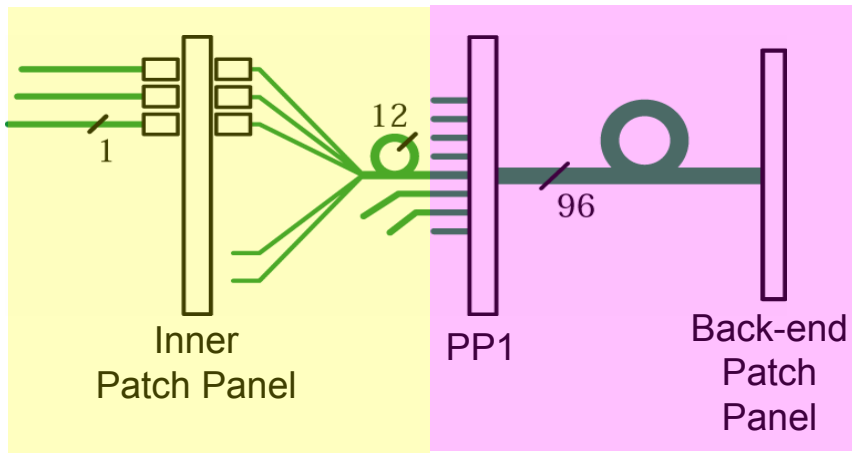
Optical Links Quality Assurance process

Our group is involved since 2004 in defining, equipping, validating and scheduling all the QA activities.



Details on QA procedures:
K. Gill et al. "Integration of CMS Tracker optical links"
Proc. of 12th LECC Workshop, Valencia, Sept. 2006.

TK Optical Links Quality Control Program



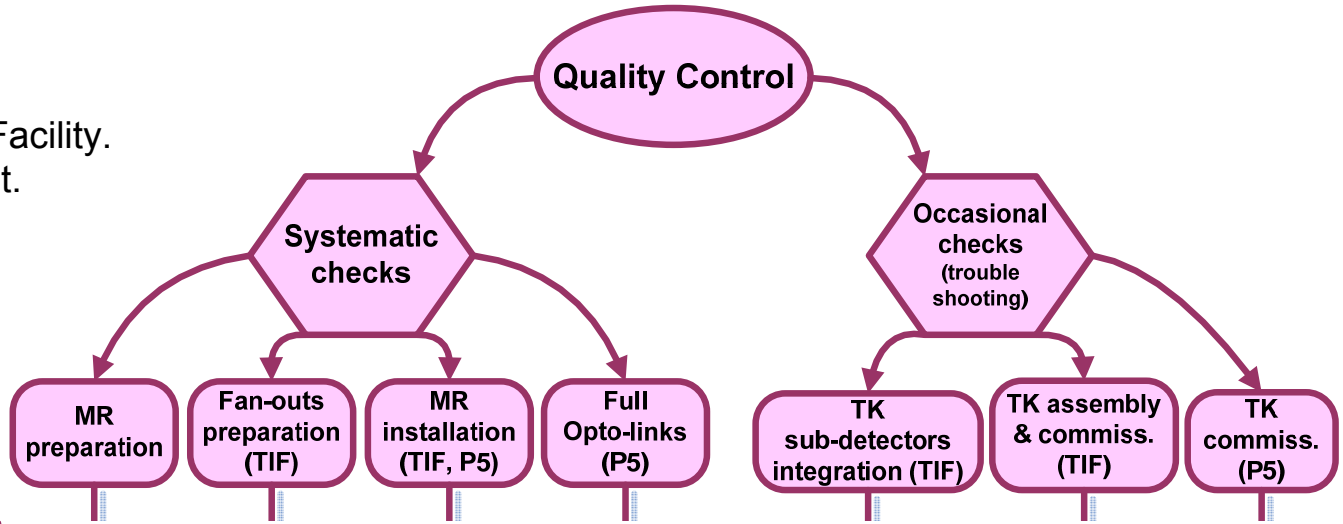
Main objectives (P5):

- cabling **installation acceptance**;
- PP1 **connections validation**;
- total working **length measurement** with precision **better than 20cm**
  ⇒ sync. of TK readout to ~1ns.

Aiming to these objectives, **tools and procedures have been practiced** during the sub-detectors integration **at TIF**.

TK Optical Links Quality Control Program

TIF: Tracker Integration Facility.
P5: CMS integration point.



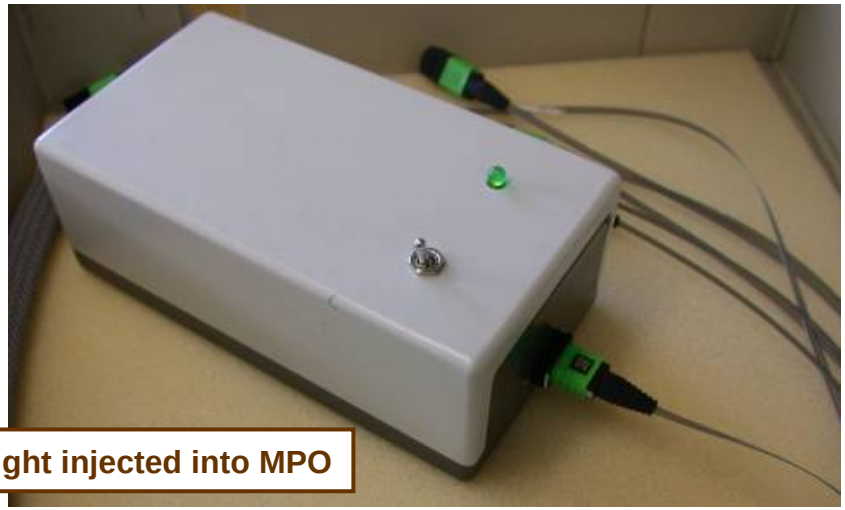
Tools	Test type
Naked eye	Visual inspection along full accessible length
Light box Light pen Microscope	Test with light injection
OTDR Switch	OTDR test + length on 1 fibre/time
OTDR Splitter	OTDR test + length on 12 fibres/time
Microscope Adapters	Microscope inspection (all connectors)

Activity planning determined by experience

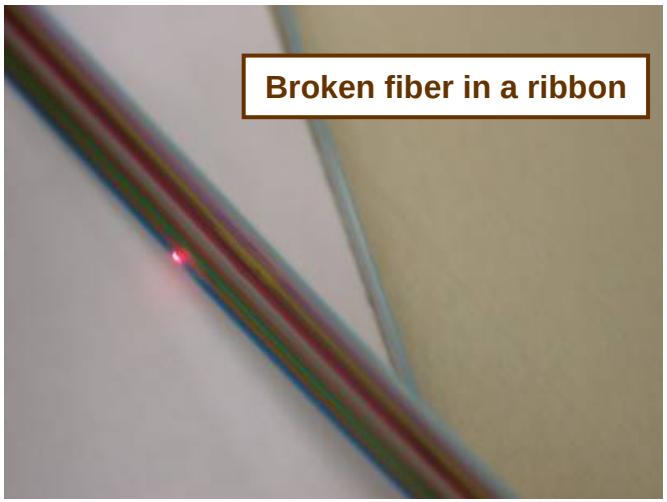
QC: test tools

Fault locators

for ribbons

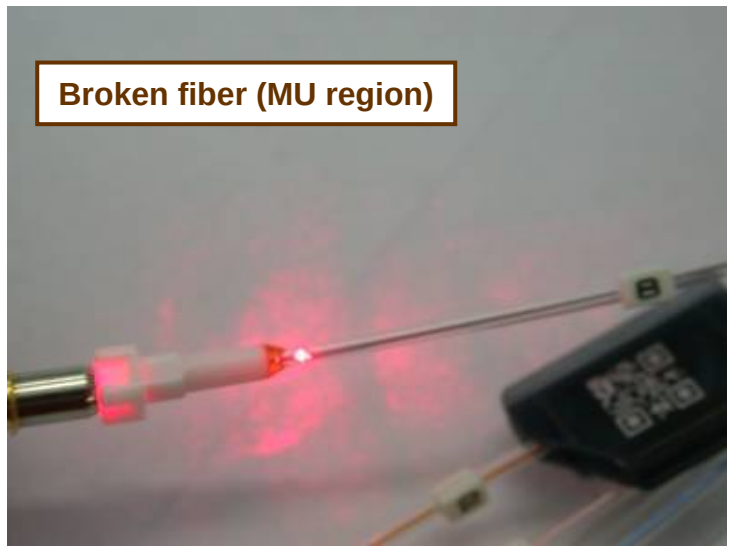


Light injected into MPO



Broken fiber in a ribbon

for single fibers

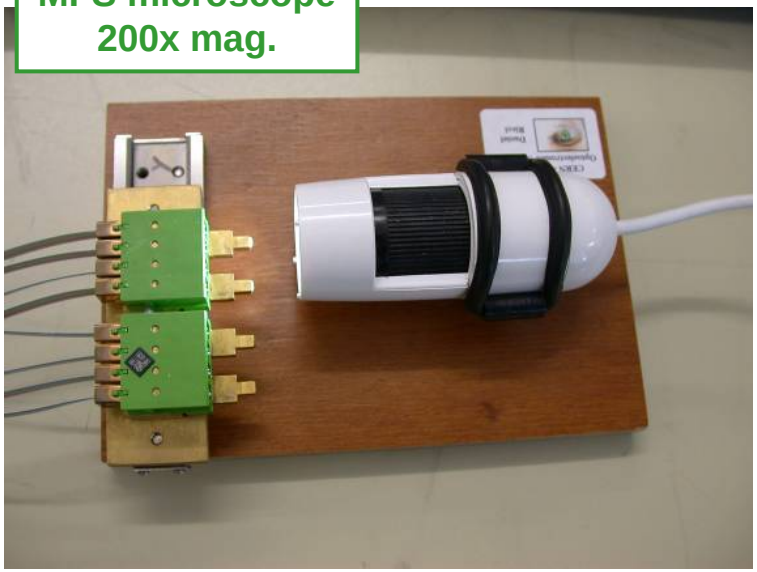


Broken fiber (MU region)

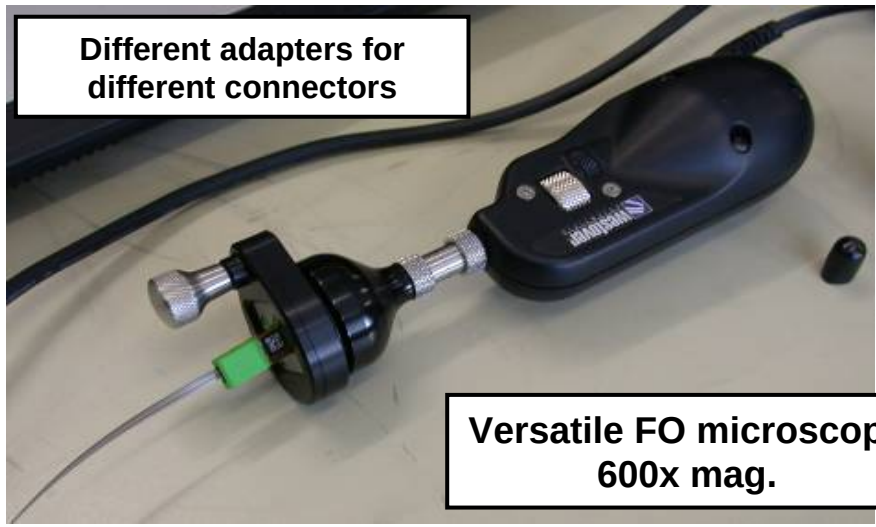
QC: test tools

Microscopes

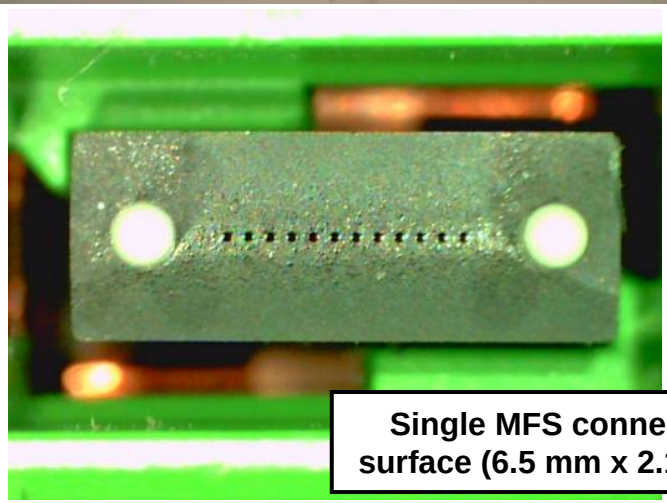
MFS microscope
200x mag.



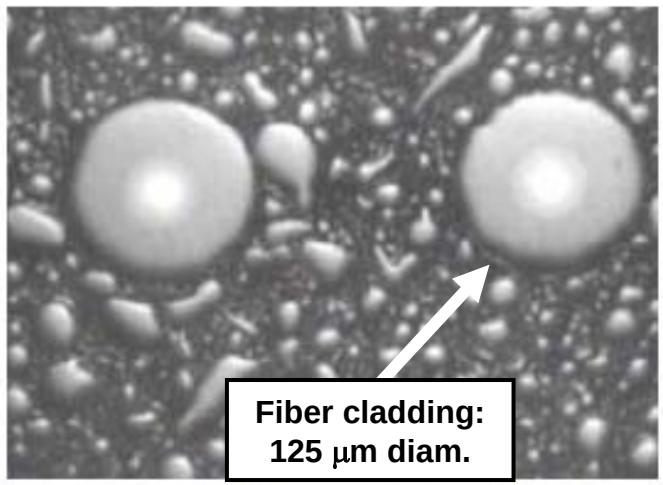
Different adapters for
different connectors



Versatile FO microscope
600x mag.



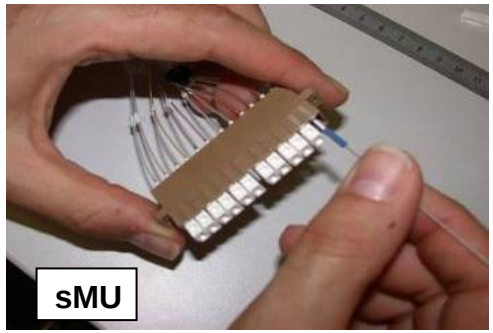
Single MFS connector
surface (6.5 mm x 2.1 mm)

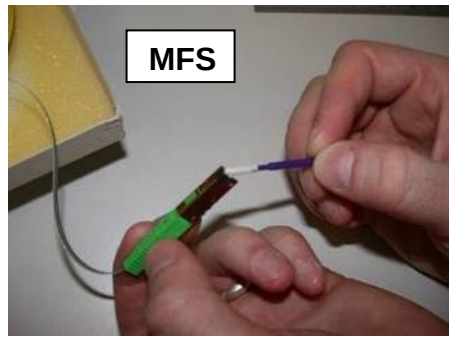


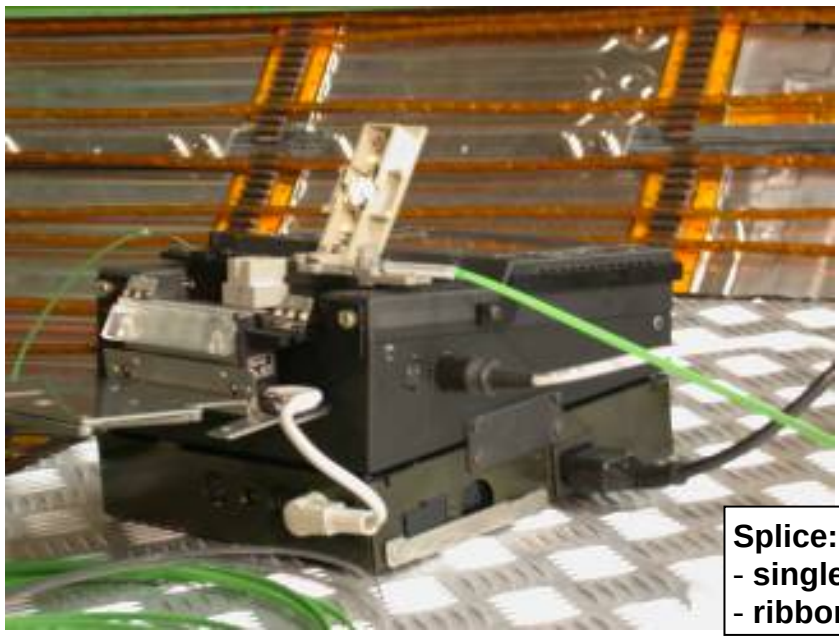
Fiber cladding:
125 μm diam.

QA: actions

Cleaning and splicing tools







Splice:
- **single fibers**
- **ribbon**

The OTDR test setup

OTDR: Optical Time Domain Reflectometer

Basic principle:
- optical pulse injected into the fiber;
- backscattered optical power is measured;
- time delay of backscattered signal ⇒ distance.

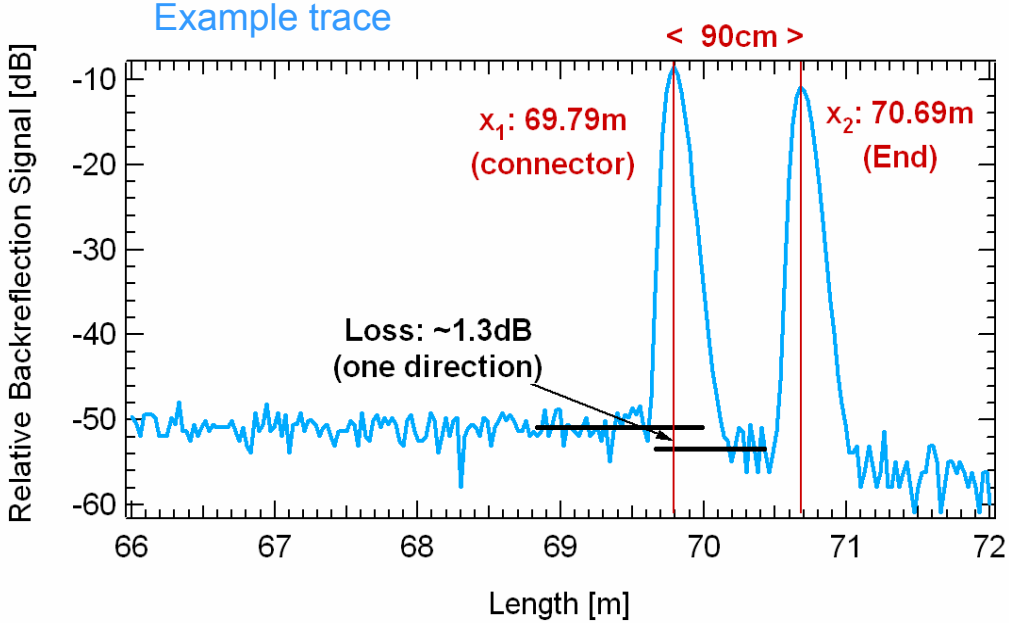
Test performed on one fiber end!

Photon-Counting OTDR

Sunrise Telecom (ex-Luciol) ν-OTDR

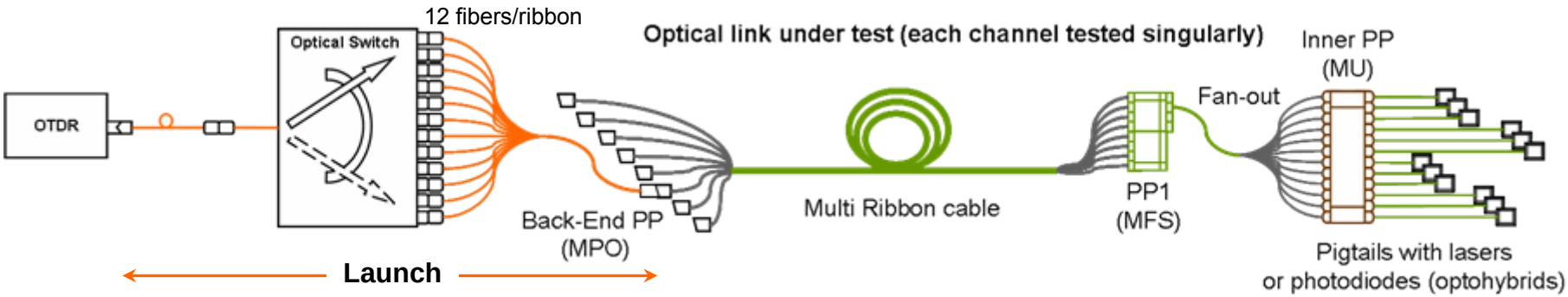
- Counts the single photons;
- Two points resolution: 10 cm;
- Loss sensitivity: 0.1dB depending on size of reflected peak (because of dynamic range limit);
- Dimensions [mm]: 260×90×265;

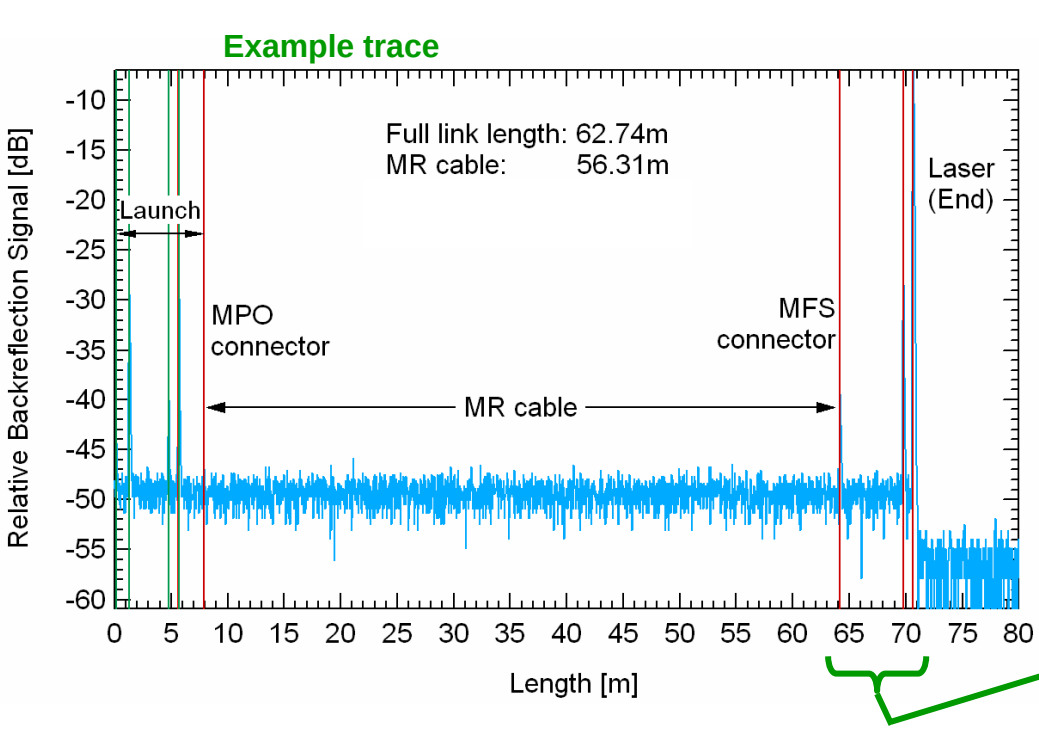
Example trace

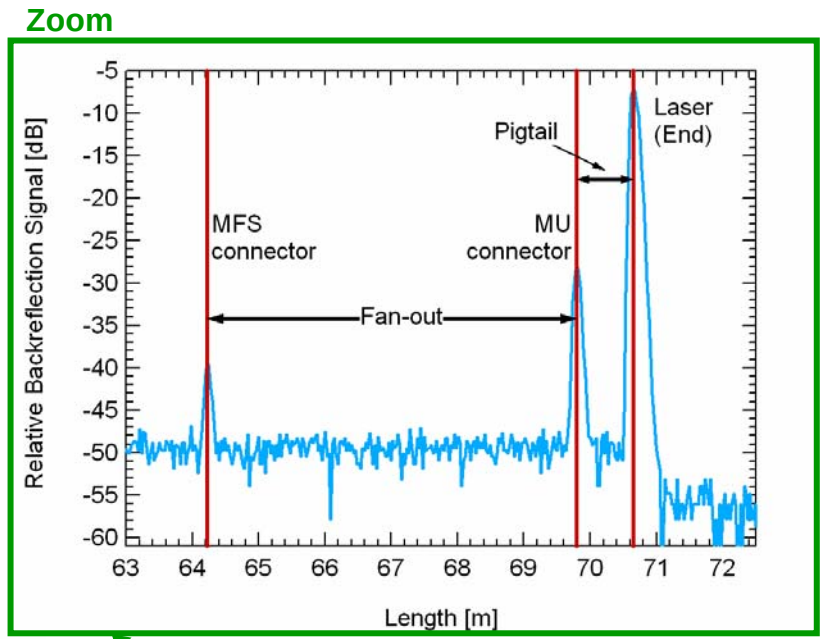


Instrument is ideal (and necessary) for measuring the CMS Optical Links (short distances, many connectors, accessibility only on one end).

OTDR + switch



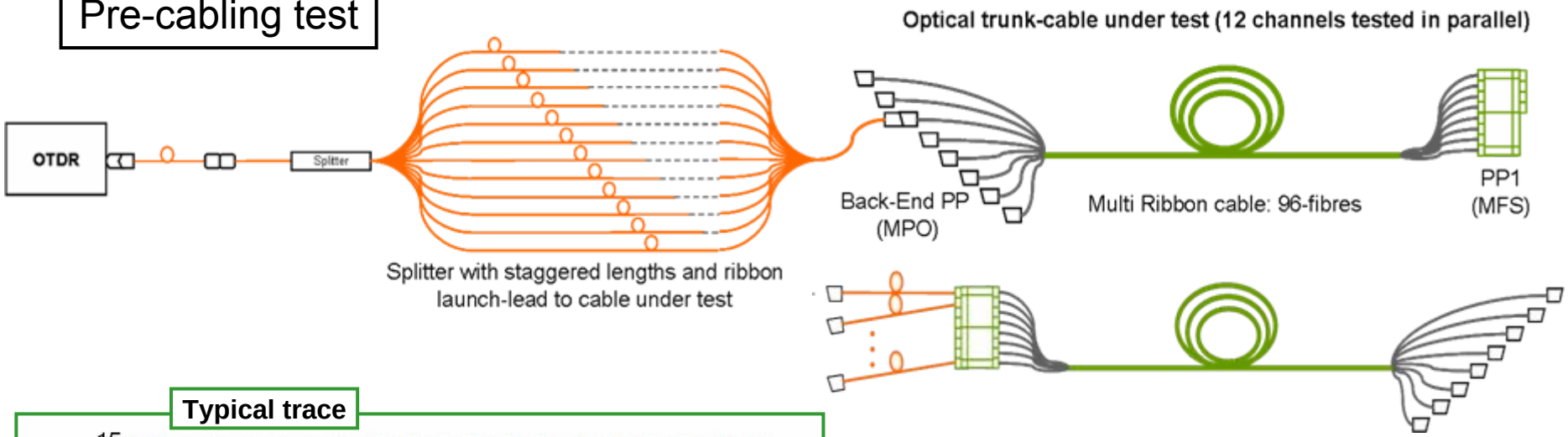




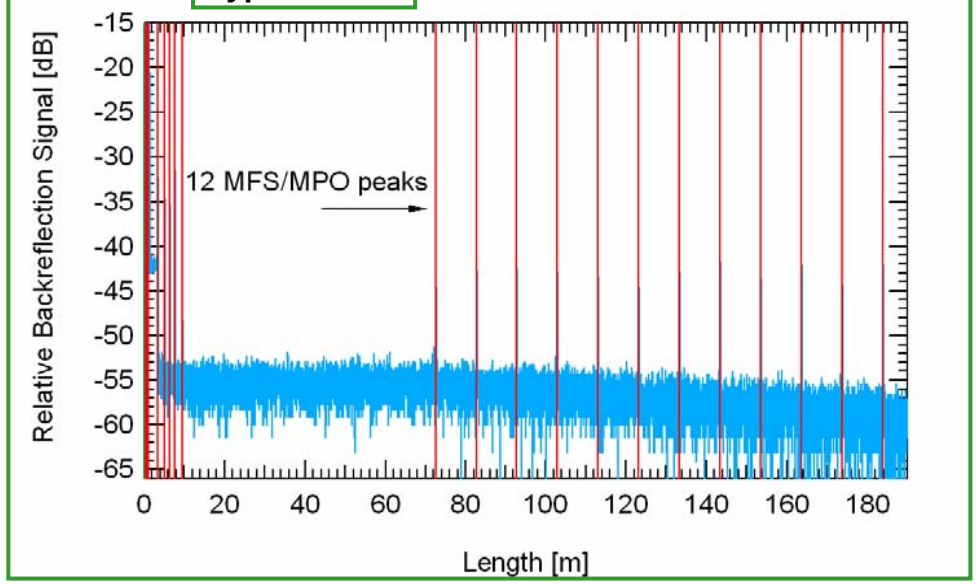
Time of measurement: **1Hour/MRcable** (96-fibres) Acquisition: ¾ time, cleaning/connect: ¼ time

OTDR + splitter

Pre-cabling test



Typical trace



Time of measurement: **19min/MRcable**
- acquisition: **3min**
- cleaning and connections: **16min**

(8 ribbons)

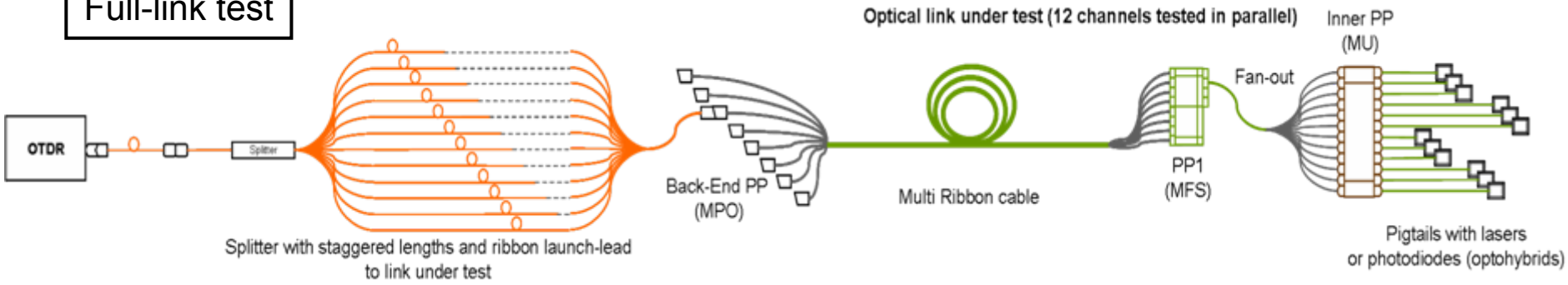
Ideal to fit in the shadow of cables installation.

Trunk cable can be tested from either end! (TK will test from PP1)

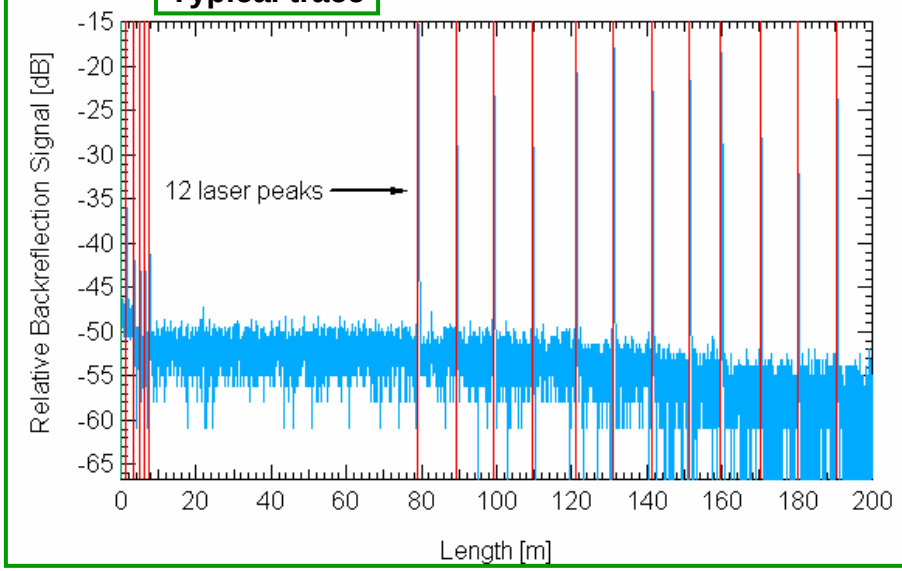
Novel development: speed up acceptance of MR and full-link!

OTDR + splitter

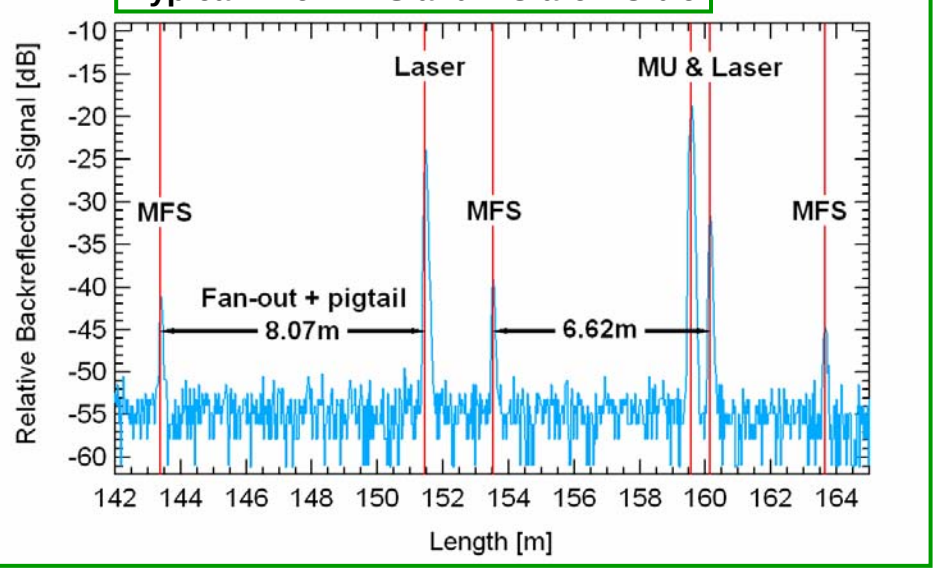
Full-link test



Typical trace



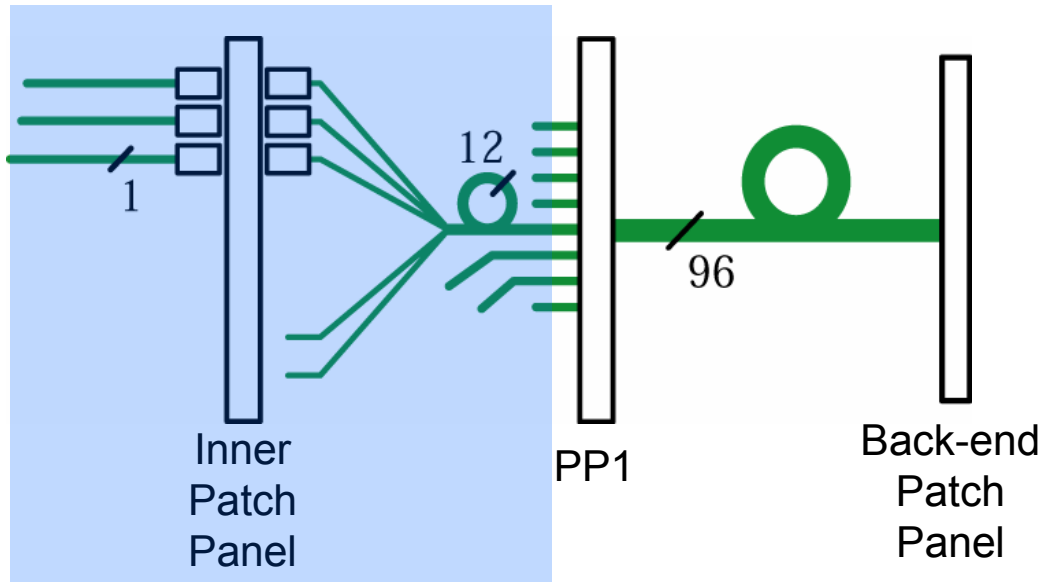
Typical when MFS and MU are visible



Time of measurement: **19min/MRcable** (96-fibres) Acquisition: **3min**, cleaning and connections: **16min**.

Tracker Integration Facility timescale

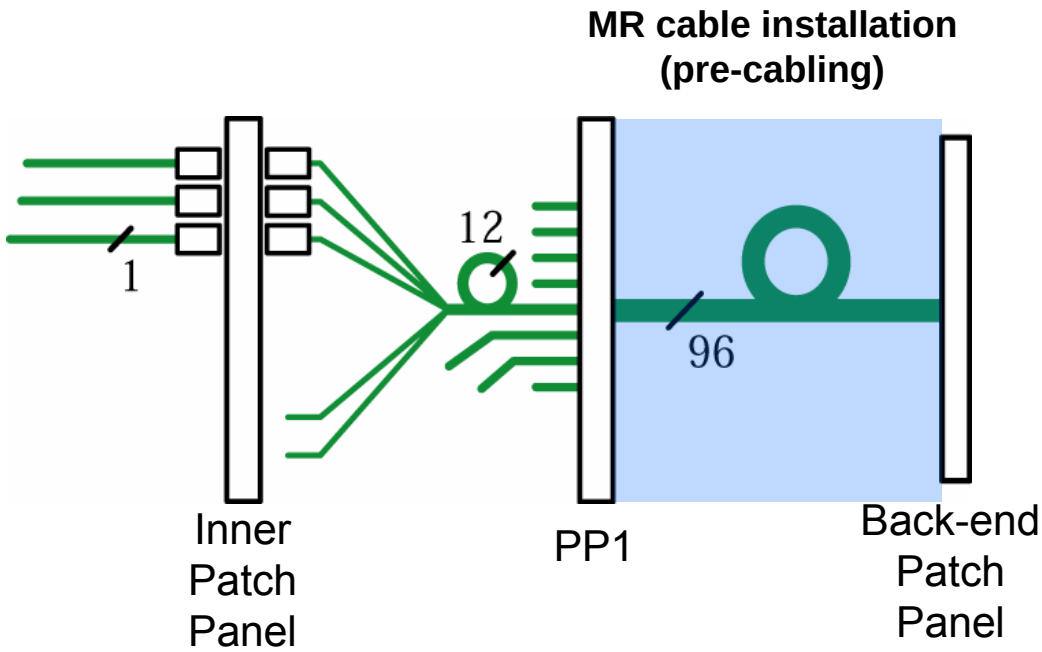
Sub-detectors integration



Type of activity: troubleshooting (as “expert on-call”)

Aims: solve problems + practice tools

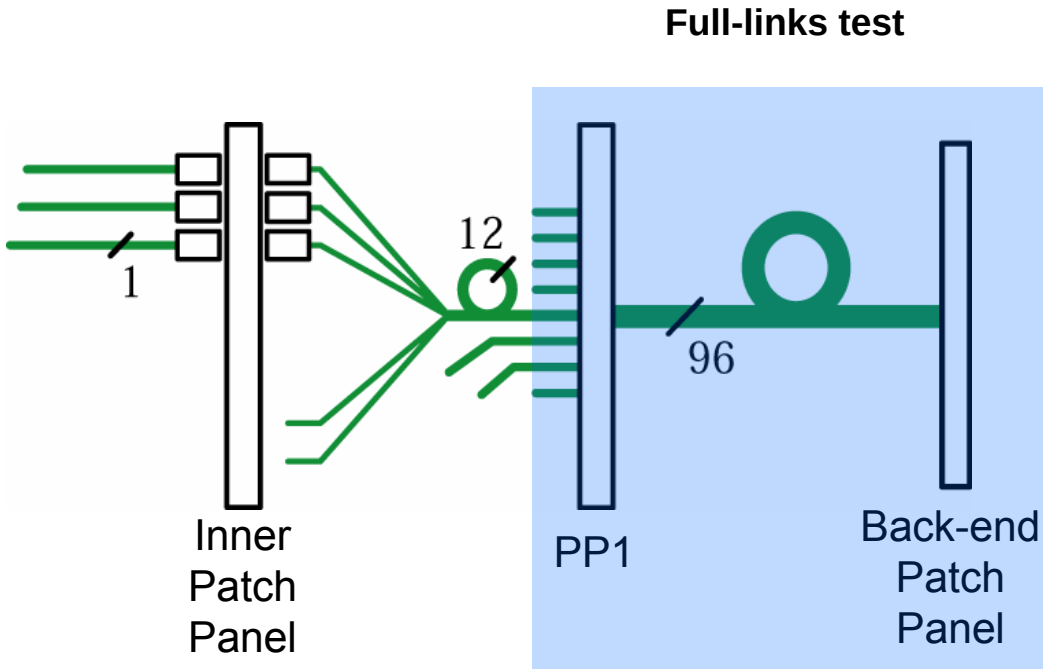
Tracker Integration Facility timescale



Type of activity: systematic test

Aims: provide services + practice procedure and tools

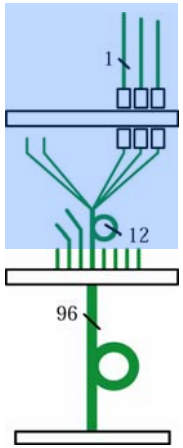
Tracker Integration Facility timescale

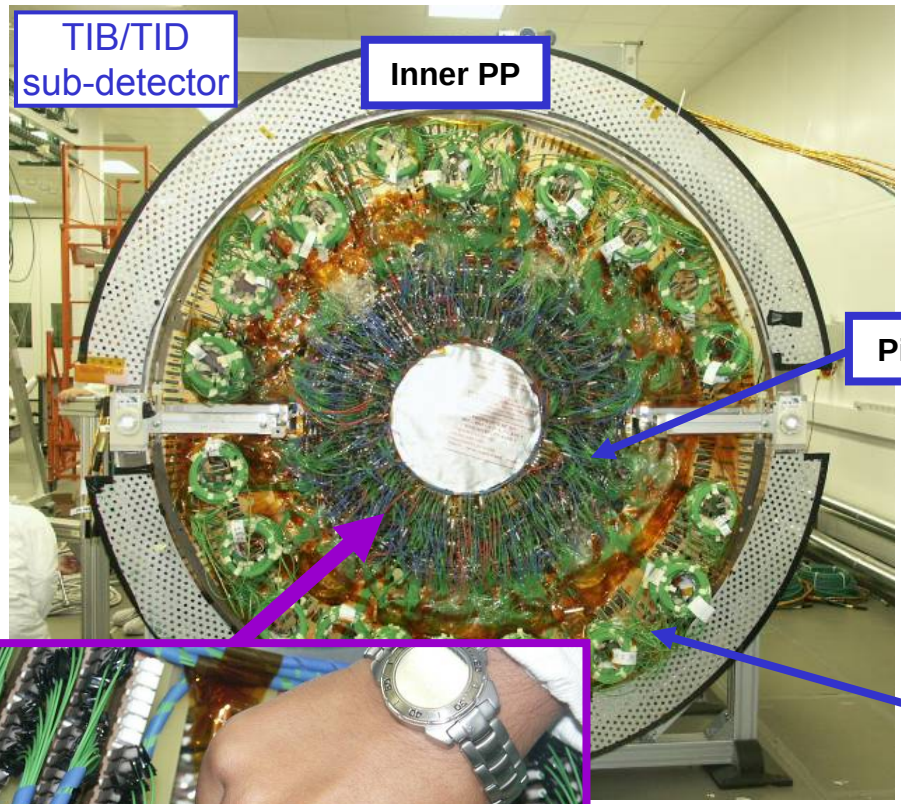


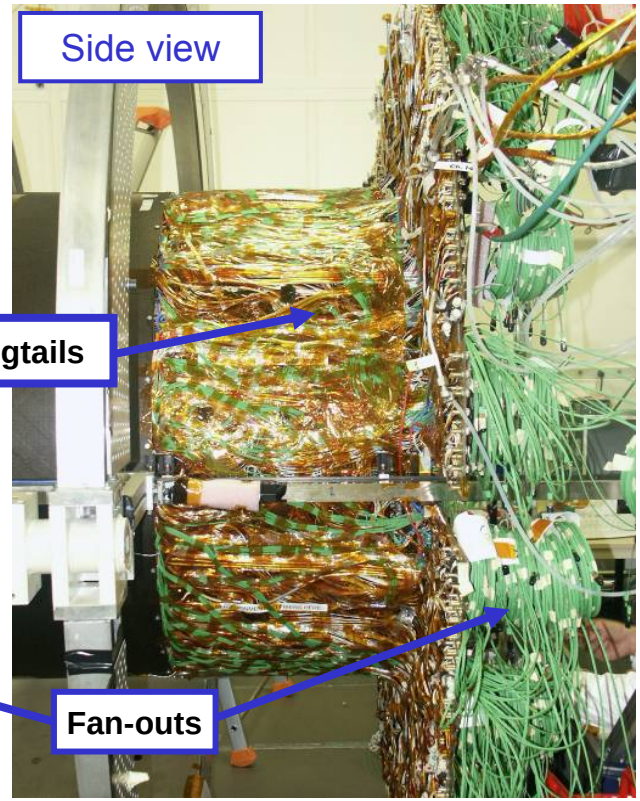
Type of activity: troubleshooting (as expert on-call)

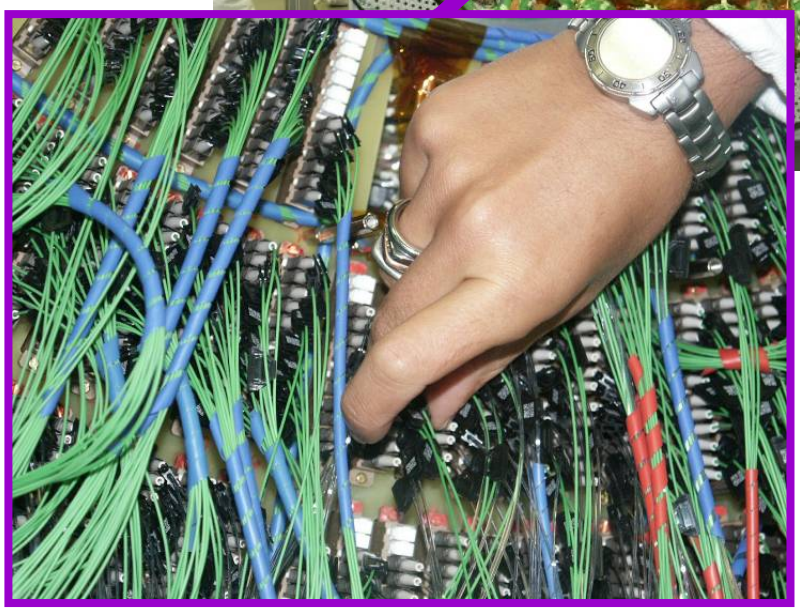
Aims: solve problems on cables/connections + practice tools/procedures

Experience & Results: sub-detectors integration







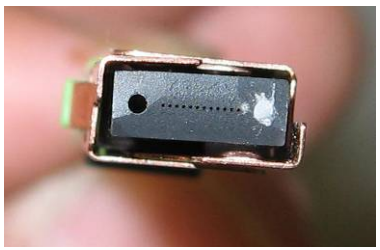


- Optical channels tested with DAQ during assembly;
- **Optical expert intervention required when**:
  - DAQ was not able/available to fix the problem;
  - physical defect was suspected/seen on a fiber/ribbon;

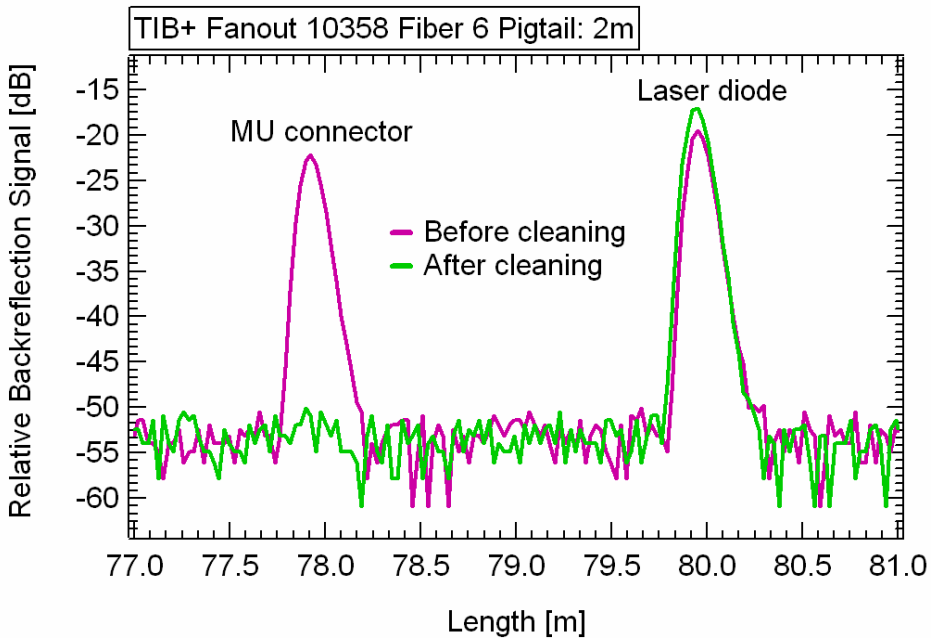
Experience & Results: sub-detectors integration

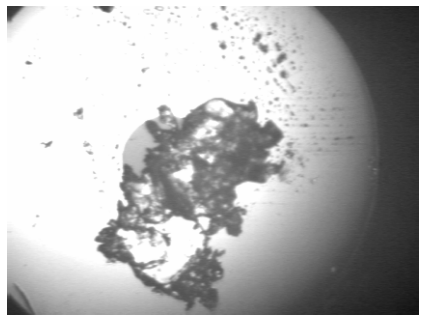
Optical parts	Total tested	Good	Recovered	Broken	Defective
Pigtails	**51** (27 microscope, 14 OTDR+micr., 10 OTDR)	**1**	**40** (cleaned)	**2** (splice not possible)	**8*** (3 MU ferrule scratched, 5 over bending)
Fan-outs	**68** + 604 pigtails (65 OTDR, 3 visual insp.)	**65** 604 pigtails	**3** (spliced)	1 fibre (unused)	/

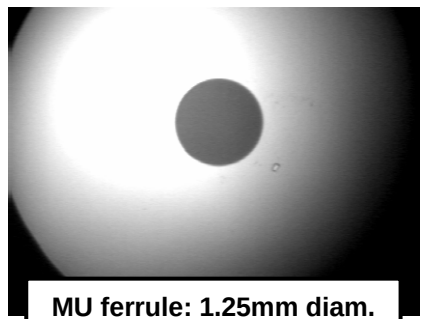
* 2 channels working with very low gain that cannot be compensated by varying the LLD gain.



Damages on fan-outs



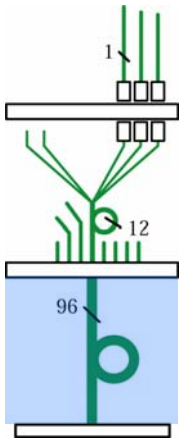




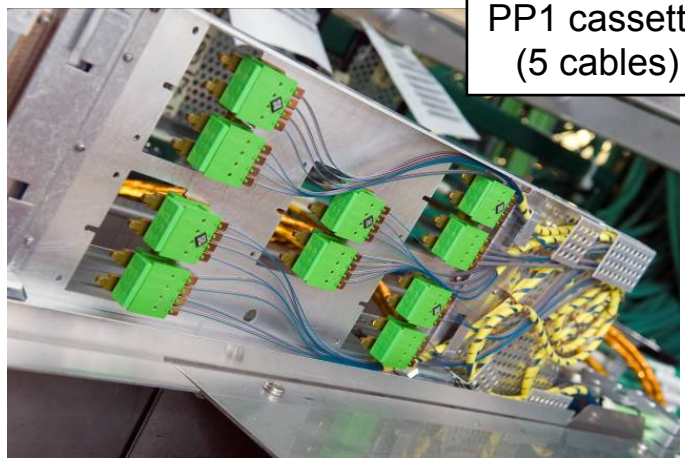
MU ferrule: 1.25mm diam.

OTDR+DAQ: 100% problems understood/solved ⇒ combined action is very powerful!

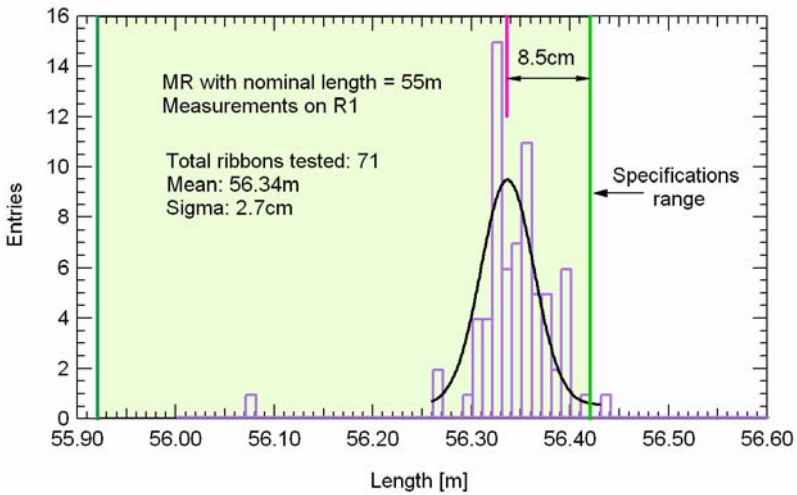
Experience & Results: TIF pre-cabling



Temporary installation of MR cables (Nov. 06) for 20% TK sector test
(using final cables and same procedure of Point 5).



PP1 cassette
(5 cables)

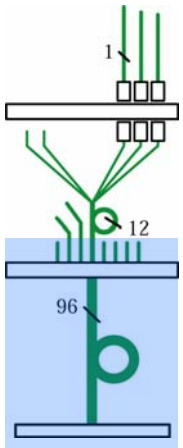


Systematic OTDR (splitter) test on all the trunk cables installed:

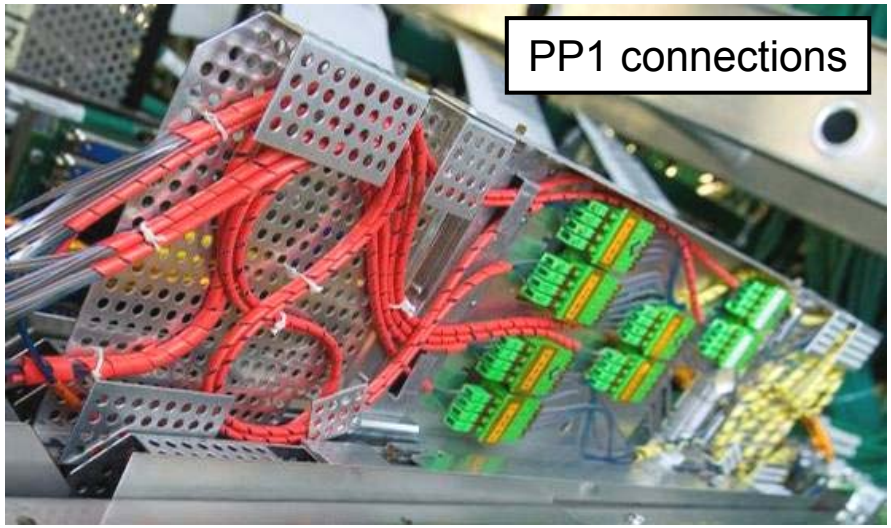
Optical parts	Total tested	Good	Broken	Faulty
MR cables	101 (9696 channels)	101	0	0

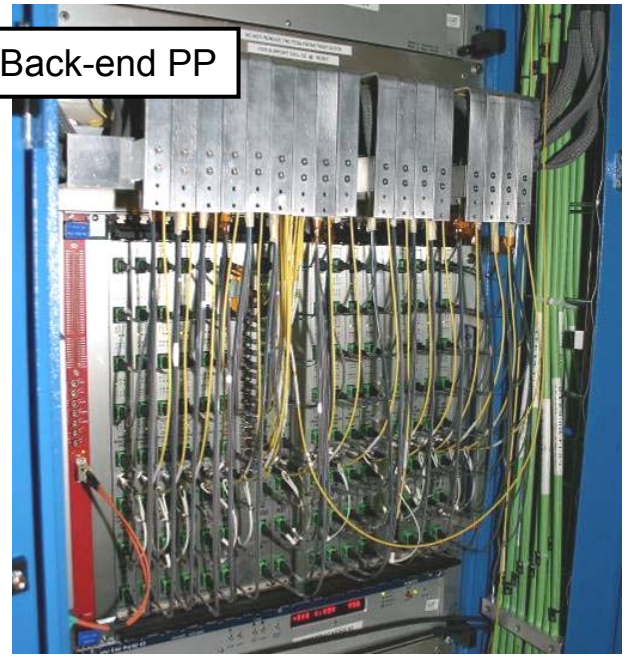
Installation and test procedures validated successfully!

Experience & Results: TIF full-links



Full-link tests to do before TK is powered.



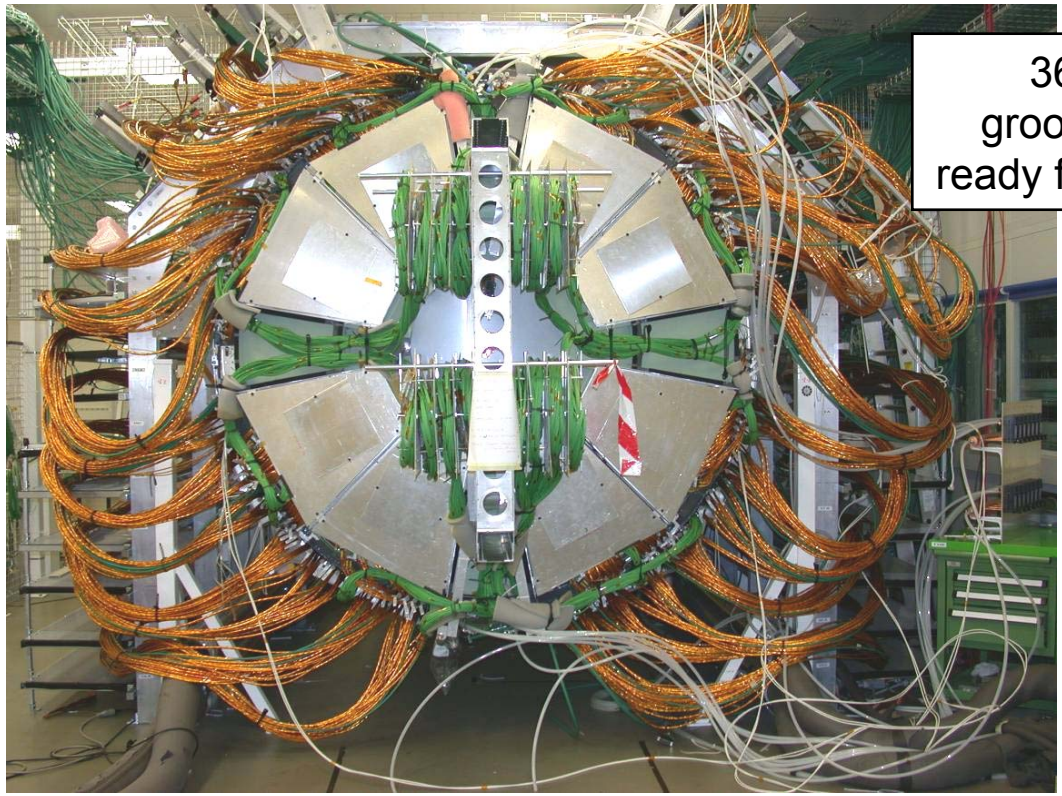


Aims: troubleshooting + experience with OTDR and connection procedures

Optical parts	Total tested	Dirty connections	Flagged pigtails (dark for DAQ)
MR cables	16 34 ribbons; 408 optical links; (microscope + OTDR + DAQ feedback)	13 MFS 2 MPO 1 inside FED (NGK) All recovered by cleaning!	2 over bended (50cm and 70cm from laser) 1 MU disconnected (or fibre broken very close)

Total connections: 808 MFS, 808 MPO
Total optical channels: 9696

Experience & Results: TK summary



3624 fan-outs
groomed & packed
ready for TK installation

Tested by DAQ at TIF or Assembly Centers

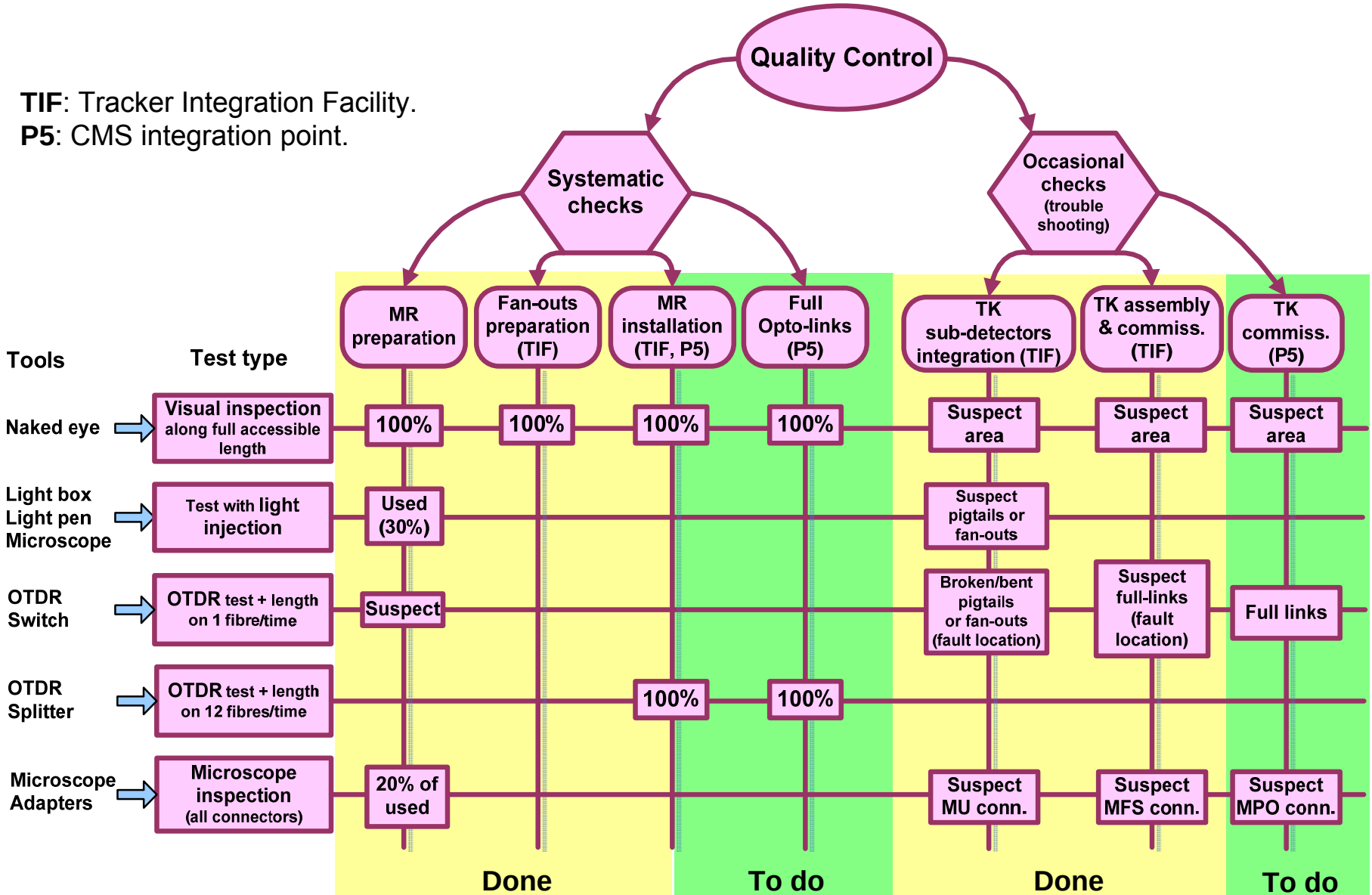
Opto-links team contribution at TIF

Optical parts	Total installed	Installed optical fibers	Broken fibers	High loss fibers
Pigtails	15860 (Optohybrids)	39240 1012 (2.6%) 54 problems 47 solved (87%) + 228 channels recovered in fan-outs and connections	19 (2) 0.05%	18 (5) 0.05%
Fan-outs	3624 (68)		41 (unused) (1)	0
MR cables	101*	9696	0	0

*** 20% of total MR to install at P5**

TK Optical Links Quality Control Program

TIF: Tracker Integration Facility.
P5: CMS integration point.



Conclusions

- The **QC program and activities** for CMS TK (and ECAL) optical cabling have been presented;

- The **OTDR test system** (customary enhanced at CERN) as key of the test program, allows **cabling installation/connections validation and lengths measurement**;

- **QA/QC procedures** and tools were **extensively practiced** at the Tracker Integration Facility:
  - as "**experts on-call**" for troubleshooting and for increasing our confidence in the test systems;
  - with **systematic tests** (MR cables) for practicing and validating QA/QC procedures;

- **Very good results** in terms of:
  - procedures: 101 MR cables (**20% of final installation**) were installed **without failure** at TIF;
  - troubleshooting capability: **87%** of the problematic fibers and the **100%** of the problematic connections **recovered successfully;**
  - quality and reliability of the TK optical system: **0.1%** of broken/faulty optical channels!

Next steps:

- **ECAL optical fibers cabling** on the Barrel detector in P5 is starting;

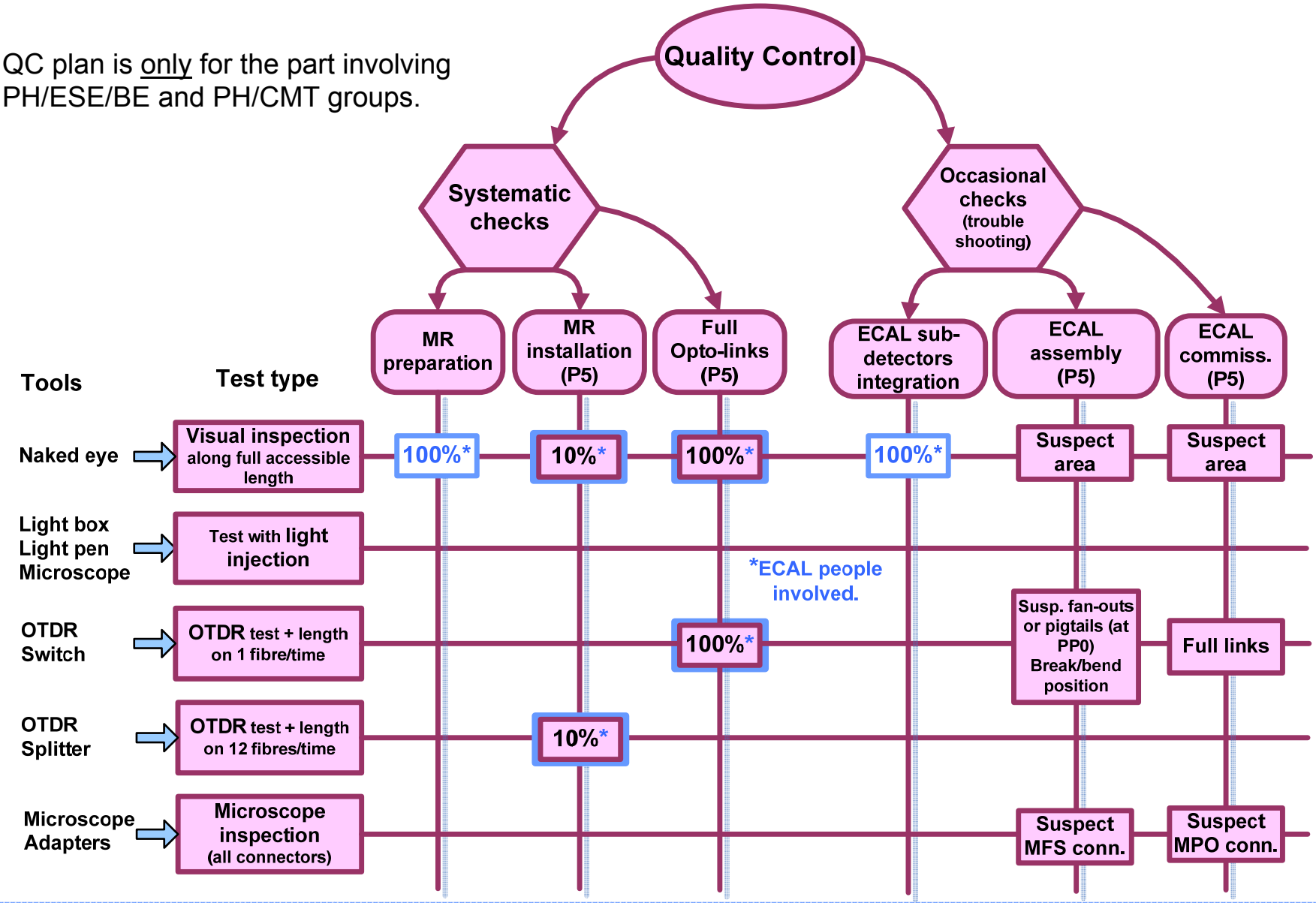
- **TK optical cabling** will follow: maximum effort required to Opto-links team
  - people well trained; procedures and test setup tuned;

- **WE ARE READY FOR OPTICAL CABLING IN P5!**

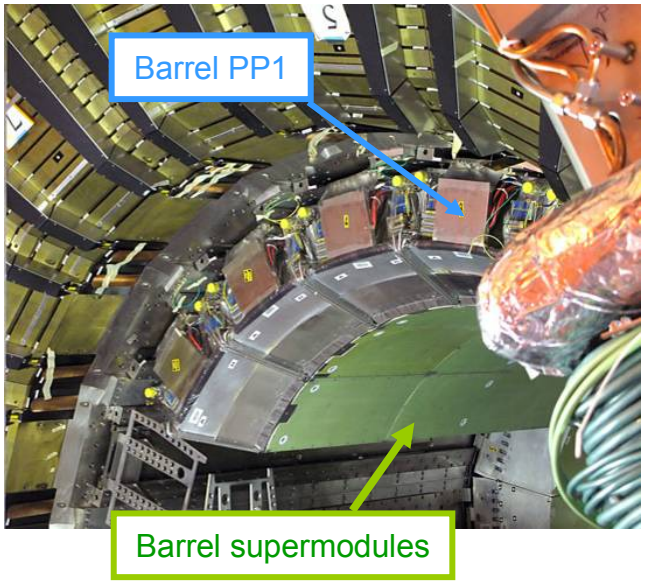
Extra slides

ECAL Optical Links Quality Control Program

QC plan is only for the part involving PH/ESE/BE and PH/CMT groups.

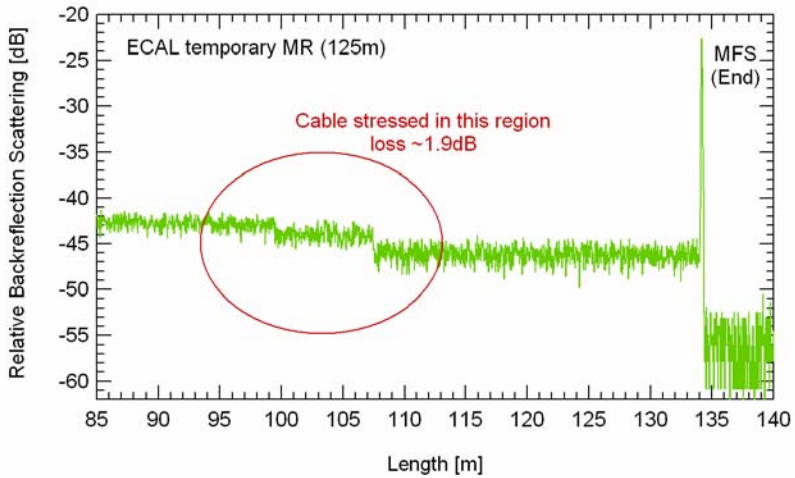


Experience & Results: ECAL troubleshooting

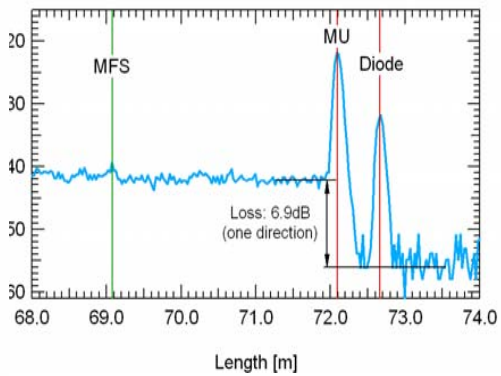


Optical parts	Total tested	Good	Recovered	Defective (working for DAQ)
Pigtails	668 all in fan-outs (OTDR)	666	/	2 (MU losses)
Fan-outs	65 (OTDR)	65	/	/
End Caps ribbons (MPO-MPO)	15	7	8 (broken, spliced by ECAL staff)	/
MR cables	2 (temporary installed)	1	/	1 (stressed)

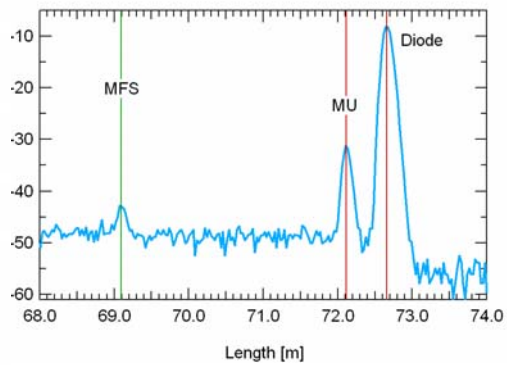
Pulling stress on MR cable



Sample: MU dirty or non latched



Typical good MU connection



MR cables removal and preparation

Storage area for cables removed/inspected/protected

Protection/inspection benches

All the 534 cables for TK + 30 for Pixels are protected, assigned and ready to use.

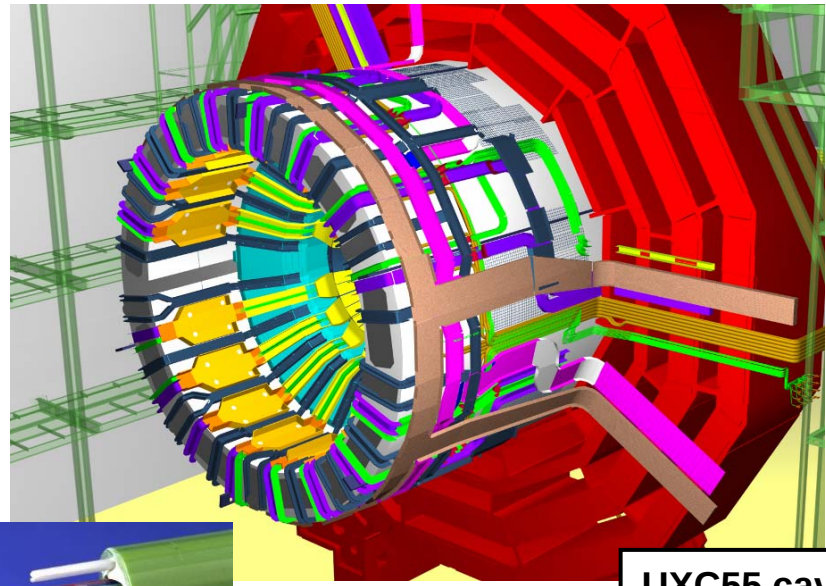
All used cables were collected and tested. The 38% will be reused in P5 for the TK:

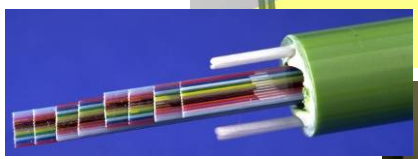
Optical parts	Total tested	Good	Recovered	Broken
Used MR	**178** 134 removed from TIF; 67 to be used in P5.	**161**	**5** 4 delamination; 1 missing QR.	**12** 5* MFS pin broken; 5* broken fibers close to connectors; 2 broken in the middle.

* still repairable (splice)

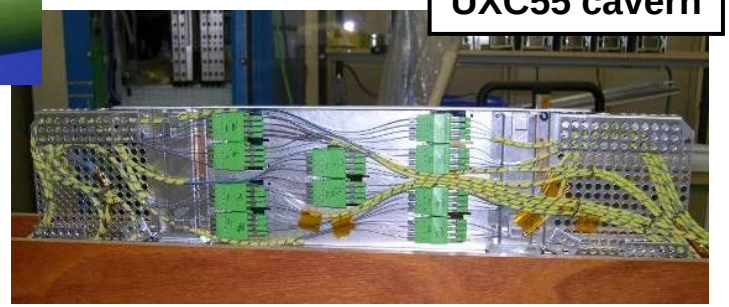
Optical Links: cabling details

USC55 cavern





UXC55 cavern



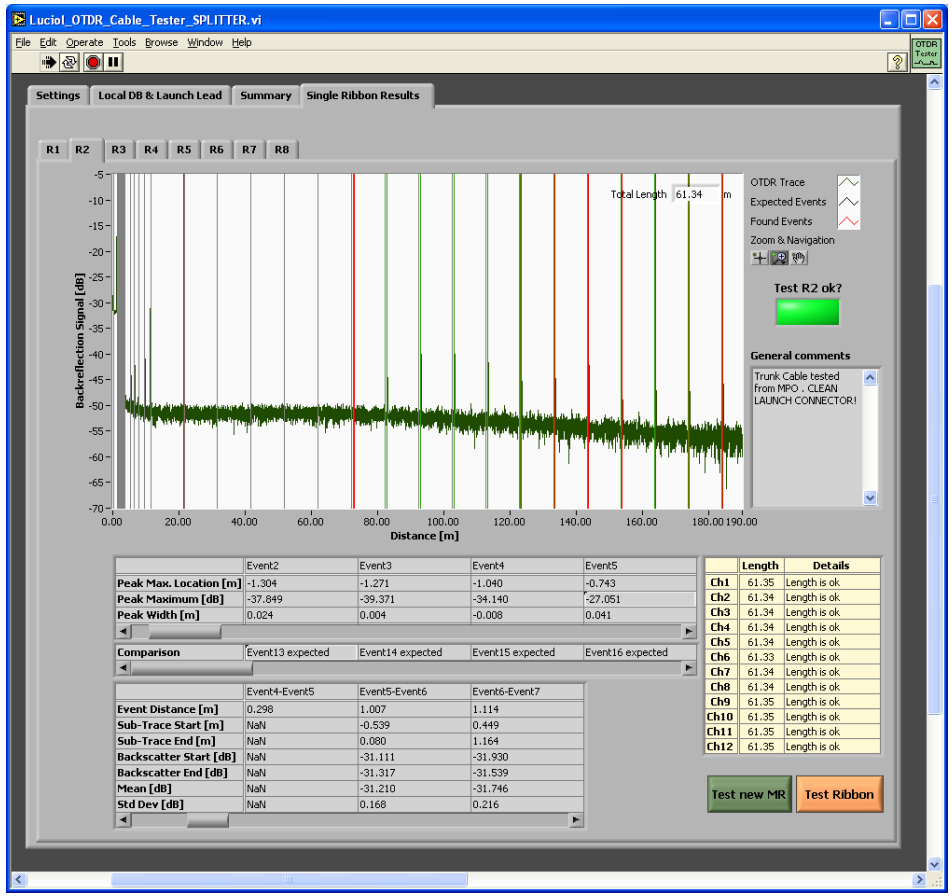
- PP1 already equipped with cassettes;
- ECAL cabling is starting;
- TK cable trays completed along the whole path.

OTDR Software

✓ User can choose at any time if working in full automatic way (repetitive tests) or manual (specific cases);
✓ Online analysis (quality/lengths) performed, data stored in raw and analyzed form;
✓ Cables information are registered in Inventory (local database);

Analysis details:

• launch is taken as reference and reflections measured are compared with expectation derived from cable specs;
• not expected reflections are flagged as suspect and require user interpretation;
• overall length is measured;
• no individual segments lengths; suspected channel inside the TK flagged for DAQ analysis;
• length tolerance is ±10cm.



	Event2	Event3	Event4	Event5
Peak Max. Location [m]	-1.304	-1.271	-1.040	-0.743
Peak Maximum [dB]	-37.849	-39.371	-34.140	-27.051
Peak Width [m]	0.024	0.004	-0.008	0.041

Comparison	Event13 expected	Event14 expected	Event15 expected	Event16 expected

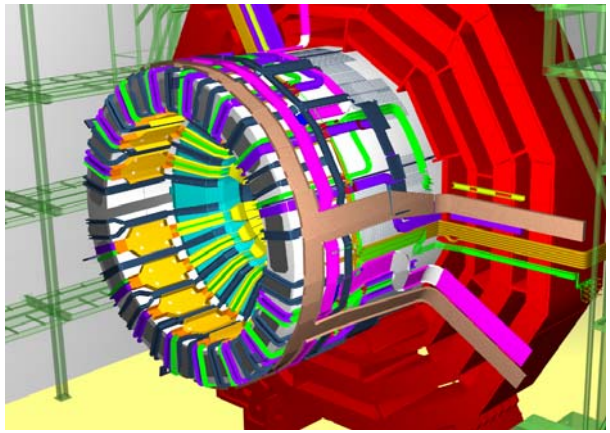
	Event4-Event5	Event5-Event6	Event6-Event7
Event Distance [m]	0.298	1.007	1.114
Sub-Trace Start [m]	NaN	-0.539	0.449
Sub-Trace End [m]	NaN	0.080	1.164
Backscatter Start [dB]	NaN	-31.111	-31.930
Backscatter End [dB]	NaN	-31.317	-31.539
Mean [dB]	NaN	-31.210	-31.746
Std Dev [dB]	NaN	0.168	0.216

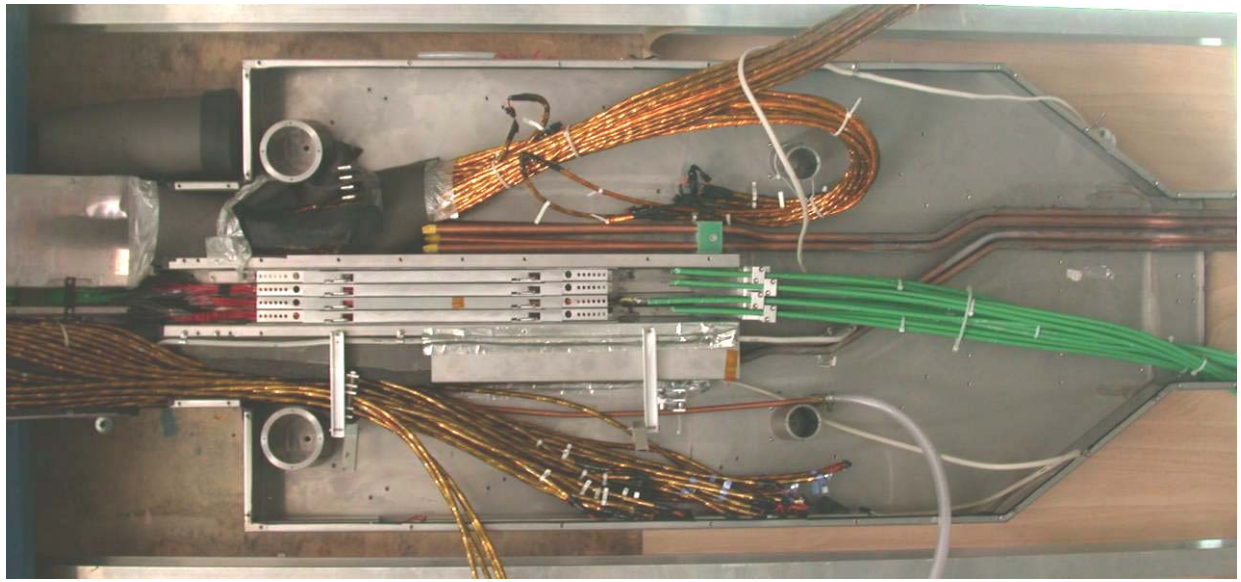
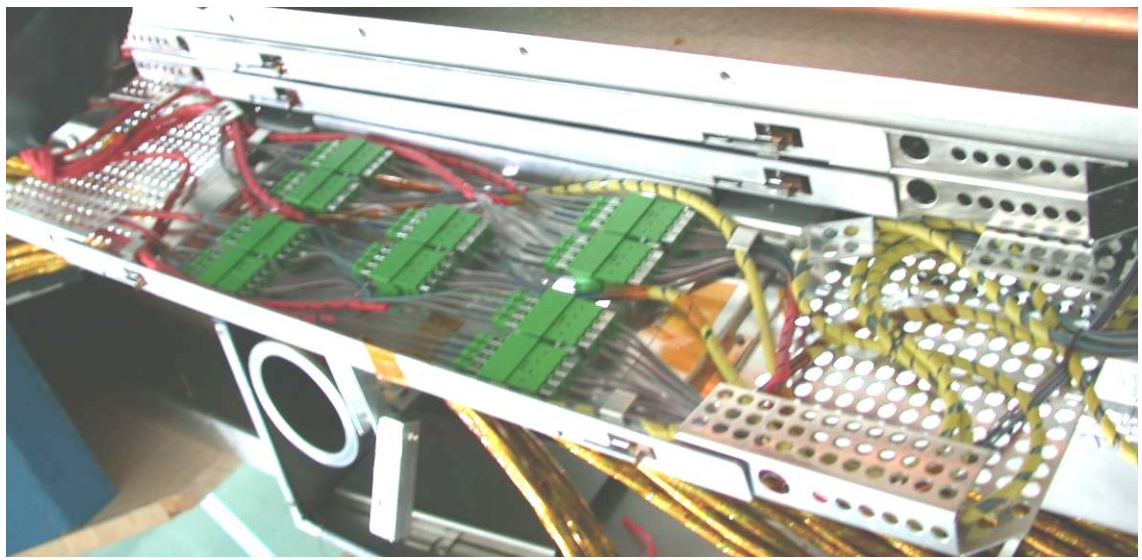
	Length	Details
Ch1	61.35	Length is ok
Ch2	61.34	Length is ok
Ch3	61.34	Length is ok
Ch4	61.34	Length is ok
Ch5	61.34	Length is ok
Ch6	61.33	Length is ok
Ch7	61.34	Length is ok
Ch8	61.34	Length is ok
Ch9	61.35	Length is ok
Ch10	61.35	Length is ok
Ch11	61.35	Length is ok
Ch12	61.35	Length is ok

All the instruments were extensively used already in the TIF and cable preparation. Procedures and SW have been tuned for P5.

Outlook for P5: practicing the final conditions

Mockup of TK PP1 (one sector).





Cables, ribbons and connectors positioning is satisfying.