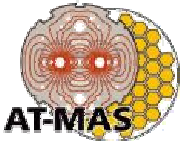


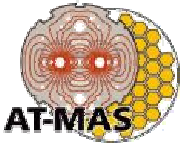
Follow up and checkpoints of cable properties

Luc OBERLI



Outline

- Cable properties relevant for the field quality
- Follow up of the cable properties during the production
- Status and trend of the cable dimensions
- Conclusion



Cable properties relevant for field quality

- Cable dimensions :

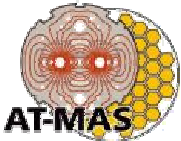
Tolerances were given by the estimation of the errors generated by variation of the conductor placement (to minimize the field errors components)

- Mid-thickness at $\pm 6 \mu\text{m}$

The mid-thickness is defined at 50 MPa (prestress in the dipole)

- Keystone angle at $\pm 0.05^\circ$

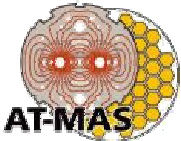
- Width 15.10 mm +0/+80 μm



Cable properties relevant for field quality

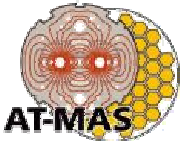
- Cable magnetization

- The persistent currents are eddy currents flowing inside the NbTi filaments. The field created by the persistent currents opposes the main field.
- The persistent currents in dipole are seen at injection as variation of the magnetic field errors
 - b3 most important error coming for 70% from the outer layer
 - b7 coming from the inner layer
- To control the effect of the persistent currents, the width of the magnetization loop at 1.9 K shall be :
 - $2 \mu\text{M} \leq 30 \text{ mT}$ for the inner strand
 - $2 \mu\text{M} \leq 23 \text{ mT}$ for the outer strand
- Strand magnetization value should remain fixed with a maximum variation of $\pm 4.5\%$ around the Center Line.



Cable properties relevant for field quality

- Interstrand cross contact resistance R_c of the cable
 - Interstrand eddy currents are flowing between the strands of a cable. They are the source of field errors generated mainly from the inner layer cable.
 - They are kept under control by oxidizing the SnAg layer of the strands at 200 C to get a contact resistance
 - $R_c \geq 20 \mu\Omega$ for the inner layer cable
 - $R_c \geq 40 \mu\Omega$ for the outer layer cable
 - Cables with different R_c between upper pole and lower pole (up-down asymmetry) will be the source of skew components a_2 and a_4 .



Follow-up of the cable properties during the production

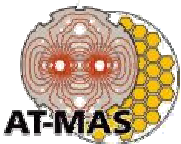
- 1. Billet approval

The strand piece lengths produced from a billet shall be approved by CERN before to be used for cabling

A magnetization measurement is **mandatory** for the approval of every billet.

Strand magnetization values of each supplier are followed by SPC.

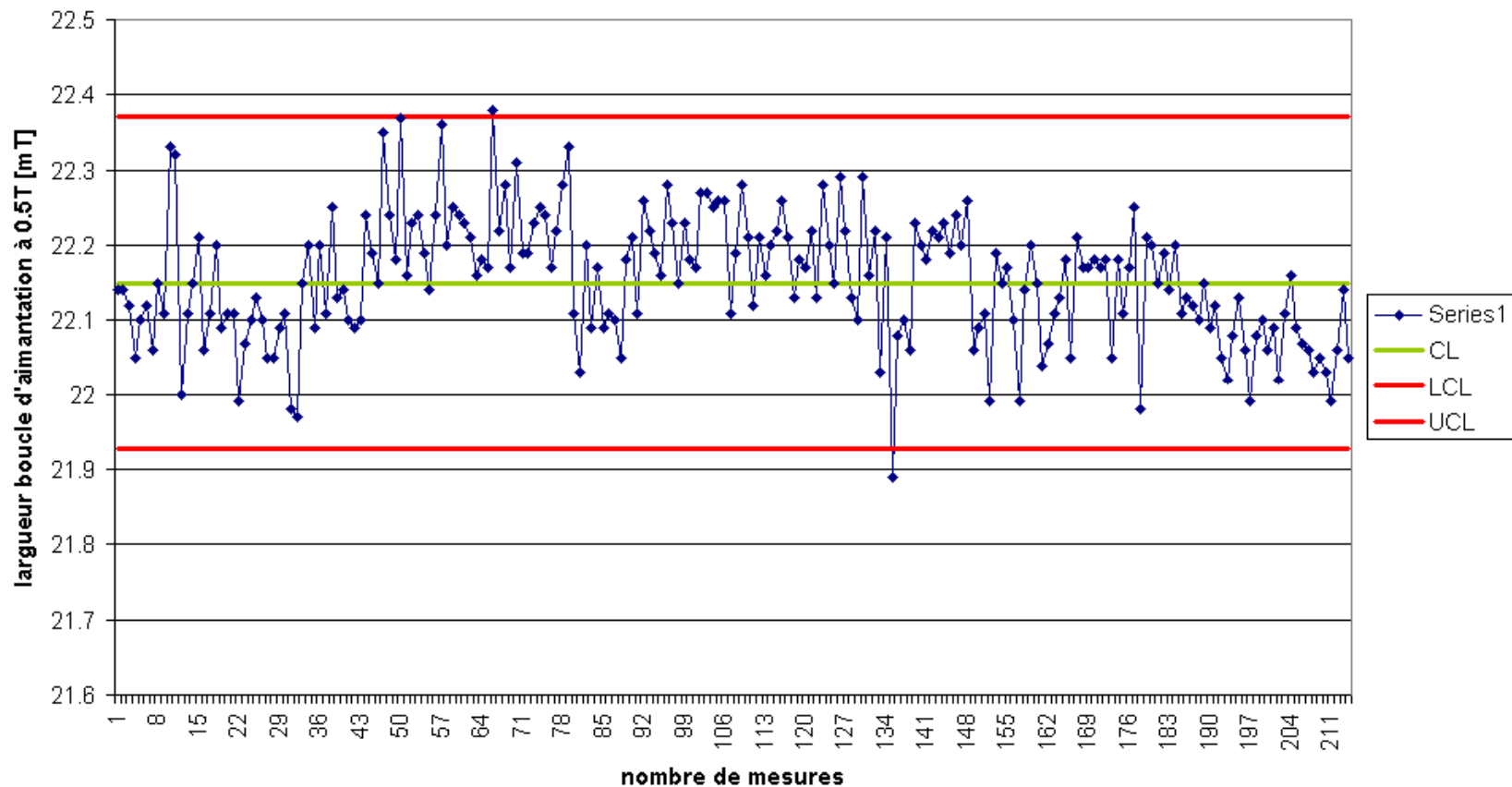
Strand magnetization is only measured by CERN, reproducibility better than $\pm 1\%$.

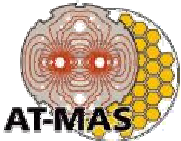


Magnetization of the reference wire to follow the reproducibility of the test station

(Courtesy of S. Le Naour)

Echantillon de référence
à 1.9K





Follow-up of the cable properties during the production

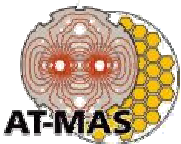
- 2. Cable strand map approval

The contractor must submit to CERN a cable strand map for each unit length and must get CERN's approval before to start cabling (only strands from approved billets can be used for cabling).

The cable heat treatment duration is given to the contractor to get the correct R_c according to the average thickness of the SnAg layer of the strand map.

The magnetization of the cable is calculated as the sum of the strand magnetization of each strand position in the map.

The contract follower checks that the magnetization is within the control limits of $\pm 4.5\%$ around the center line determined for each manufacturer.



Dashboard for cable strand map approval

Oracle Forms Runtime

Action Edit Query Block Record Field Tools Exit CableDB Window Help

Strand Map Approval

Strand Map Approval

Strand map **B10374** rev. 0 Decision ? **APPROVED**

Firms' data Cable Ic [A] **15564.2** Cable Ic at 4.2K recalculated by CERN from BILFAB **15560.8**

4.222K Strand Ic [A]: sum **15564.2** min **501.6** max **562.7** avg **555.9** std **11.66** **2.1** %

CERN data 4.222K Calculated cable Ic at 4.222K **15489.4**

1.900K Strand Ic at 1.900K [A]: Calculated cable Ic at 1.900K **16070.6**

Avg M [mT] **27.01** N **28** N **28** min **518.7** max **580.2** avg **573.95** std **11.13** **1.9** %

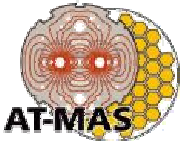
Strand Pos.	Str Id	Remaining length [m]	Billet approval document	Acc Accept ?	Accept type	M out of CL	Average billet M at 1.9K	Strand Cu/Sc by Firm	Average billet CuSC by CERN	Strand Ic at 4.222K calculated by Firm	Strand Ic at 4.222K calculated from MFDB	Strand Ic at 1.9K calculated by CERN
1	01B00587A82S	316	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
2	01B00337A02S	1882	BA01B8651	A	01	Y	30.97	1.666	1.674	501.6	501.5	518.7
3	01B00593A02S	465	BA01B9142	A	01	N	26.4	1.662	1.658	559	558.9	578.4
4	01B00587A05S	785	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
5	01B00593A04S	1005	BA01B9142	A	01	N	26.4	1.662	1.658	559	558.9	578.4
6	01B00587A05S	785	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
7	01B00593A05S	997	BA01B9142	A	01	N	26.4	1.662	1.658	559	558.9	578.4
8	01B00587A08S	679	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
9	01B00593A03S	355	BA01B9142	A	01	N	26.4	1.662	1.658	559	558.9	578.4
10	01B00587A10S	949	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
11	01B00587A09S	139	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
12	01B00591A03S	159	BA01B9140	A	01	N	27.51	1.667	1.666	550.2	550.1	572.3
13	01B00587A11S	476	BA01B9165	A	01	N	26.97	1.643	1.651	562.7	562.5	575.4
28	"Bump"	2	0	0	0	1	1/28	0	0/28	0	0/28	0/28

Strands SnAg coating View decision Criteria Preferences

NVE0402FUDBMapApp

Record: 1/1 <OSC> <DBG>

Start Follow_Up Oracle Forms Ru... CableMap.gif - Paint Microsoft PowerPoi... My Documents Links 16:12

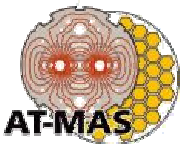


Follow-up of the cable properties during the production

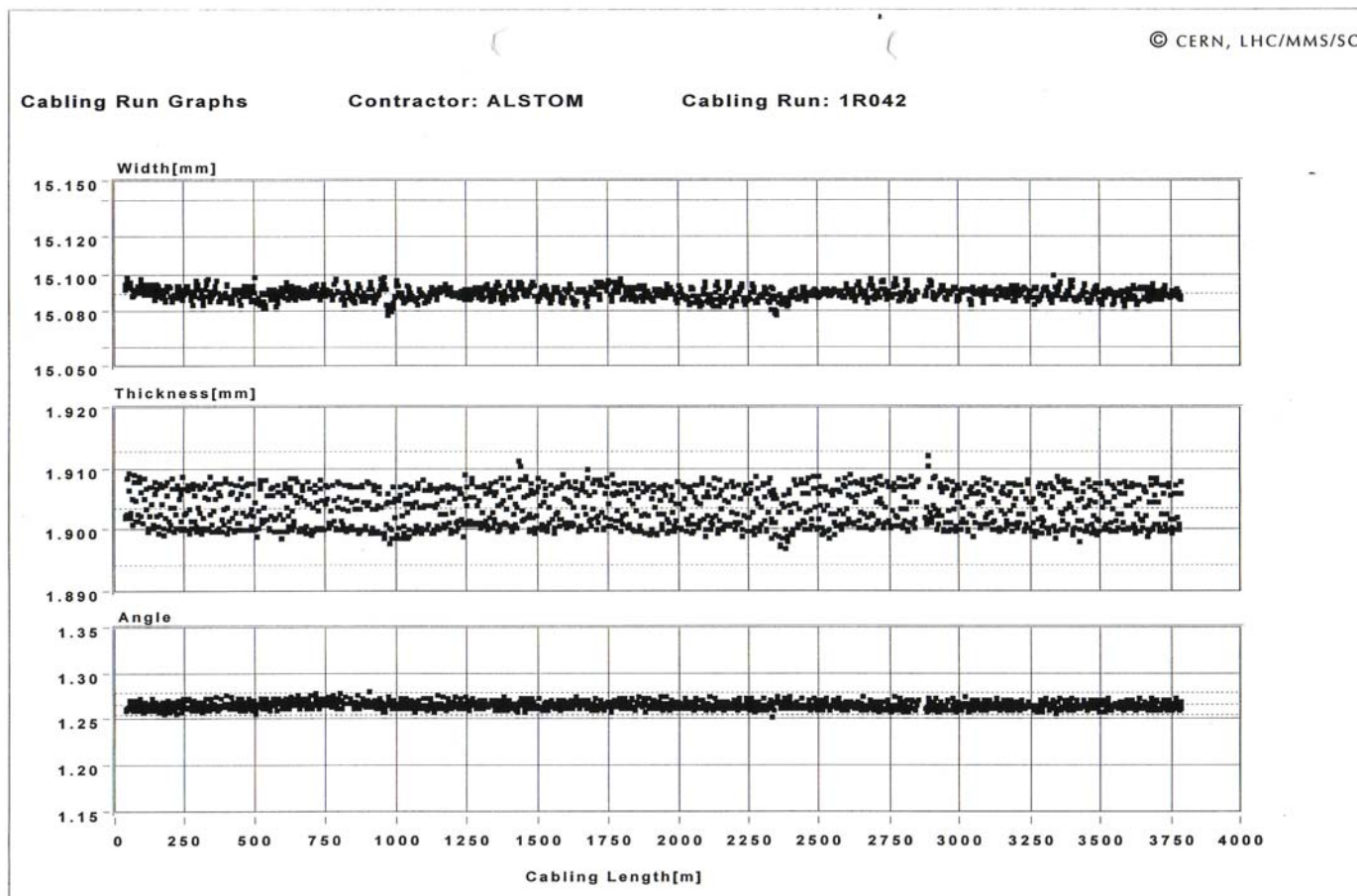
- 3. Cable shipment approval

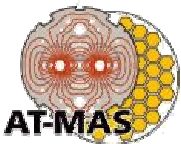
To get approval to ship a cable unit length to CERN, the manufacturer must provide :

- the cable dimension statistic over the unit length (average, min, max, sigma) and the cable fabrication data written into database tables
- a certificate of conformity and the graphs of the cable dimensions
- a 5 m long cable sample for every continuous length of cable
- a record of the cable heat treatment



Graphs of a cabling run





Graph of a cable unit length

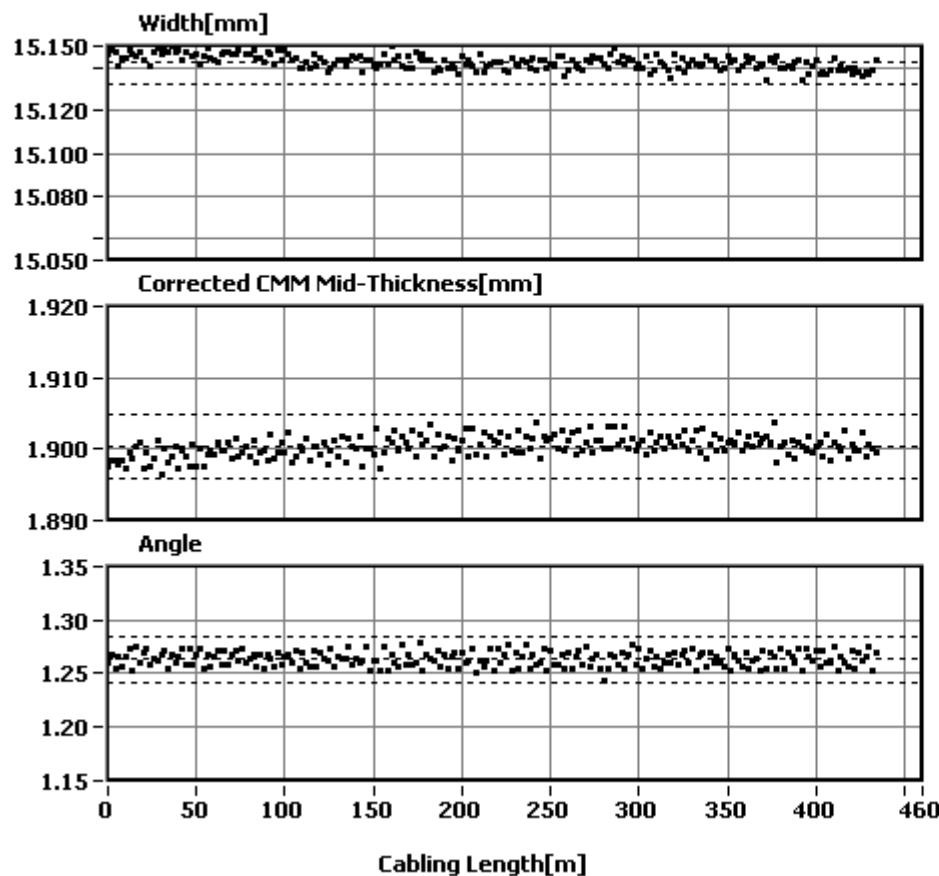
© CERN, AT-MAS-SC

Unit Length Graphs

Cable ID: 01E10323A

Cabling Run: 1R145

Location [m]: 4 <-> 438



Aver.	Min.	Max.	St.dev.
15.1427	15.1342	15.1545	0.0035

Aver.	Min.	Max.	St.dev.
1.9004	1.8965	1.9037	0.0015

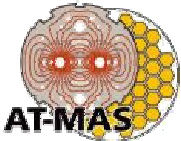
10-Stack Mid-Thickness [mm]

1.9004

Aver.	Min.	Max.	St.dev.
1.264	1.244	1.279	0.007

Pressure [MPa]

Aver.	Min.	Max.	St.dev.
19.983	19.902	19.997	0.014

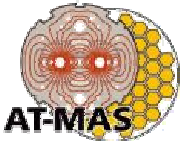


Follow-up of the cable properties during the production

- 4. Cable acceptance

To give the cable acceptance, acceptance tests are made by sampling, 1 cable Unit Length over 4 from every box delivered to CERN trying to test 1 UL from each cable strand map.

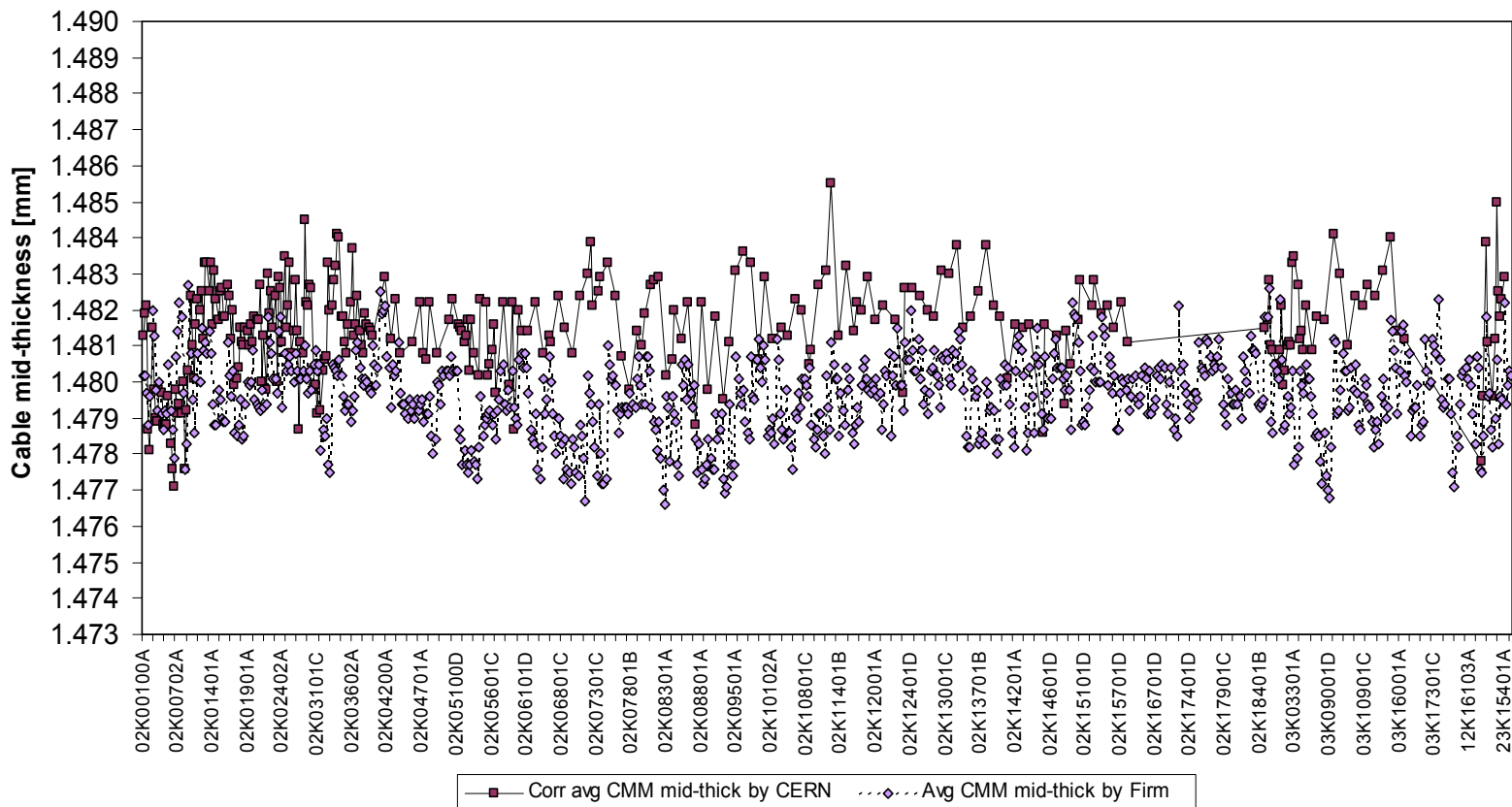
- Dimensional measurement in building 103 along the whole UL.
- 10-stack measurement made at 50 MPa at the end of the UL to correct the mid-thickness measurement made at 20 MPa by the Cable Measuring Machine (CMM).
- Rc measurements on samples cut at both extremities of the cable Unit Length.

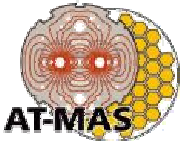


Average corrected Mid-thickness Cable 02K

Date : 13-Mar-03
Contract: F269
Prepared by OBERLI

Cable mid-thickness
Cable from 02K00100 to 23K17401

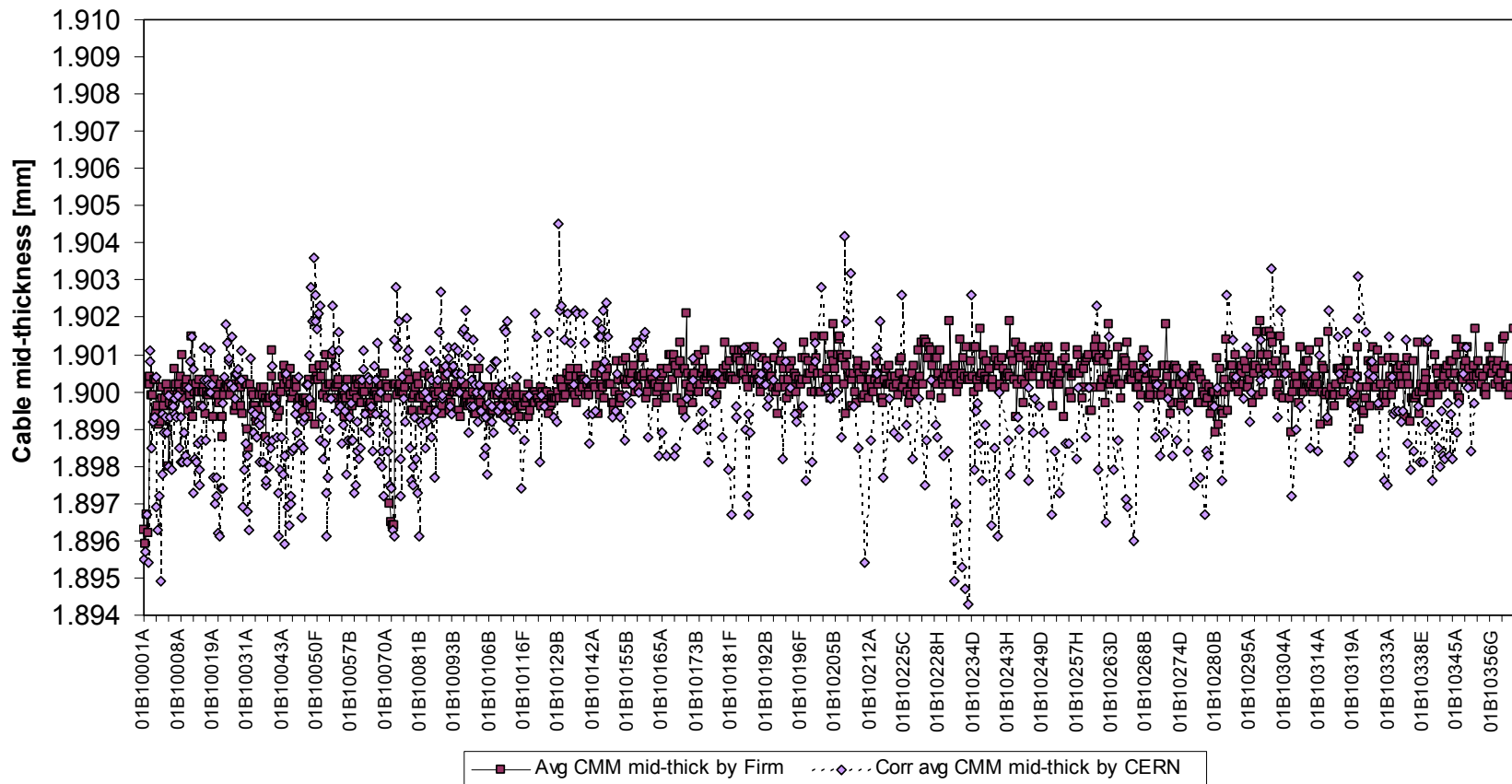


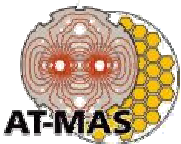


Average corrected Mid-thickness Cable 01B

Date : 13-Mar-03
Contract: F264
Prepared by OBERLI

Cable mid-thickness
Cable from 01B10001 to 01B10362



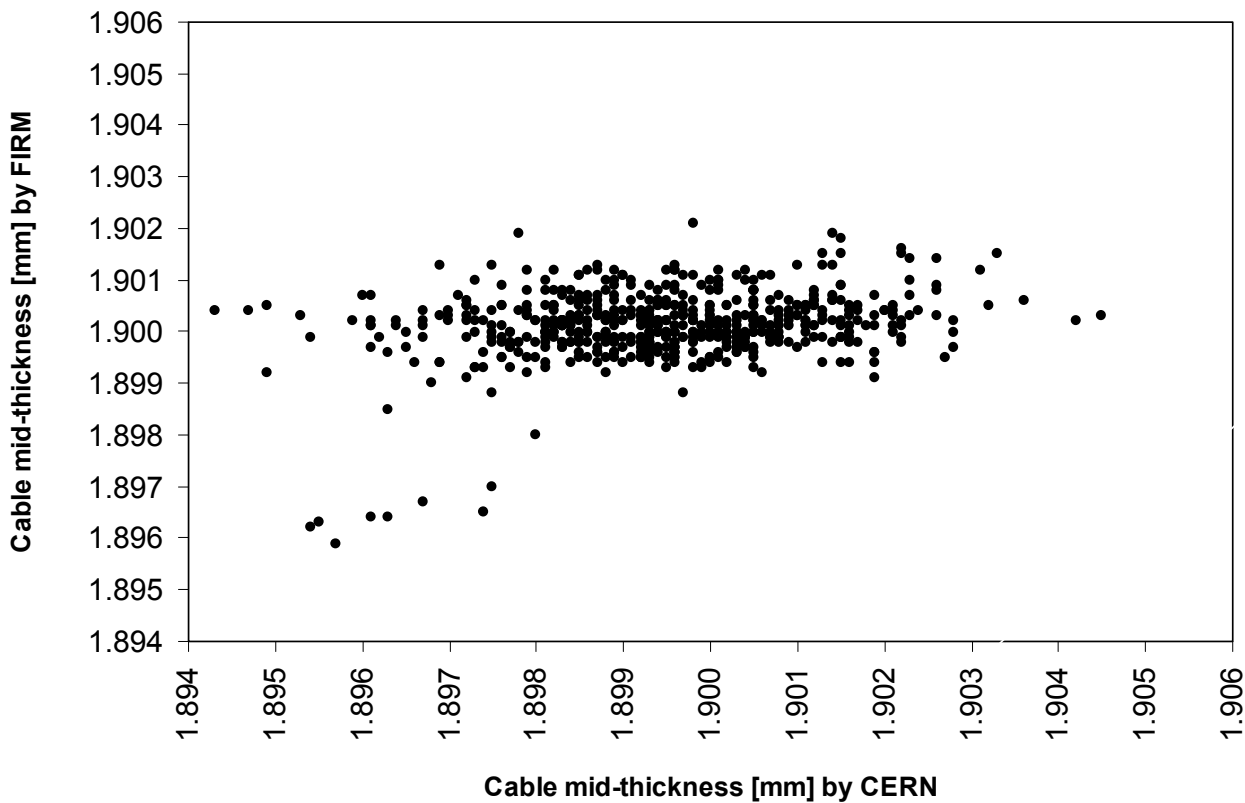


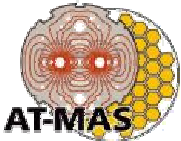
Average Mid-thickness

Correlation between CERN and supplier measurements

Date : 13-Mar-03
Contract: F264
Prepared by OBERLI

Cable mid-thickness
Cable from 01B10001 to 01B10362



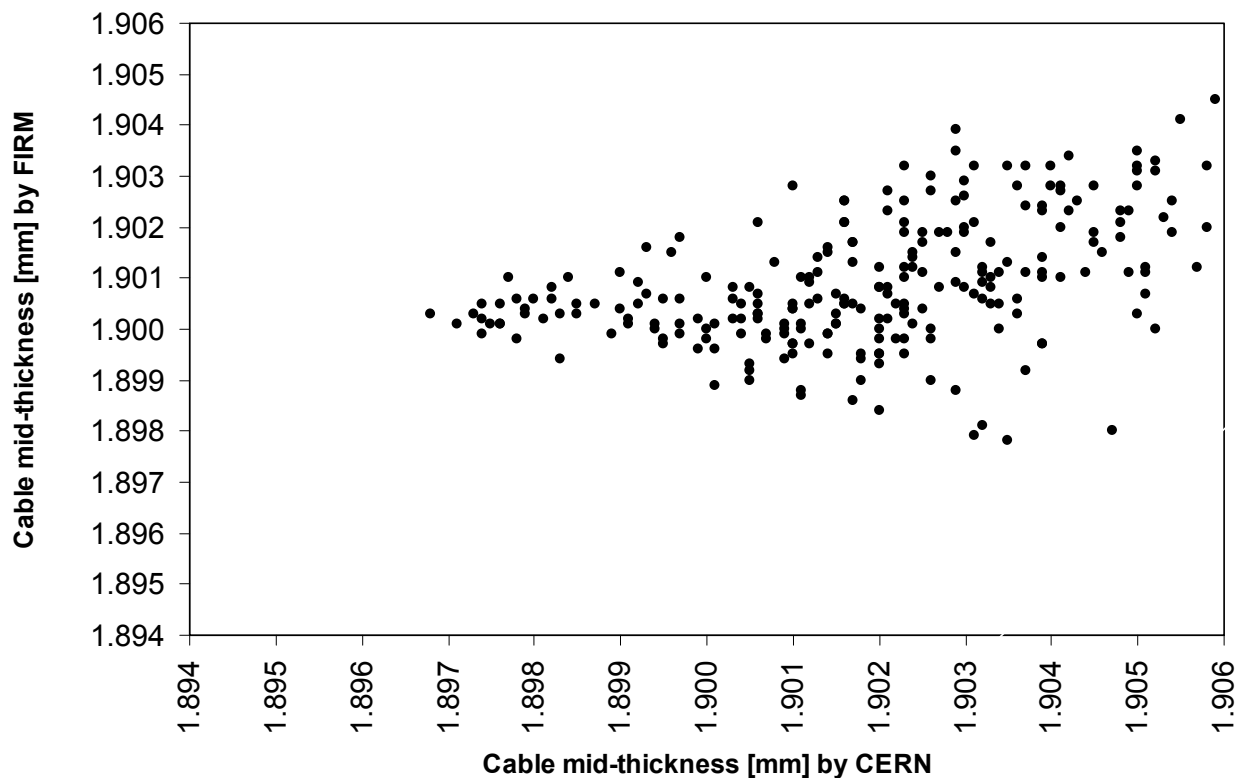


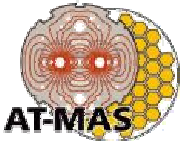
Average Mid-thickness

Correlation between CERN and supplier measurements

Date : 13-Mar-03
Contract: F266
Prepared by OBERLI

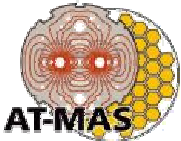
Cable mid-thickness
Cable from 01E00001 to 01E00065





Cable dimensions statistic on the production

Cable type	Mid-thickness (CERN -Firm)	Mid-thickness CERN	Sigma [μm]	Keystone Angle (Firm)	Sigma
01B	- 0.8	1.8994	1.6	1.257	0.016
01E	+ 0.9	1.9018	2.1	1.245	0.012
02G	+ 2.4	1.4816	1.6	0.897	0.015
02K	+ 1.9	1.4815	1.3	0.896	0.015
02B	- 0.3	1.4799	1.1	0.906	0.016
02C	+ 1.8	1.4834	2.7	0.897	0.012



Conclusion

- According to CERN measurements, the mid-thickness of the cable covers 2 third of the tolerance interval ($\pm 6 \mu\text{m}$)
- The average keystone angle of the cables is within the tolerances.
- Cable dimensions, magnetization and R_c are well under control with the 4 holding points introduced in the follow-up of the cable production.