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Project FELICIA - A probe to survey the RHIC magnet beampipe diameter for EIC beam screen insertion

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Electron-Ion Collider

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Project wrap-up report – BNL-224789-2023-TECH / EIC-ADD-TN-066

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Version	Date	Modifications
0.1	6/16/2023	Initial draft
1.0	8/29/2023	Document release
2.0	1/23/2025	Addition of appendix 3 – Simulation of max diameter restriction due to collaring of RHIC dipoles

Introduction

In 2022 during the preliminary EIC HSR beam screen design phase, the need arose to get a better understanding of the actual RHIC magnet beampipe diameter. This was required both for an early passively cooled beam screen design [3] and the subsequent actively cooled beam screen design.

A probe was designed and built to systematically measure the diameter of spare RHIC magnet beampipes. This report will summarize the main points of the design of the probe, its precision and accuracy data and the results from its measurement campaign.

While these points have been addressed and summarized on the paper THPA184 published at IPAC23, subsequently copied in this report, all measurement data will also be made available in this technical note for future needs.

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FELICIA - A probe to survey the RHIC magnet beampipe diameter for EIC beam screen insertion

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Abstract. The Electron Ion Collider (EIC) Hadron Storage Ring (HSR) will reuse many of the existing superconducting (SC) magnets of the RHIC storage rings. To comply with the beamline vacuum requirements in more demanding operational scenarios, the beampipe of the RHIC SC magnets will be equipped with low surface impedance, low secondary electron yield (SEY) beam screens. The installation of these beam screens will be done with the SC magnets as installed today, thus making it a critical operation for a timely EIC installation. The beam screen inner dimensions must be maximized to retain enough aperture to the beam. On the other hand, keeping enough clearance between the screen and the beampipe is critical to ensure a smooth beam screen installation. A survey probe was designed and built to measure the inner diameter of several RHIC SC magnets in-situ and provide critical data for the beam screen design optimization. This paper reports on the design of the probe and the results from the survey campaign.

1. Motivation and requirements

Featuring shorter bunches than RHIC [1] and large radial offsets for certain beam energies [2], the EIC hadron beams would produce an unacceptable heating on the current stainless steel RHIC beampipe. The solution adopted is to install a low impedance beam screen in the beampipes of the RHIC SC magnets [3]. Conceptual designs for this beam screen have evolved from a passively cooled solution [3] to an actively cooled beam screen with circulation of helium in a welded capillary (see Fig. 1).

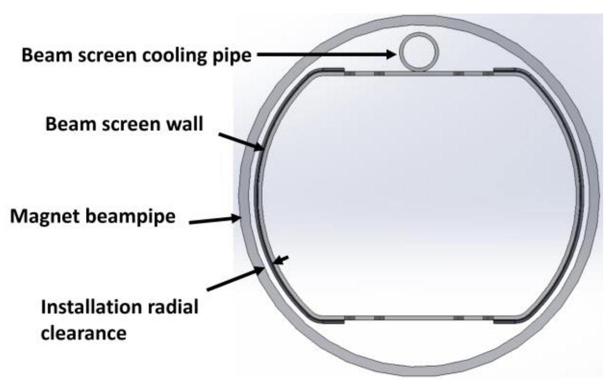


Figure 1 View of the actively cooled beam screen cross section.

The radial clearance between the beam screen and the beampipe diameter must be carefully set. A too tight clearance would lead to installation issues by interference with the beampipe while a too large clearance would reduce the beam aperture unnecessarily. So, the knowledge of the actual beam pipe diameter is a crucial prerequisite to a sound beam screen design.

Most magnets in the RHIC arcs have a nominal beampipe diameter of Ø69.1 mm except for the so-called snakes and spin rotators. The RHIC arc cold masses have lengths between 3 m and 12 m. The aim of this work was to design a survey probe that can measure the diameter of a complete magnet beampipe with a precision better than +/- Ø 0.1 mm.

2. Design of a survey probe

The survey probe is based on a touch probe concept. Stainless steel balls are pushed against the beampipe inner diameter, and the position of these balls is measured with linear potentiometers. The balls are attached to a tilt module. When tilting down, this module pushes against a spring-loaded linear potentiometer (see Fig. 2). Opposite to the tilt module is another touch ball positioned on a fixed arm. The potentiometer linear extension is therefore an image of the distance between the fixed ball and the tilt ball (i.e. pipe diameter). Each main module is equipped with four touch balls constituting two perpendicular measurements each with a tilt ball and a fixed ball.

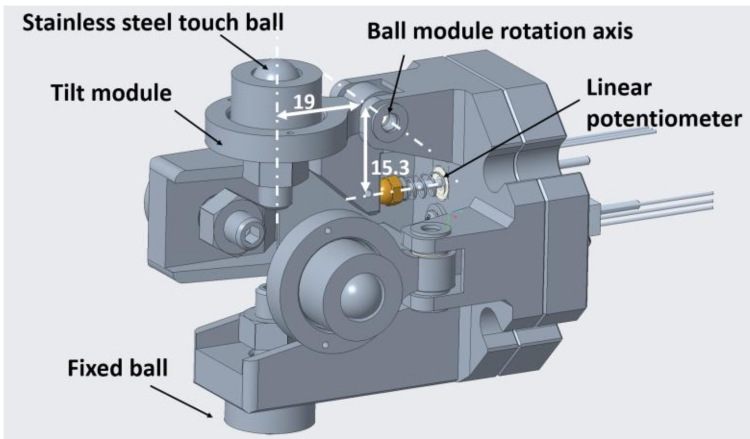


Figure 2 Probe Measurement Module.

The allowable diameter measurement range of the probe is 66 mm to 72 mm. The potentiometer shaft displacement for this range is about 5 mm corresponding to about half the potentiometer total linear range. The potentiometer output voltage is read by a 15-bits ADC which allows a readout resolution of 0.34 µm on the touch ball position through the assembly tilt.
The complete survey mole is equipped with two main measurement modules, one at its front and the other at its back (see Fig. 3). The main body of each module is 3D-printed while the tilt modules use bronze bushing joints and stainless-steel pins. Friction in the linear potentiometer was found to induce a hysteresis effect due to the distortion of the 3D-printed module. This was a key factor in the overall probe precision. So these modules were reinforced with epoxy glued thin stainless steel sheets to stiffen the assembly and limit the amplitude of the distortion hysteresis.

To go through the 12 m long beampipe with a controlled longitudinal sampling rate, the probe has been fitted with an onboard motor and a driving wheel. The motor displaces the probe in steps of around 10 mm and stop 0.2 s at each step to make redundant potentiometer recordings. Even a small amount of dirt in the beampipe was found to hinder the smooth motion of the stainless touch balls eventually. Adopting a back-and-forth motion at each step has solved the problem by avoiding dirt accumulation in the stainless ball assembly.

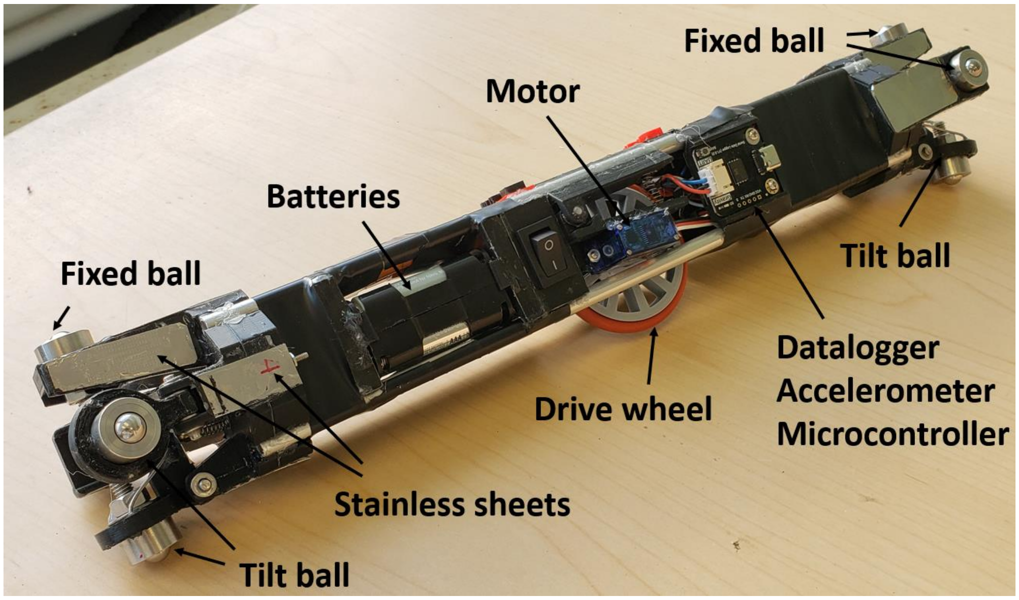


Figure 3 Assembled Survey Probe.

To keep track of the mole orientation in the beampipe, the probe is equipped with a three-axis accelerometer. The potentiometer ADC and accelerometer readout are stored in an onboard memory. The probe actuation settings and measurement data are handled through an open-source Arduino® microcontroller.

3. Results and discussion

3.1. Probe resolution, precision and accuracy

The calibration of the mole was done in a short pipe pinched with a C-clamp. The clamp was loaded and unloaded by steps of 0.15 mm and the potentiometer readout was recorded. A very good response linearity is achieved. The measured resolution is between 0.29 µm and 0.32 µm. The repeatability is measured between +/- 24 µm and +/- 38 µm.

The probe accuracy was evaluated by making use of a machined cylindrical plug of precise diameter. The C-clamp was used to distort the pipe inner diameter snugly around the plug outer diameter and the probe diameter readout was compared to the round plug OD. This has shown that, at worst, the probe diameter readout is 0.27 mm lower than the actual diameter. Overall, the probe accuracy was found always Ø0.05 to Ø0.27 mm under the actual diameter. This is thought to be linked with assembly misalignments of the opposing touch balls.
In summary, the precision and accuracy of the different measurements are summarized in Table 1.

Table 1 Summary of Measurement Precision and Accuracy

Potentiometer	**V front**	**V back**	**H front**	**H back**
Precision +/- (mm)	0.030	0.024	0.038	0.036
Accuracy (mm)	-0.16	-0.26	-0.27	-0.05

3.2. RHIC Arc dipole beampipe survey

The probe was used to measure the beampipes of a total of 12 RHIC arc dipoles (DRG) stored as spare. The dipole beampipe has three main sectors: a short run of pipe sticking out of the magnet cold mass, another run through the end volumes where the magnet leads and superconducting bus expansion loops are connected, and then the sector within the coils where the beam is subject to the magnetic field. The end volume and end pipe are also present on the other side of the coil section.

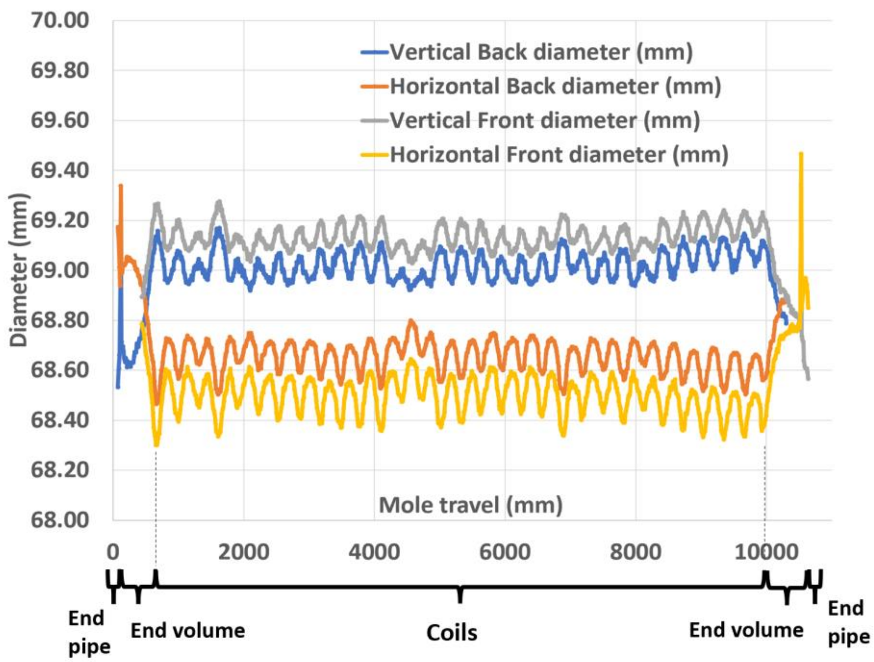


Figure 4 ID Survey of RHIC Dipole DRG567

As shown in Fig.4, the beampipe ID at the coil segment displays an oscillating pattern in both horizontal and vertical planes. This pattern was found consistent for all dipoles measured. Here the amplitude measured is around 0.3 mm and the horizontal and vertical oscillations are 180° out of phase. The horizontal ID is consistently lower than the vertical ID.

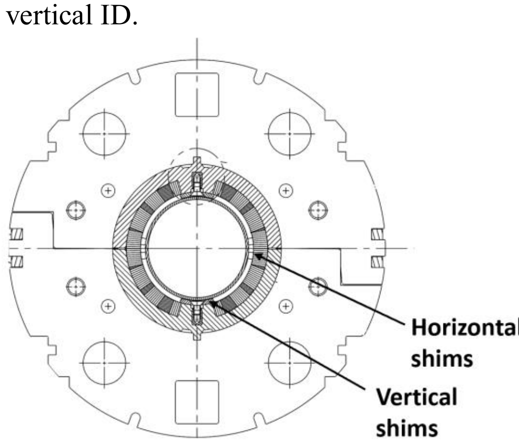


Figure 5 Cross Section of a RHIC superconducting dipole magnet [5]

The oscillation pattern is explained by the way the dipole magnets are assembled. The collaring of RHIC dipoles is done by pressing the two parts of the yoke together to apply a pre-stress on the coil (see Fig. 5). The dipole yoke is then bent to imprint a horizontal sagitta to the magnet and the cold mass outer shells are welded on [4]. The beampipe is centred in the yoke by means of locating shims. These locating shims are placed about 0.3 m apart. Horizontal and vertical shims are staggered. The imprint of these shims explains the oscillation wavelength, amplitude and relative phase seen of Fig 4.

The average minimum diameter and standard deviation (σ) for the beampipe of a sample population of 12 dipoles are used to determine the lower bound beampipe diameter that is likely to allow a smooth beam screen insertion. Under the assumption that the sample population is representative of the magnets installed in RHIC and that the assembly tolerance conforms to a normal distribution, we elected to subtract 3σ to the average diameter to determine the maximum beam screen OD that should fit through 99.8% of all dipoles. Values are summarized in Table 2.

Table 2 Dipole Diameter Summary

Dimensions in mm	**Horizontal**	**Vertical**
Average	ϕ 68.44	ϕ 68.46
Std dev σ	0.10	0.28
Average – 3σ	ϕ 68.14	ϕ 67.62

From the dipole diameter analysis (see Table 2), the maximum OD recommended for the beam screen assembly is 68.14 mm horizontal and 67.62 mm vertical.

Adding the manufacturing tolerance and beam screen wall thickness gives a minimum horizontal beam aperture of 63 mm. For high energy beams with large orbit excursions, this was found to correspond to an expected available beam aperture within 9 – 10 σ.

3.3. RHIC DU Survey

In the RHIC straight sections, cold drift spaces are filled with dummy (DU) sections that ensure the vacuum lines, cryogenic lines and electrical bus continuity.
By design the long RHIC DU sections have welds on the beampipe that lead to the protrusion of the weld seam into the beampipe. In some instances, a pinch of the beampipe attributed to the through bolts in the aluminium I-beams has been seen during our surveys (see Fig. 6).

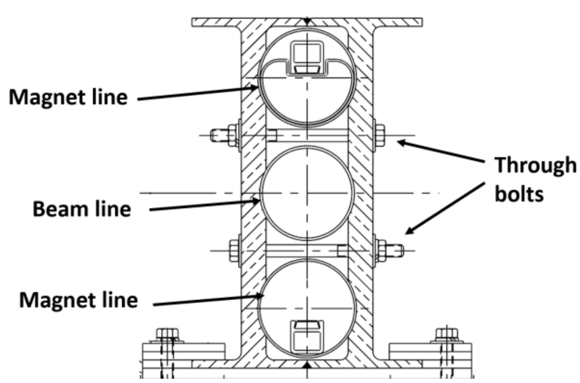


Figure 6 DU Section Cold Mass Cross Section

These features lead to significant distortions along the beampipe. Inner weld beads and through bolt pinches in the beampipe have been found to reduce the beampipe diameter to values as low as Ø66.83 mm and Ø67.50 mm, respectively. RHIC contains a limited number of DU sections, so including these values in the beam screen diameter analysis would have led to an unreasonable diameter constraint on all magnets, and further reduced the beam aperture. Therefore, the ID of each DU beampipe will be surveyed individually ahead of beam screen insertion and specific measures will be adopted on a case by case.

3.4. RHIC CQS survey

In the arcs, the RHIC dipoles alternate with a CQS assembly which contain a quadrupole, a corrector and either a sextupole or a trim magnet in a single cold mass. The CQS cold mass is collared and welded before the insertion of the straight beampipe. So there is sufficient clearance for insertion of the beampipe through the coils and no interference is expected there. Survey of a CQS beampipe confirmed that the CQS cold mass has a smooth beam pipe ID upstream of its stripline BPM module [5].

4. Why Felicia ?

Felicia was the name of a ferret working at FNAL in the late 1960s. She was working to check for blockage and clean the beam aperture of the FNAL accelerators beampipe. [6] This is a tribute to a brave ferret.

5. Conclusion

One of the early challenges of the EIC beam screen design was getting a precise knowledge of the beampipe diameter profile to set its dimensions correctly. To this end, a survey mole was engineered, assembled, and calibrated in the second half of 2022. A series of survey runs in RHIC spare magnets has led to recommendations on the beam screen assembly OD to maximise both the beam aperture and the chances of a smooth installation.

6. References

[1] F. Willeke and J. Beebe-Wang, "Electron Ion Collider Conceptual Design Report 2021," Feb. 2021, doi: 10.2172/1765663.

[2] S. Peggs *et al.*, "Large Radial Shifts in the EIC Hadron Storage Ring", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 1443-1446, doi:10.18429/JACoW-IPAC2021-TUPAB042.

[3] S. Verdú-Andrés *et al.*, "A Beam Screen to Prepare the RHIC Vacuum Chamber for EIC Hadron Beams: Conceptual Design and Requirements", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 2066-2069. doi:10.18429/JACoW-IPAC2021-TUPAB260

[4] "The RHIC magnet system for NIM", BNL technical note MDN-610-20, Nov. 15 2001.

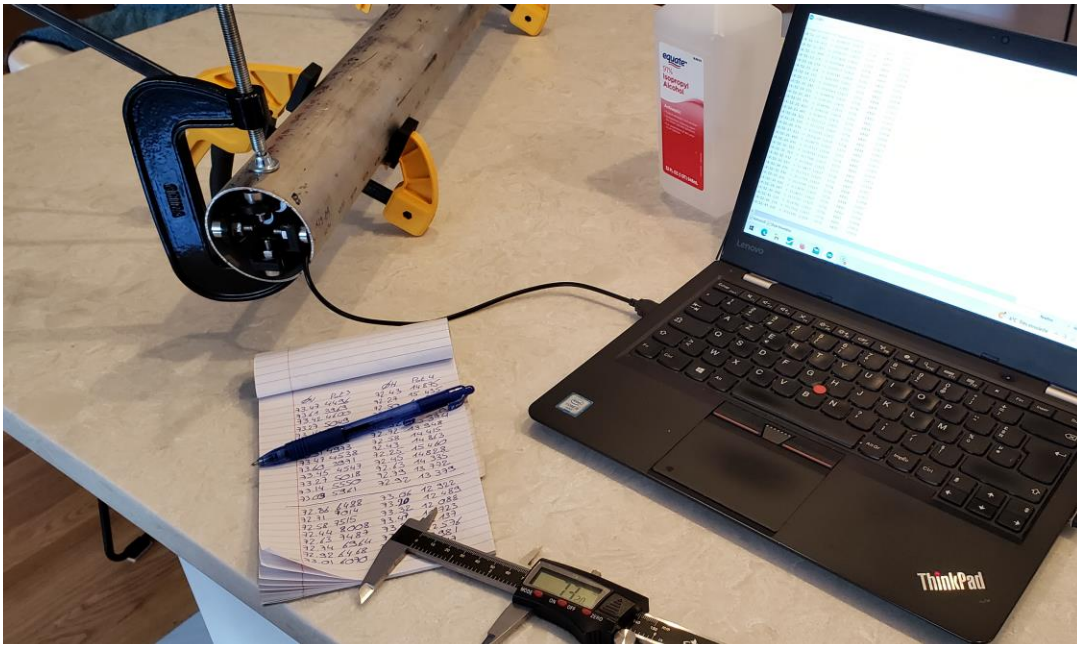
[5] P. R. Cameron, M. C. Grau, W. A. Ryan, T. J. Shea, and R. E. Sikora, "RHIC Beam Position Monitor Assemblies", in *Proc. PAC'93*, Washington D.C., USA, Mar. 1993, pp. 2328-2331.

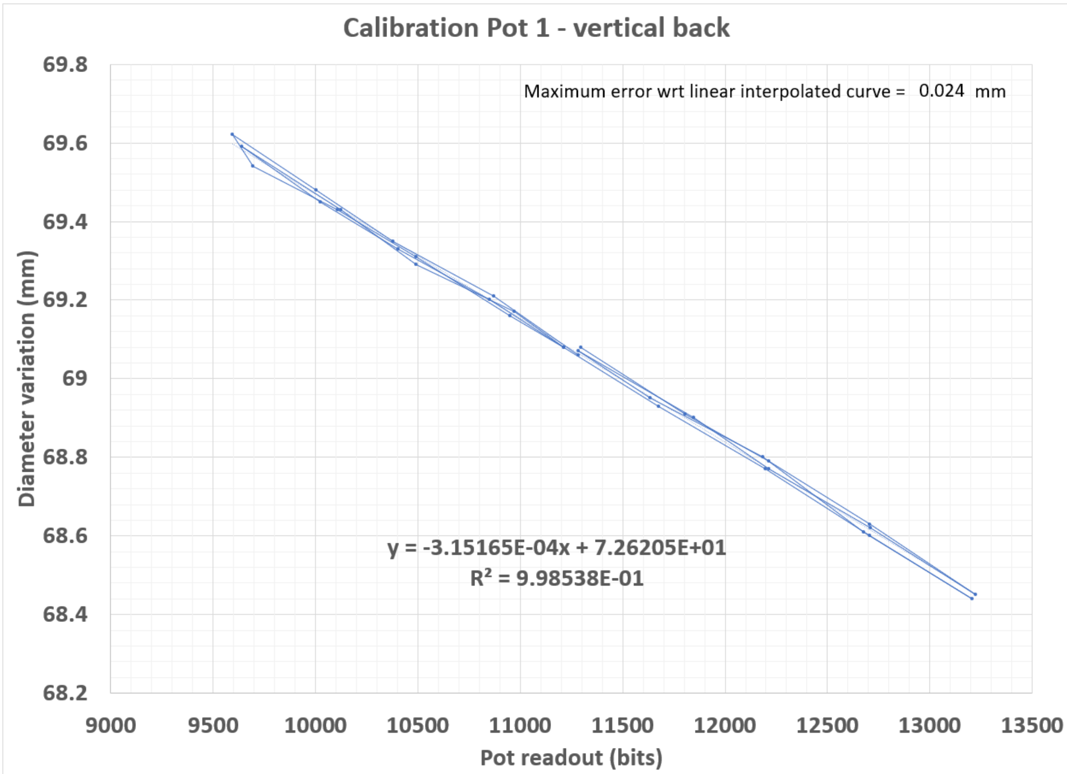
[6] Fermilab, https://news.fnal.gov/2016/10/felicia-helps-out/.

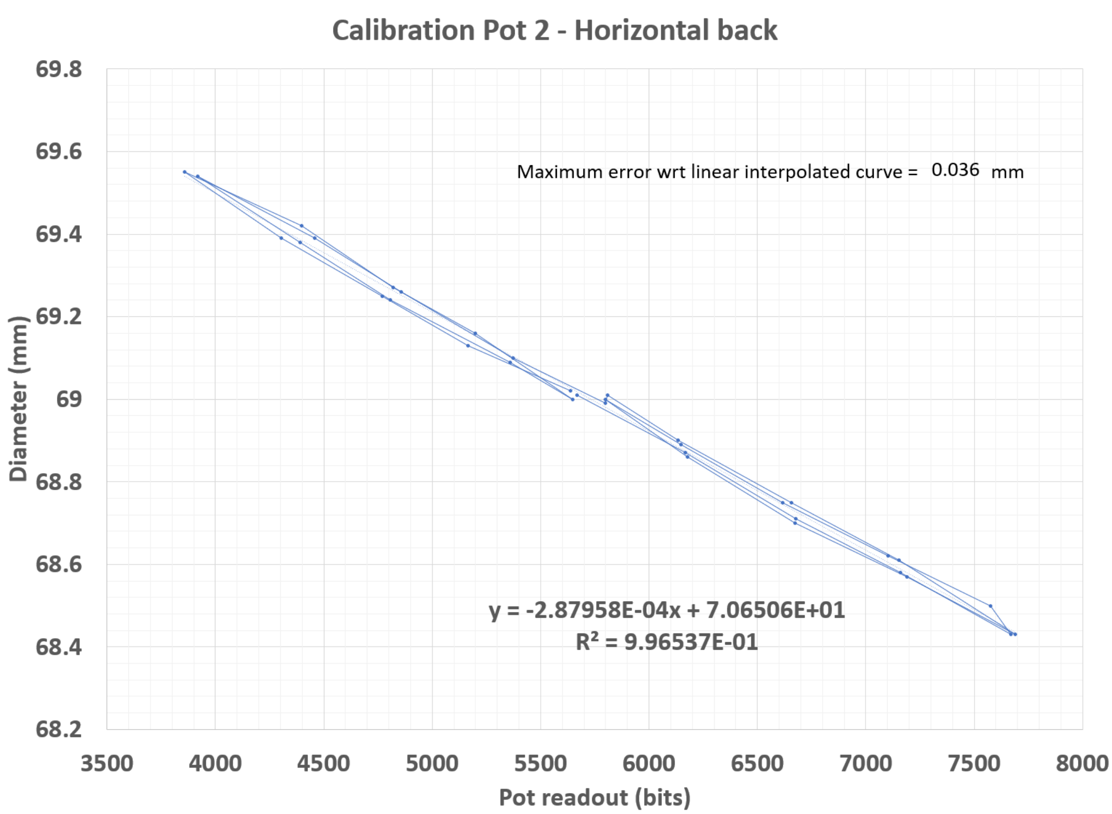
Appendix 1 – Determination of the probe resolution-precision-accuracy

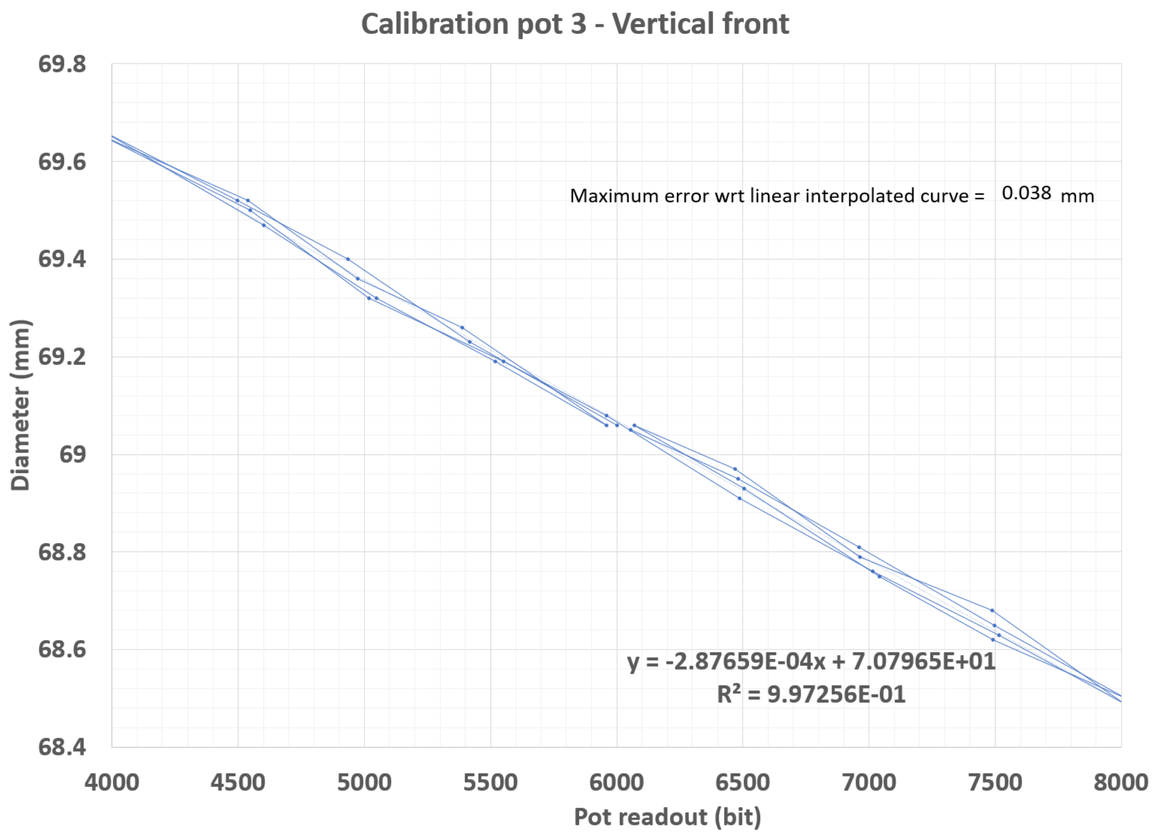
Potentiometer calibration

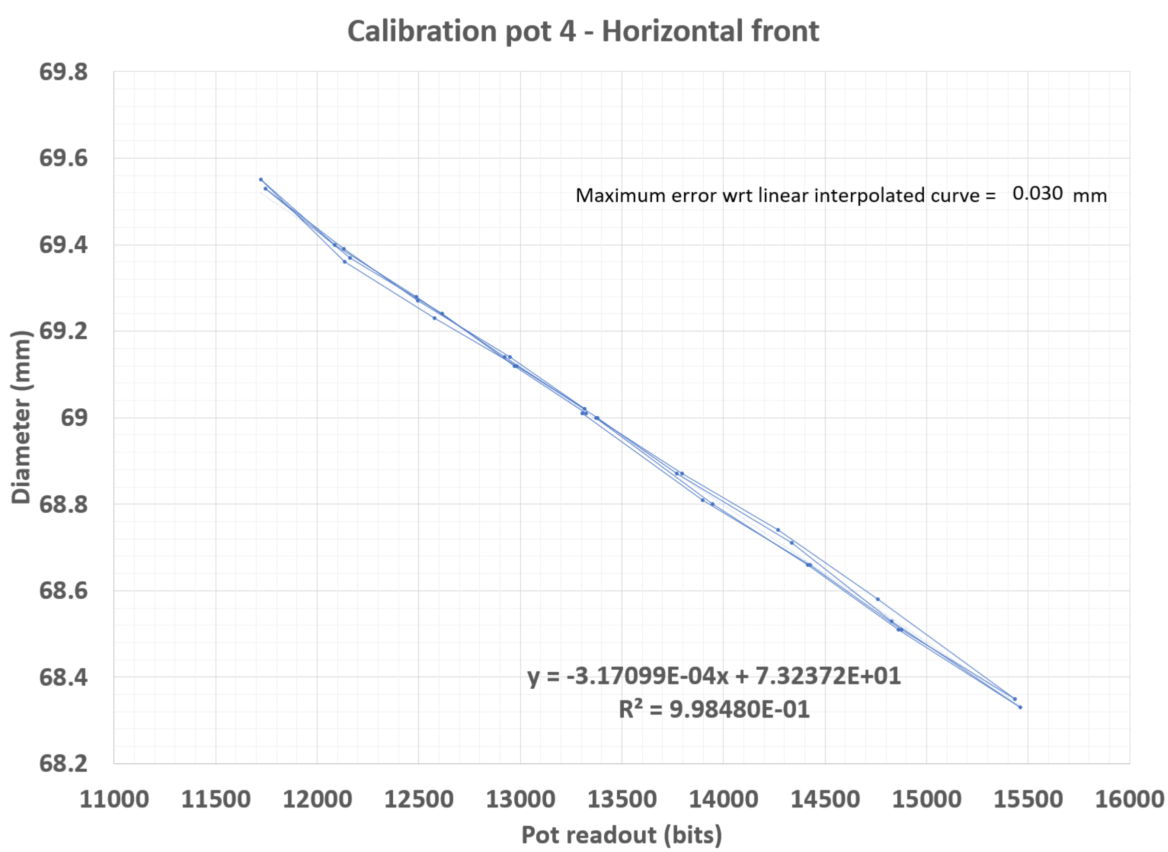
The potentiometers were calibrated by progressively pinching a short run of pipe with a C-clamp, measuring the variation of the outer diameter with a caliper and recording the ADC readout with the diameter variation.




Calibration Pot 1 - vertical back
Maximum error wrt linear interpolated curve = 0.024 mm
y = -3.15165E-04x + 7.26205E+01
R² = 9.98538E-01
Diameter variation (mm)
Pot readout (bits)
69.8
69.6
69.4
69.2
69
68.8
68.6
68.4
68.2
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500


Calibration Pot 2 - Horizontal back
Maximum error wrt linear interpolated curve = 0.036 mm
y = -2.87958E-04x + 7.06506E+01
R² = 9.96537E-01
Diameter (mm)
Pot readout (bits)
69.8
69.6
69.4
69.2
69
68.8
68.6
68.4
68.2
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000

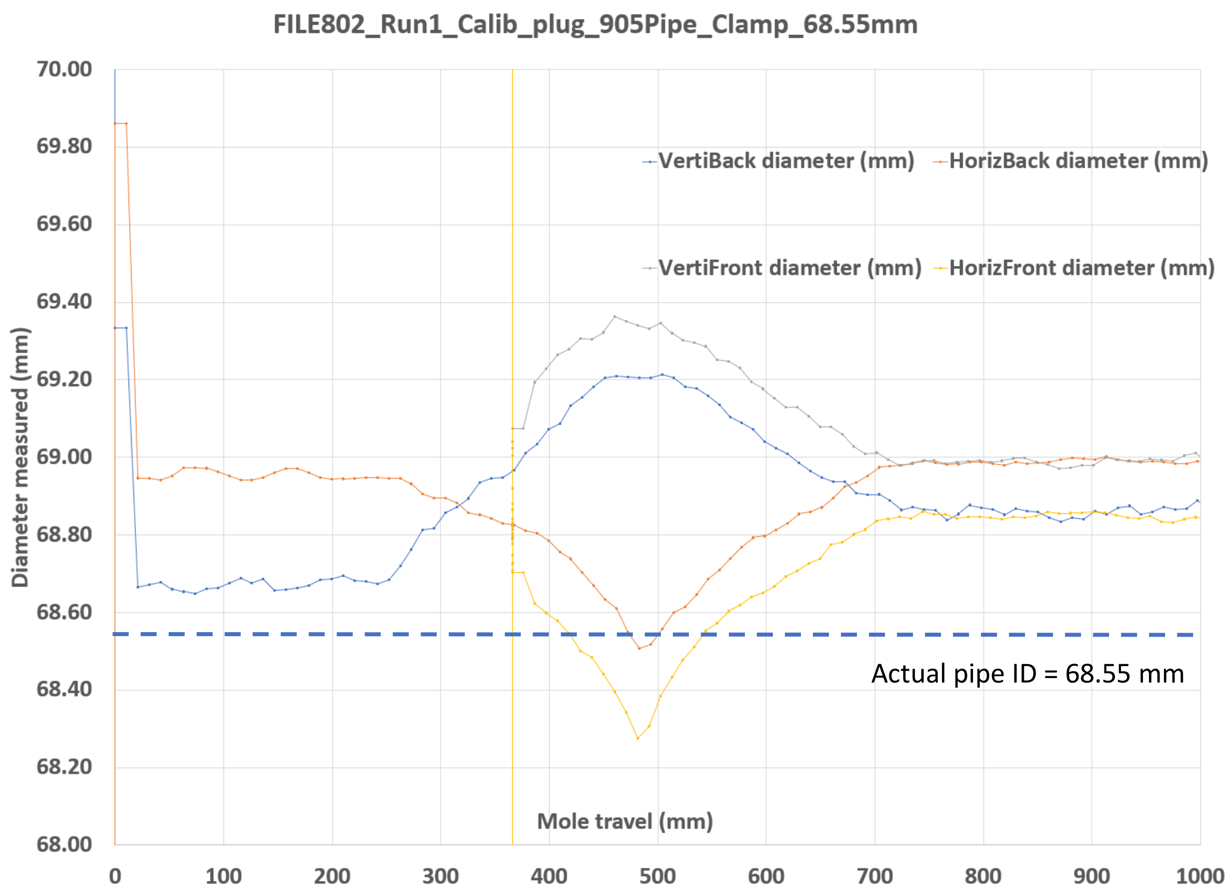

Calibration pot 3 - Vertical front
Maximum error wrt linear interpolated curve = 0.038 mm
y = -2.87659E-04x + 7.07965E+01
R² = 9.97256E-01
Diameter (mm)
Pot readout (bit)
69.8
69.6
69.4
69.2
69
68.8
68.6
68.4
4000
4500
5000
5500
6000
6500
7000
7500
8000

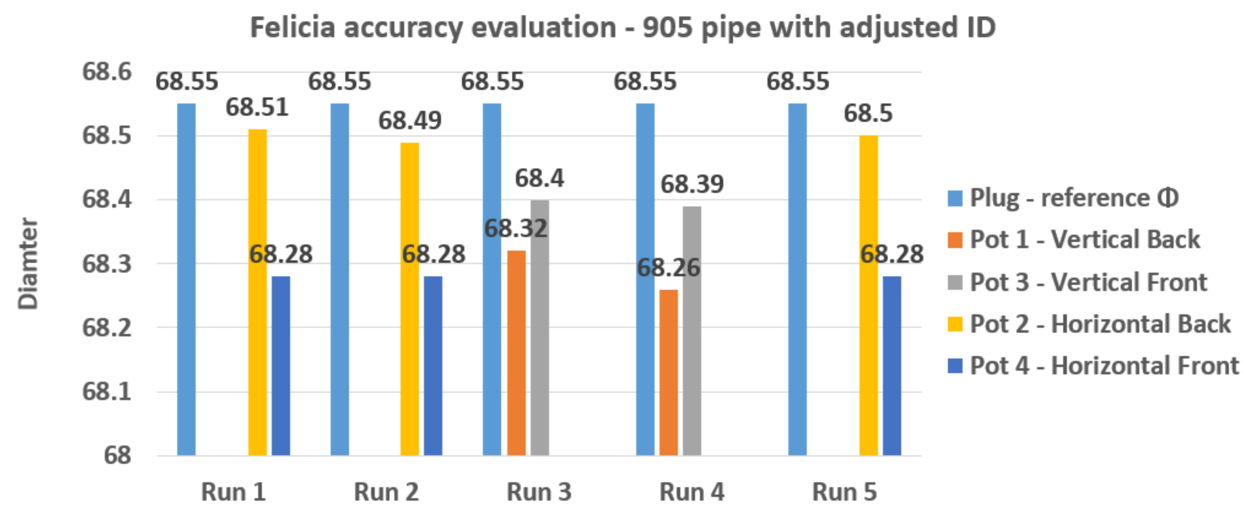

Calibration pot 4 - Horizontal front
Maximum error wrt linear interpolated curve = 0.030 mm
y = -3.17099E-04x + 7.32372E+01
R² = 9.98480E-01
Diameter (mm)
Pot readout (bits)
69.8
69.6
69.4
69.2
69
68.8
68.6
68.4
68.2
11000
11500
12000
12500
13000
13500
14000
14500
15000
15500
16000

Readout repeatability

To quantify the accuracy of the pot readout, a machined clamp with known diameter (Φ68.55 mm) was inserted on a long pipe (905 building pipe). The C-clamp was used to adjust the pipe diameter snugly around the plug.

The plug was then removed, and Felicia was run a few times through the pipe to compare its measurement with the known plug diameter. An example output is displayed in the graph below.



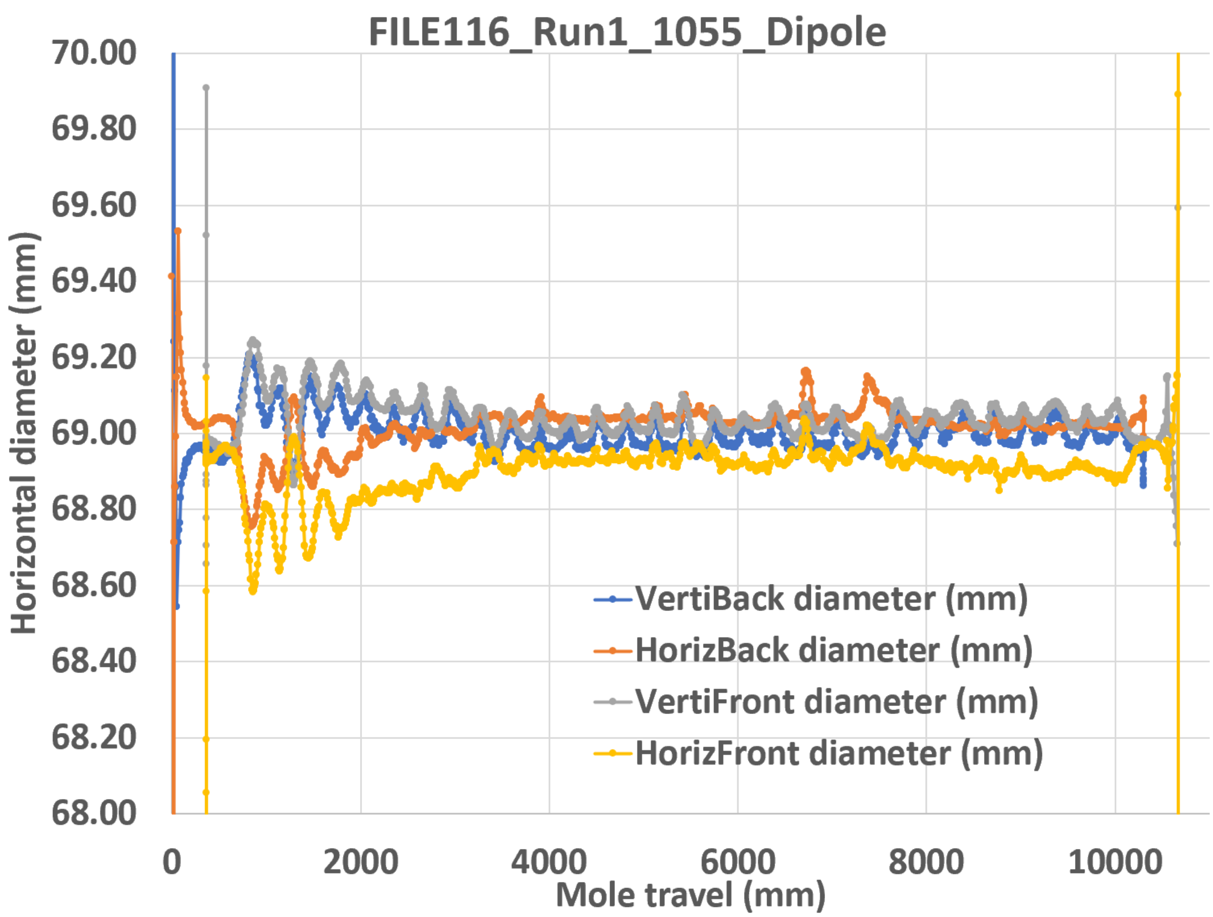


The readouts are very consistent for each run, except perhaps pot 1 which shows a variation of 0.06 mm between two runs. This is in line with the magnets measurement runs (below) where the reproducibility of the readouts was excellent.

For each magnet, whenever possible two redundant runs have been made with the same probe orientation. They will be plotted together to facilitate comparison.

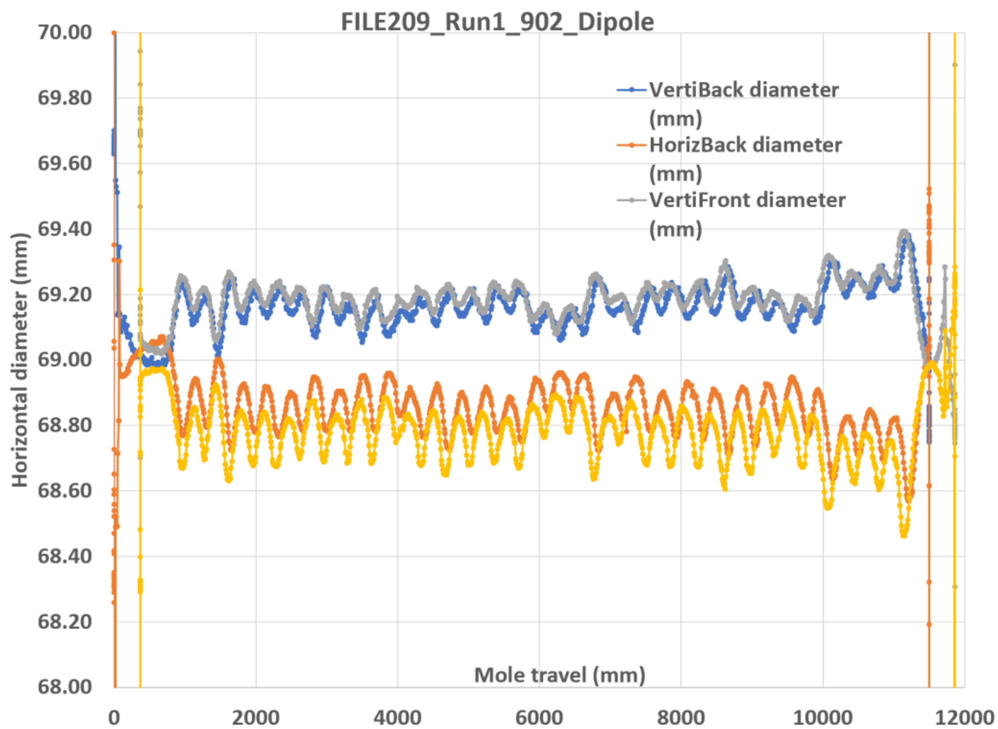
Appendix 2 – Results of the probe measurement campaign

1055 display dipole

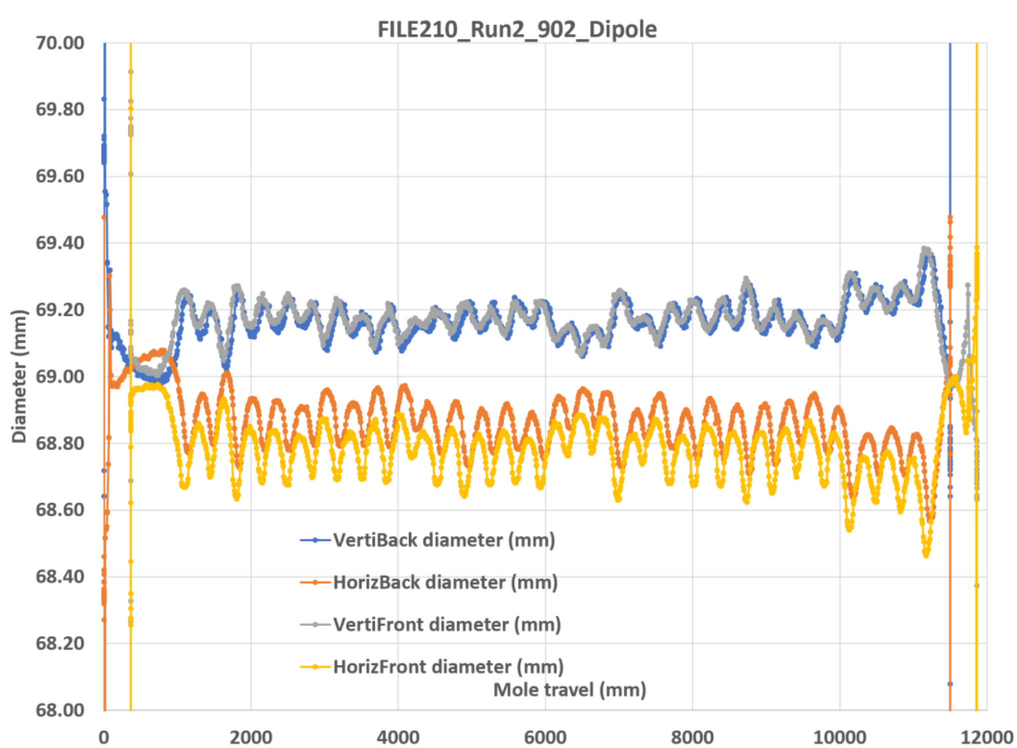


902 display dipole

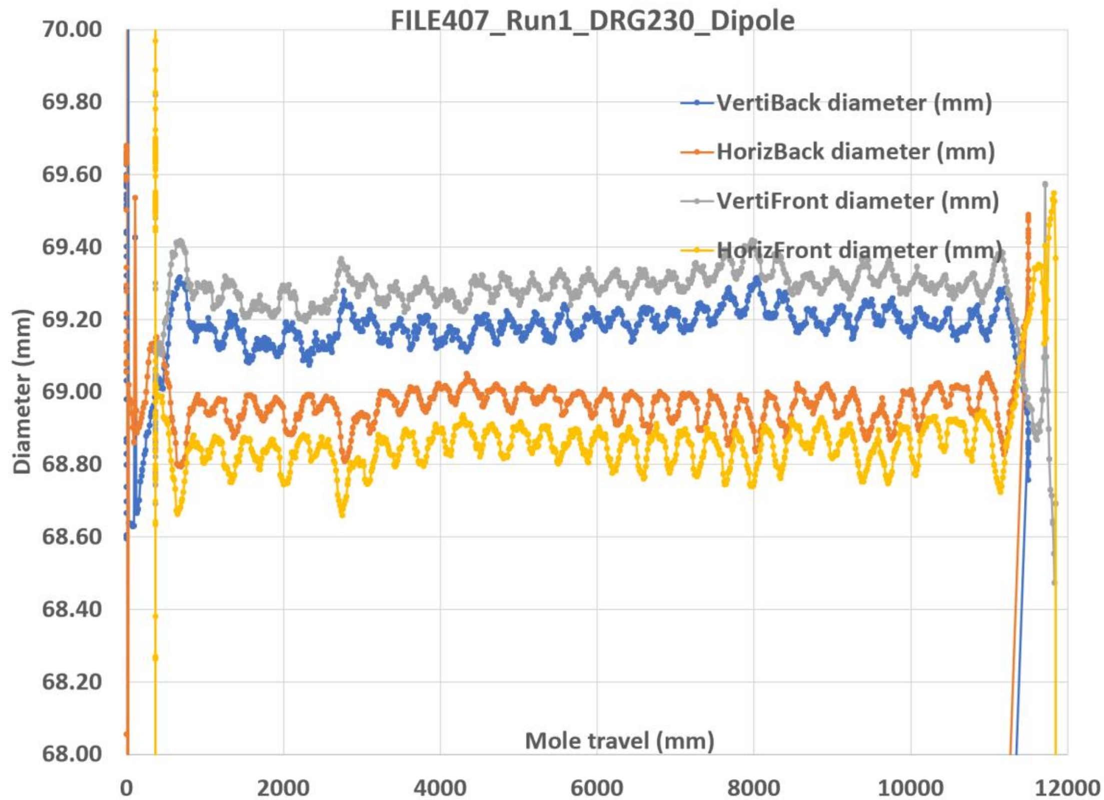
Run 1

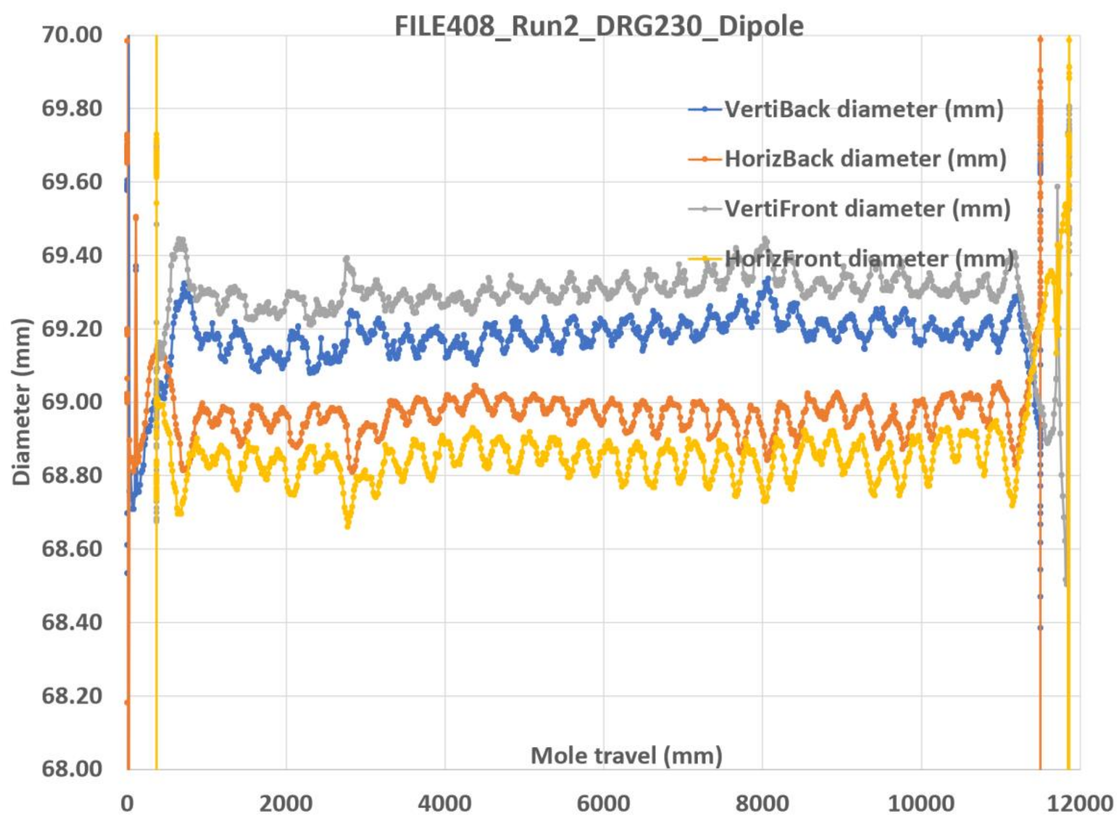


Run 2

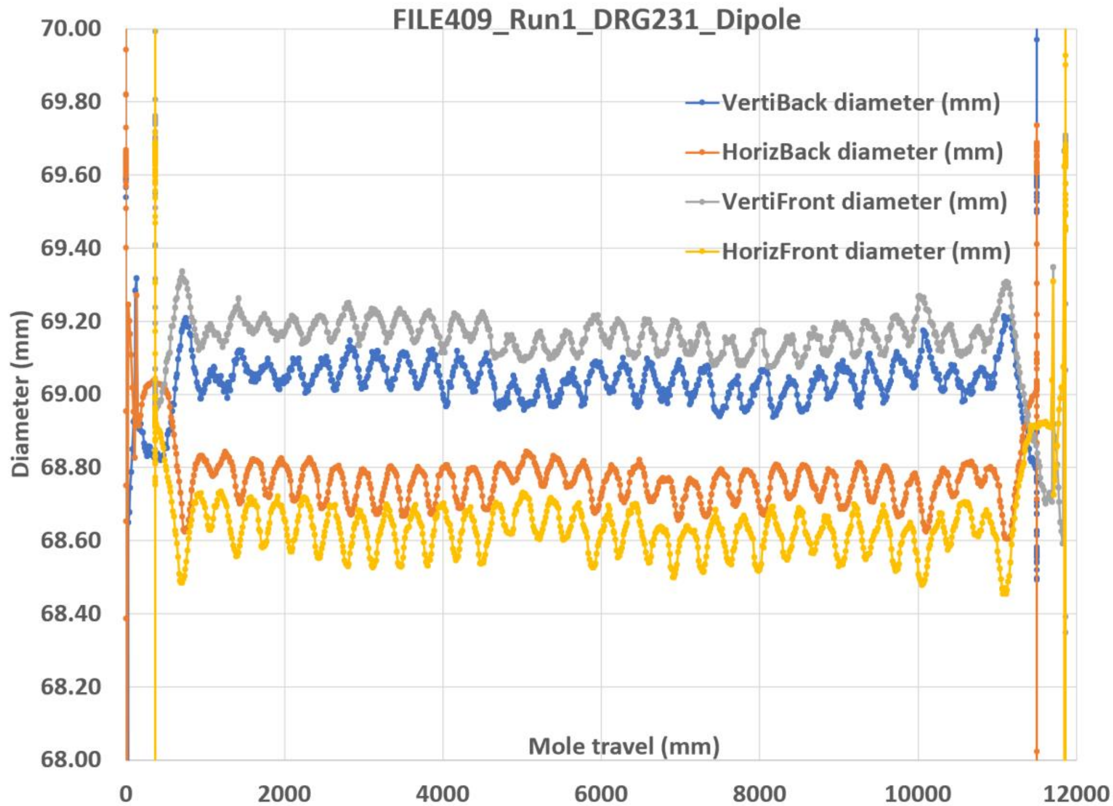


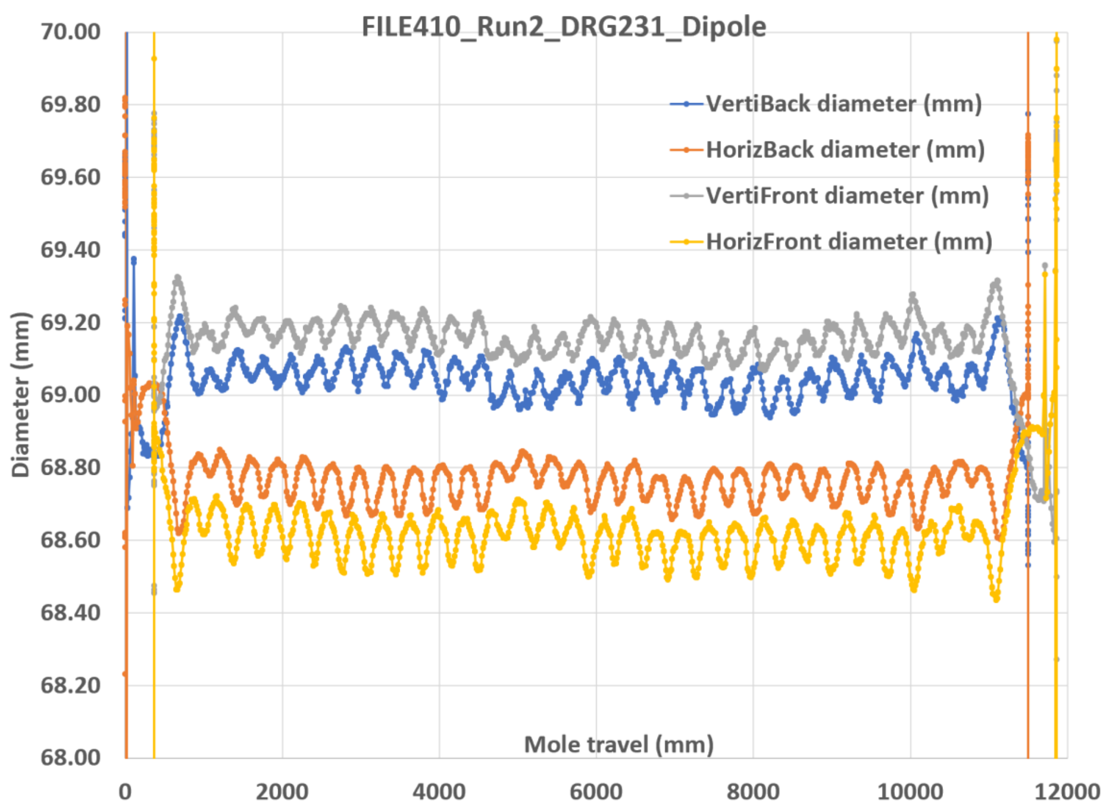
DRG230 spare dipole



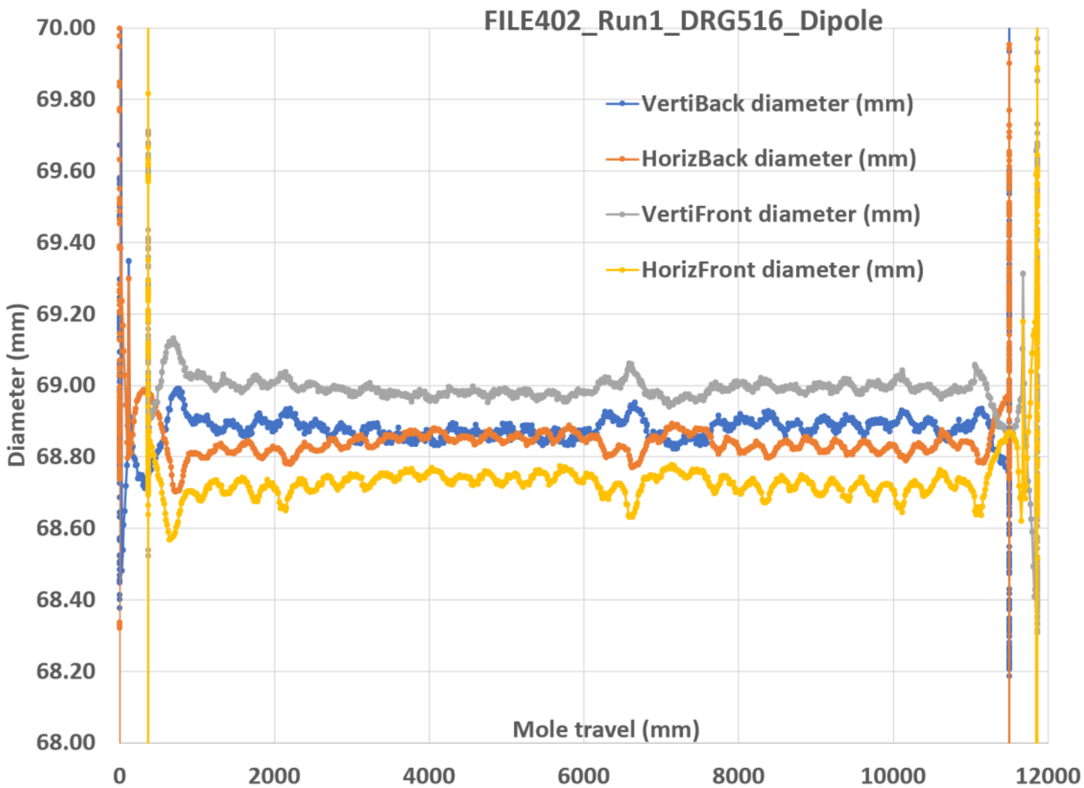


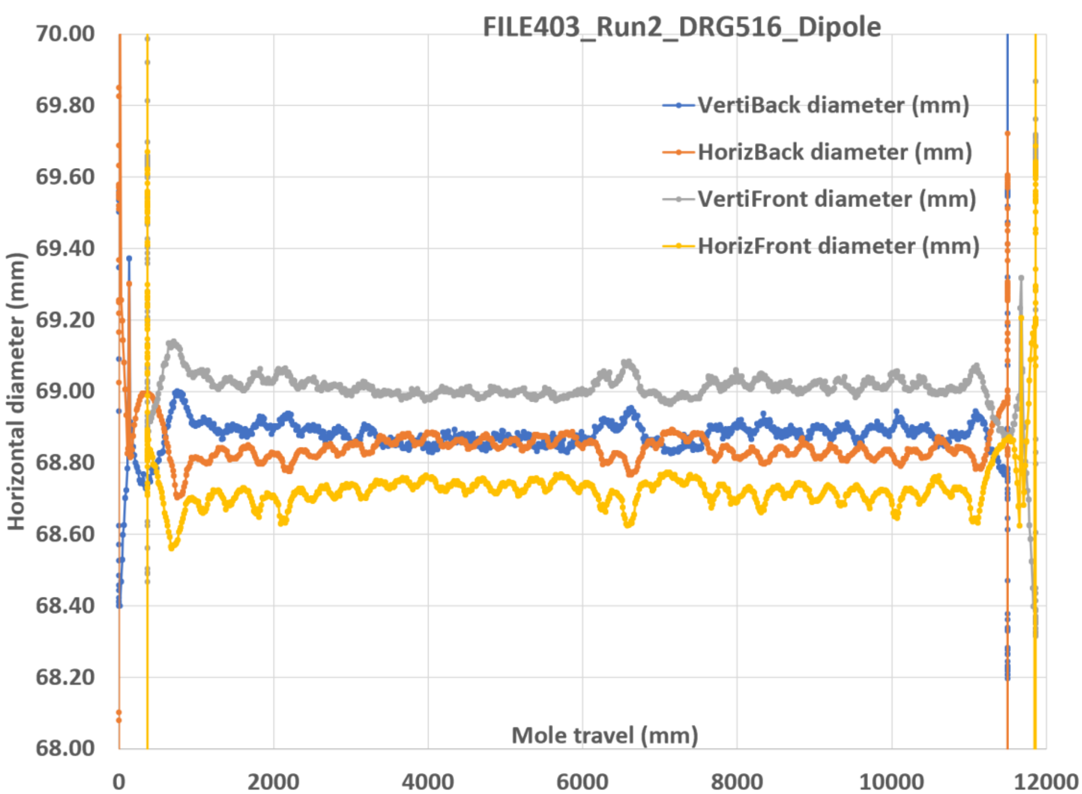
DRG231 spare dipole



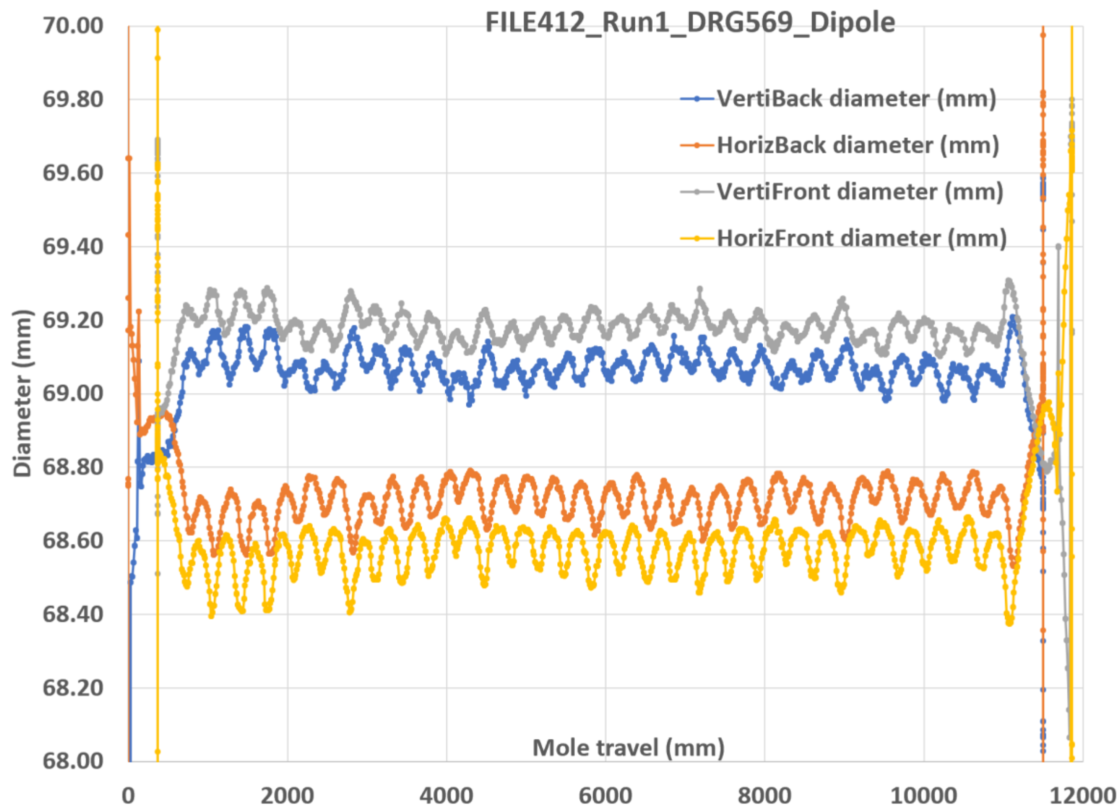


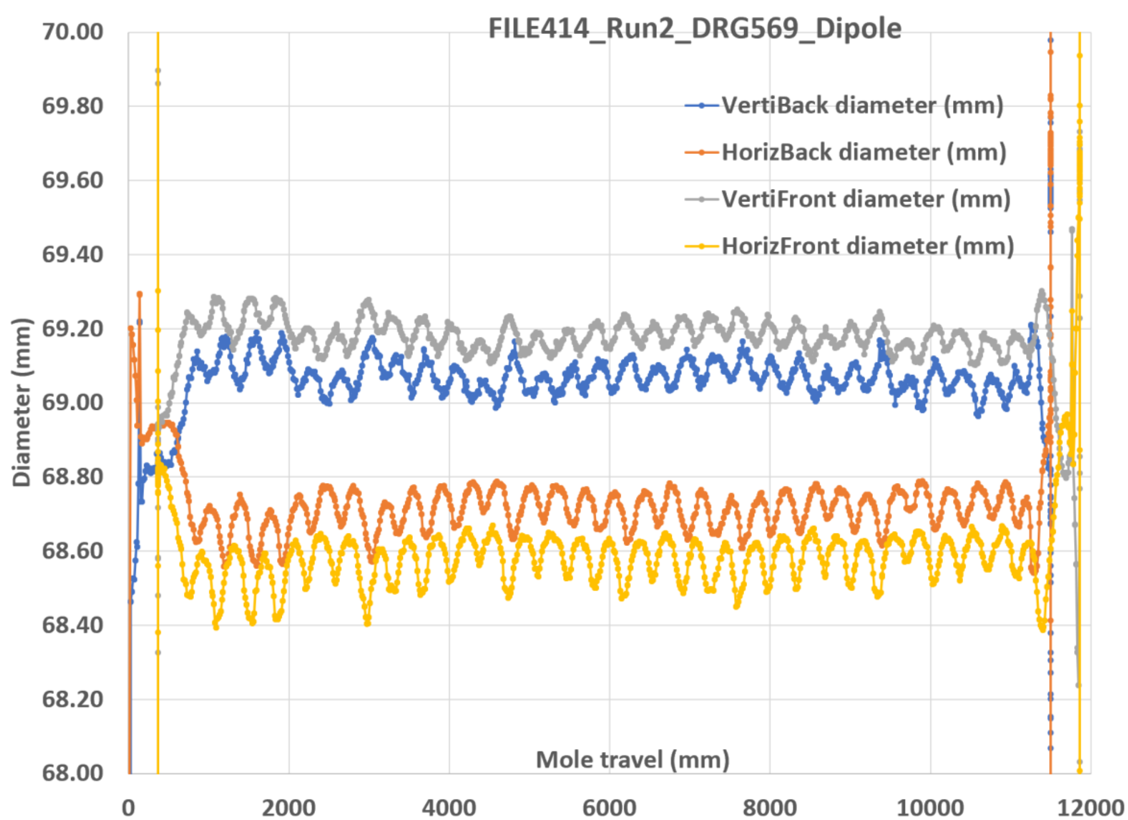
DRG516 spare dipole



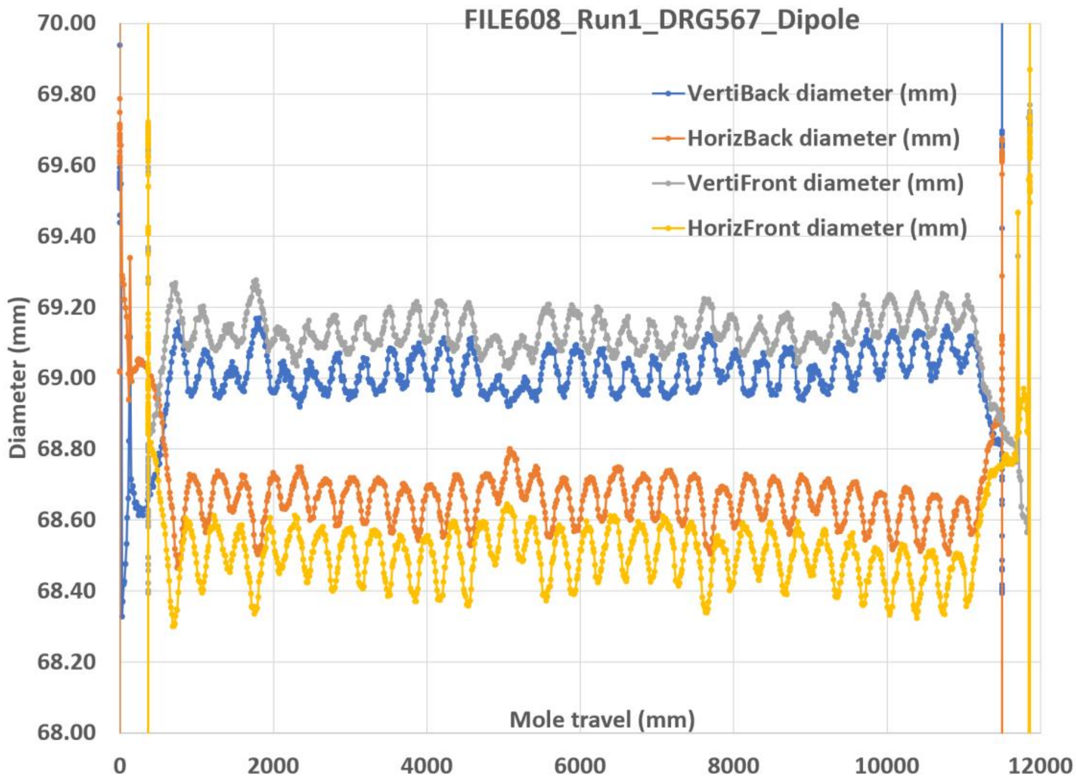


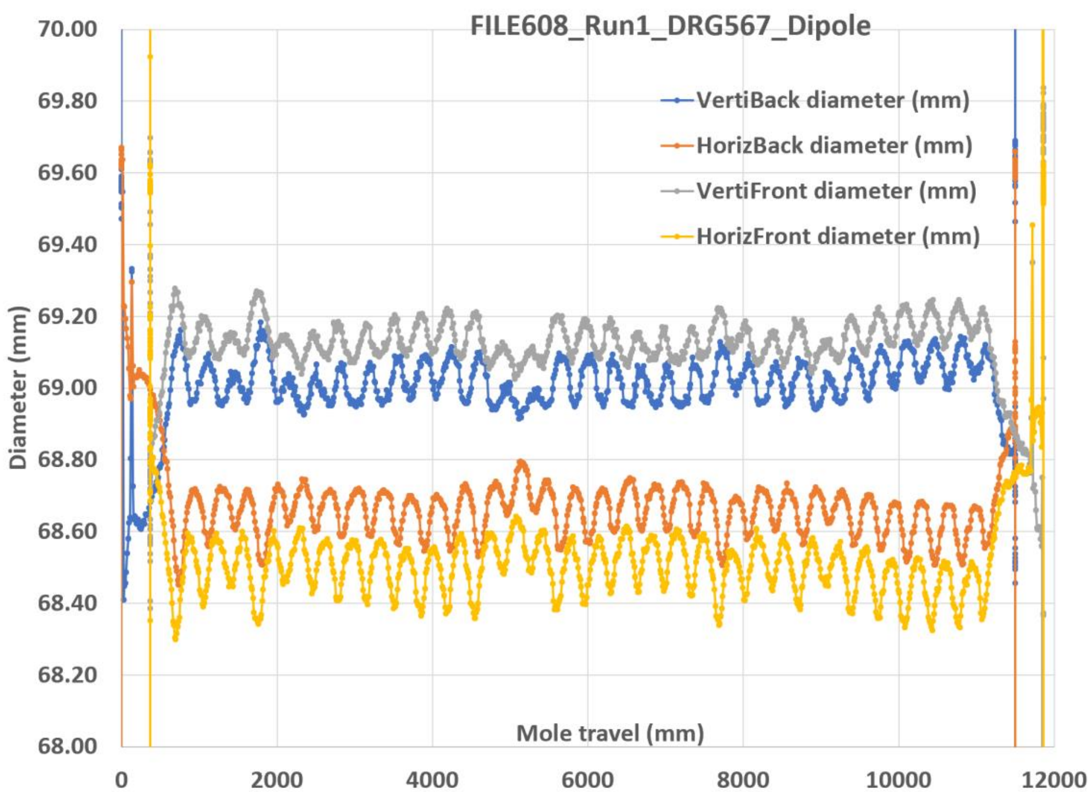
DRG569 spare dipole



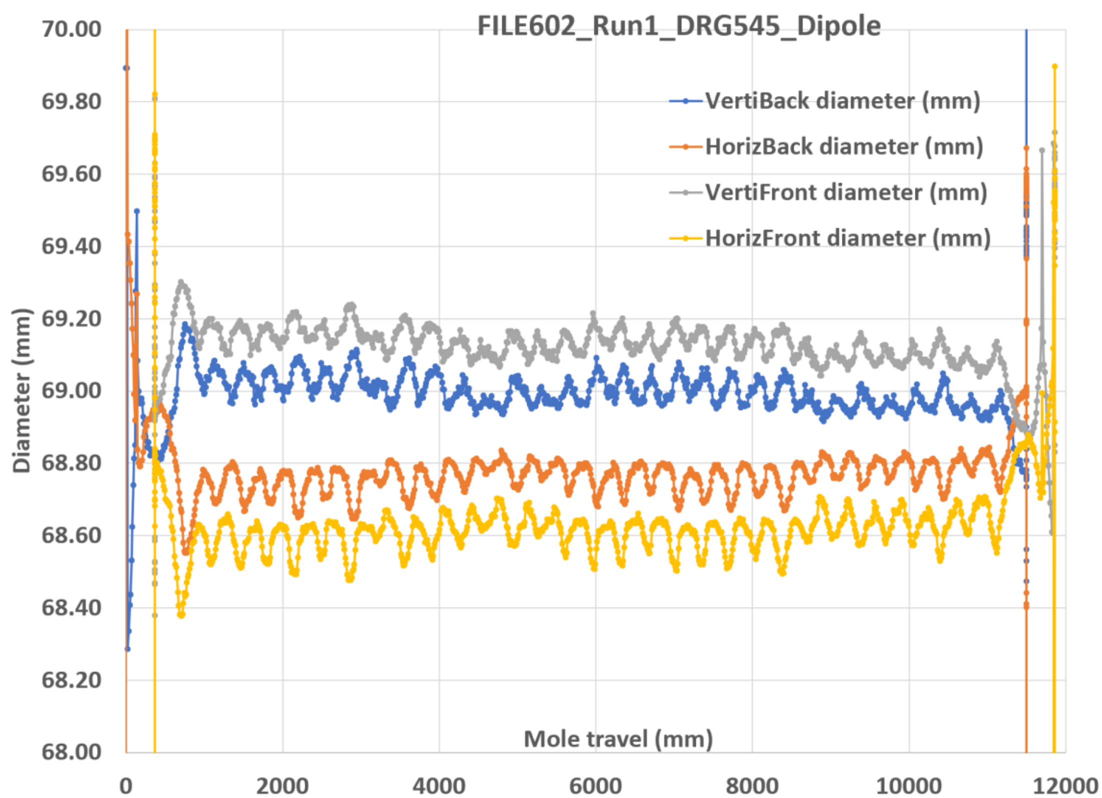


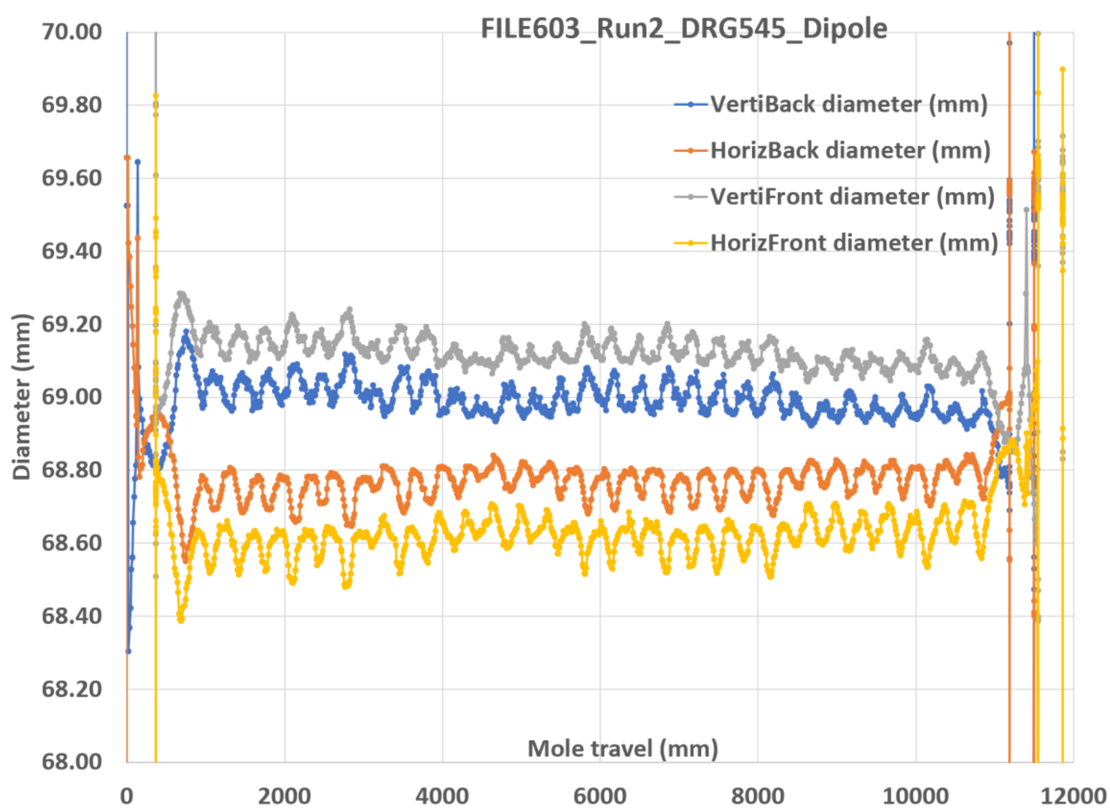
DRG567 spare dipole



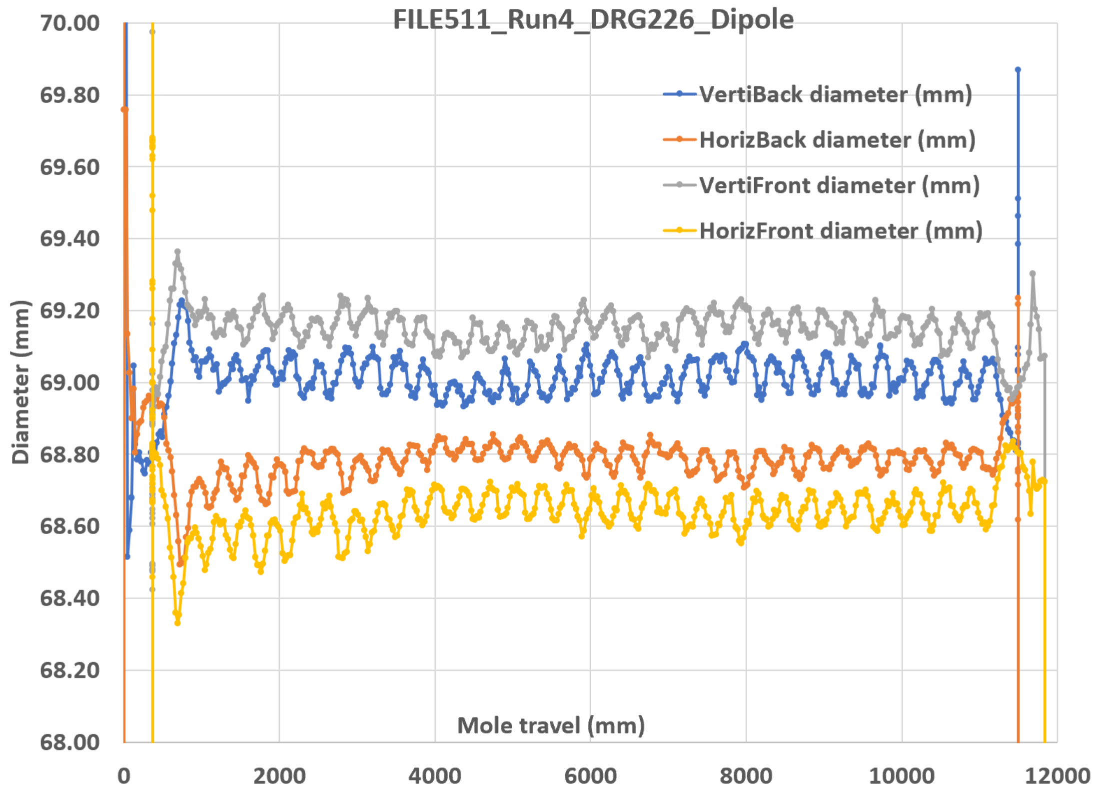


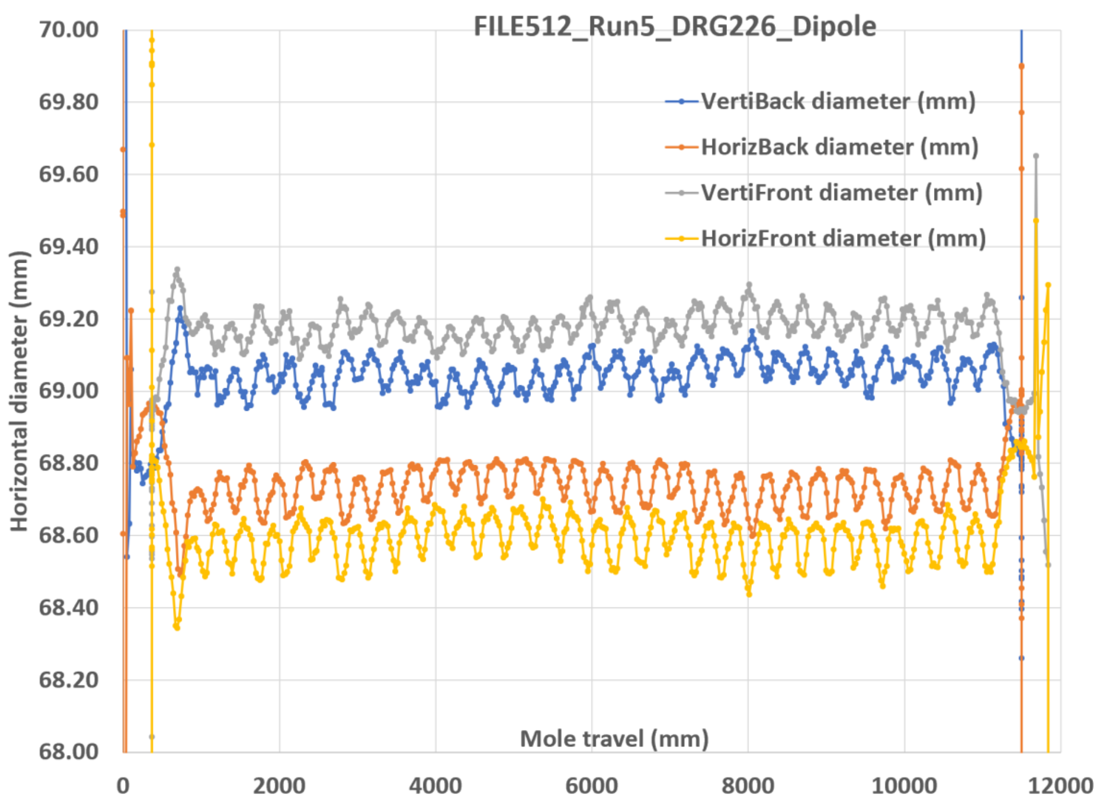
DRG545 spare dipole



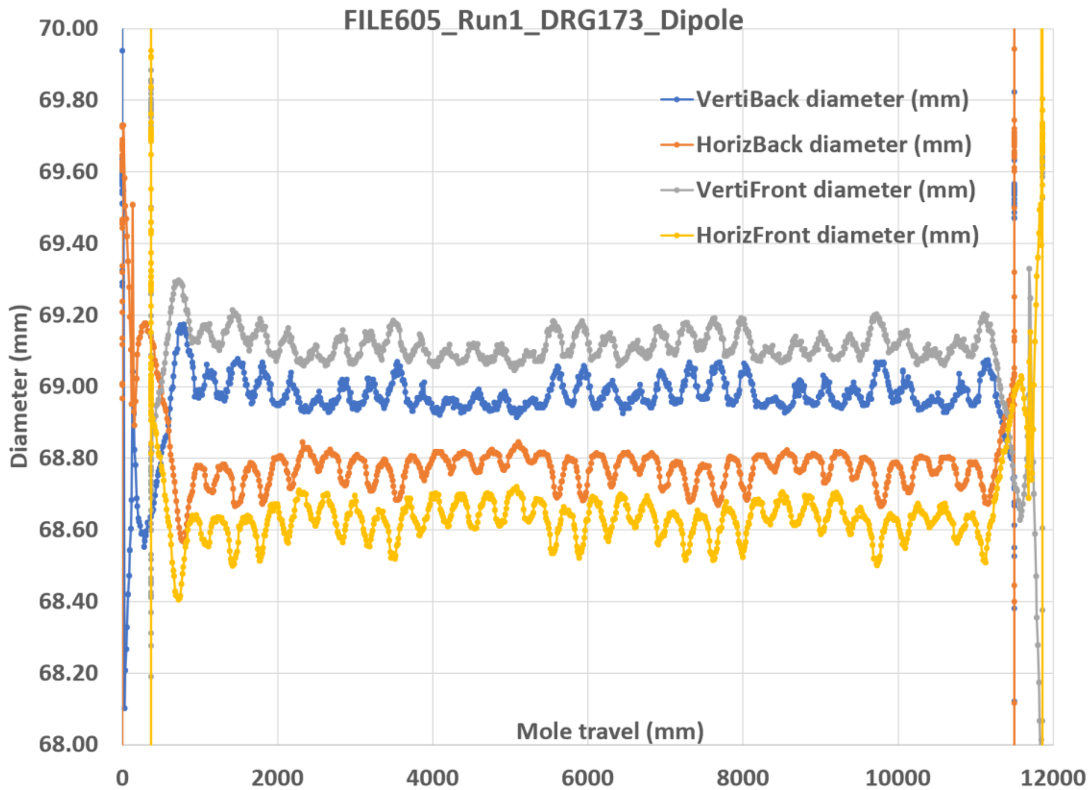


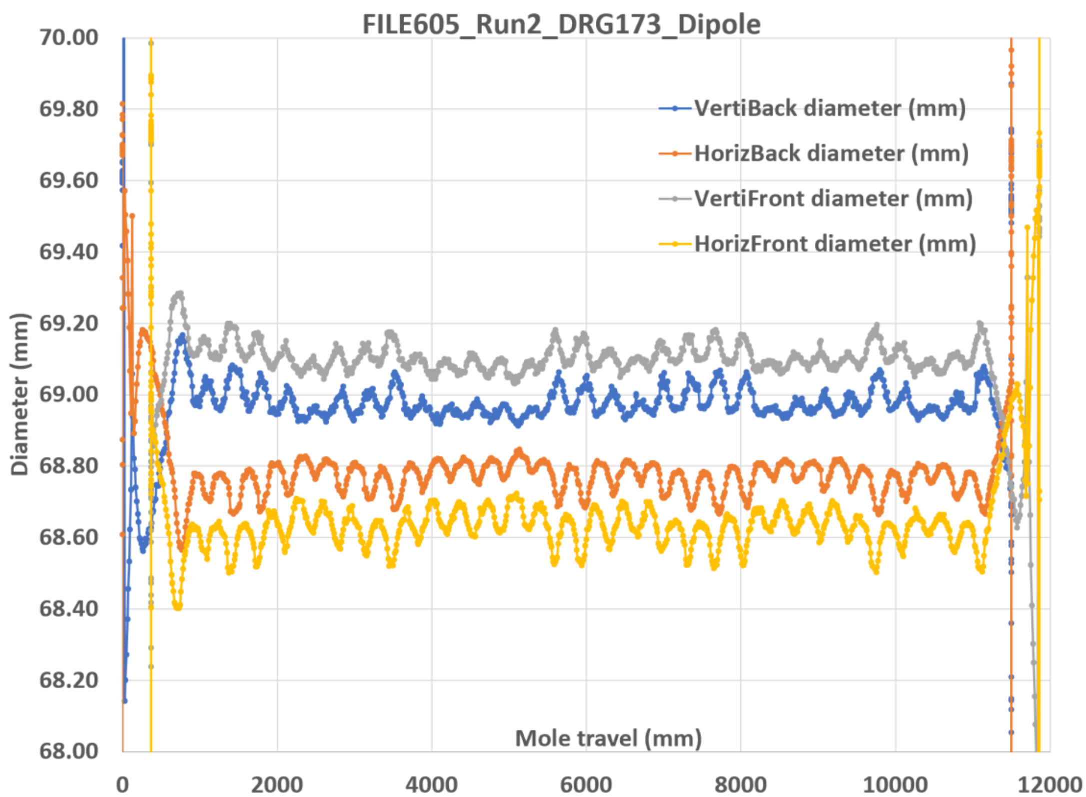
DRG226 spare dipole



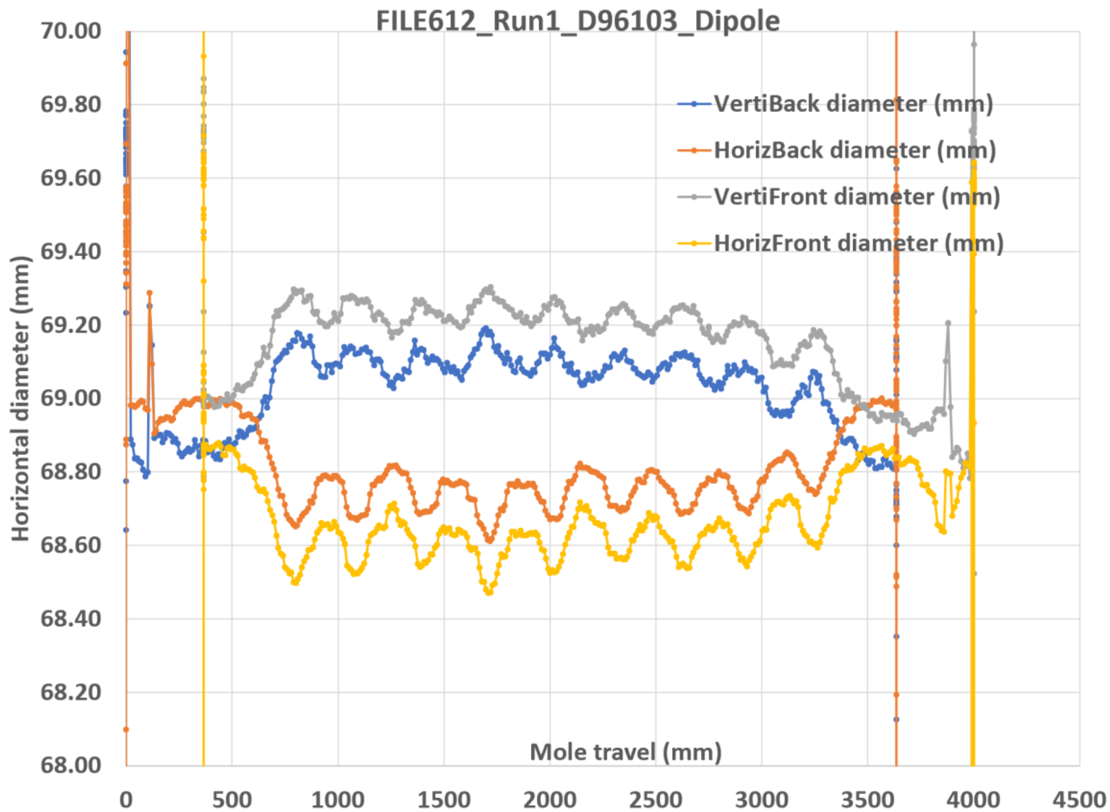


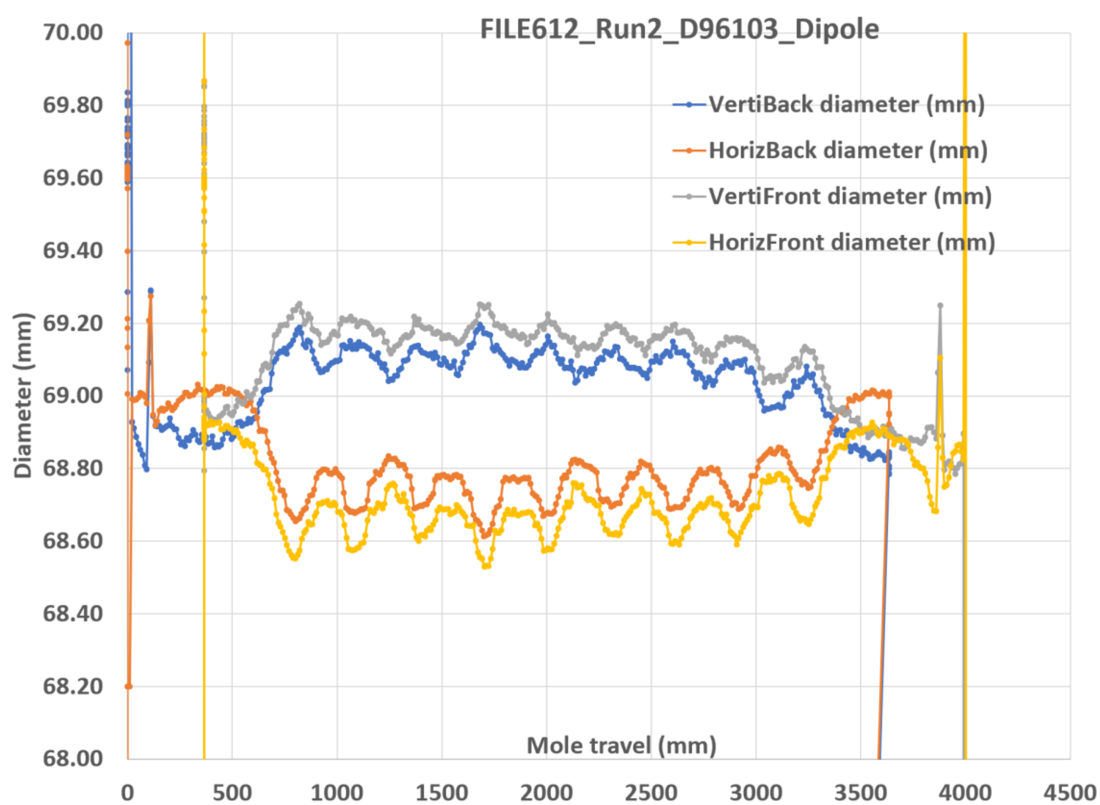
DRG173 spare dipole



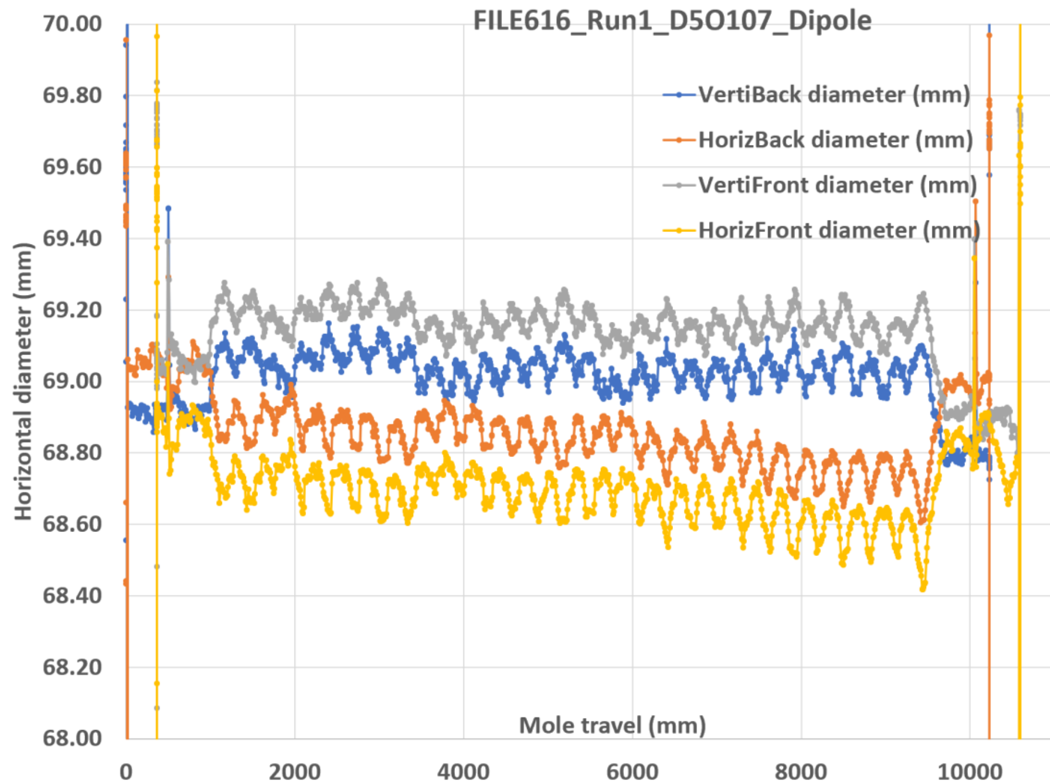


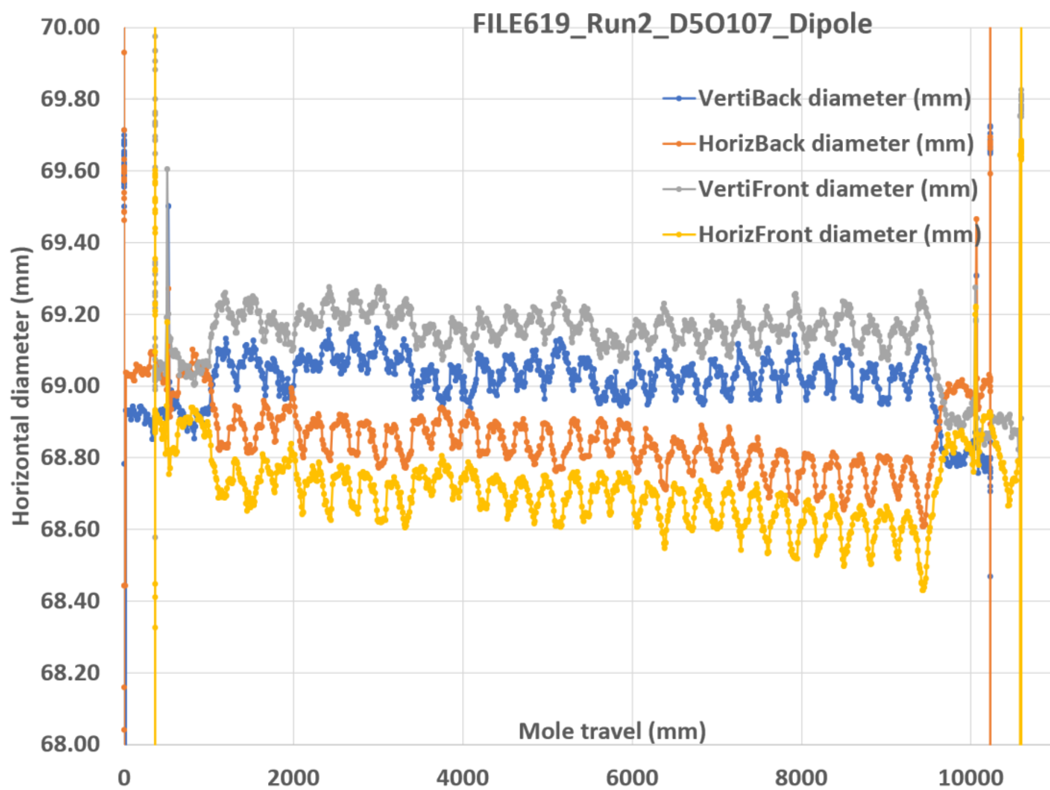
D96103 spare dipole



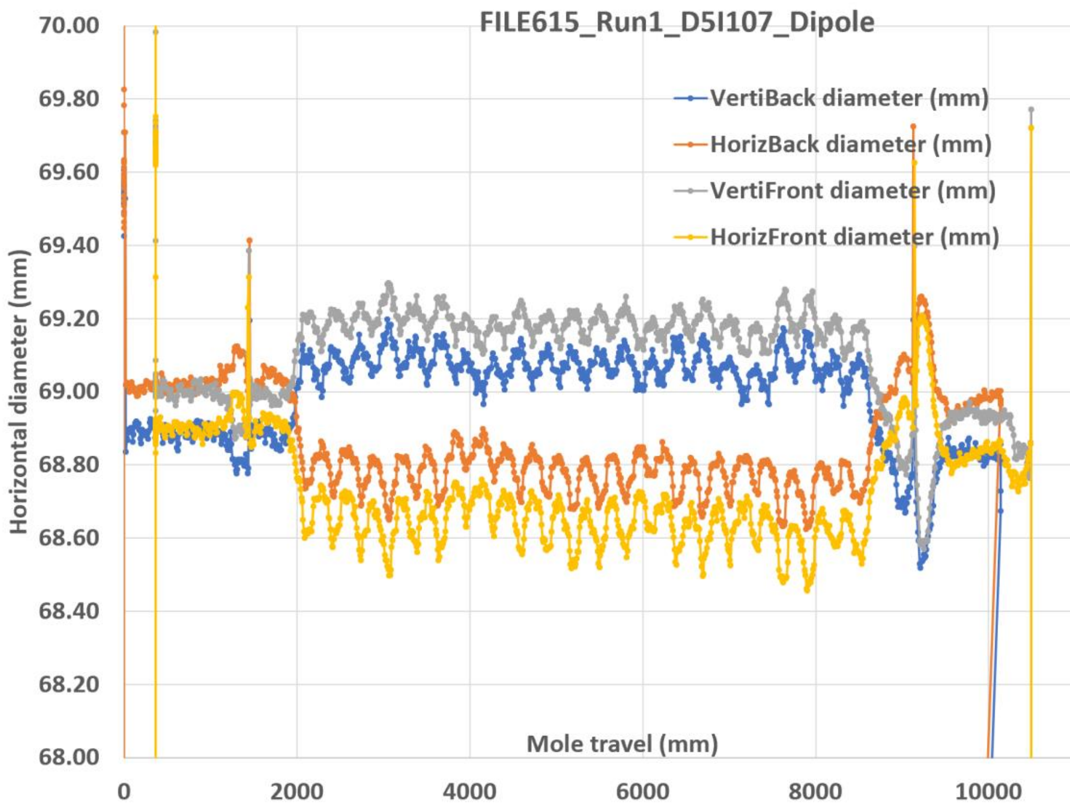


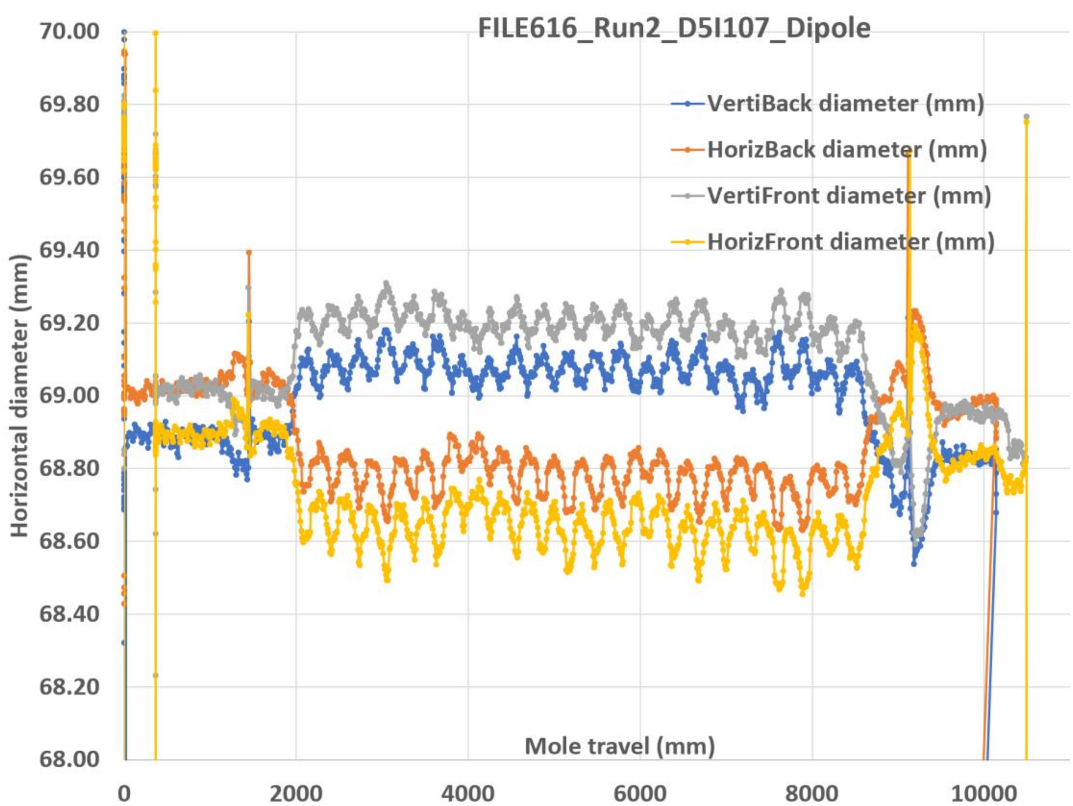
D5O107 spare dipole



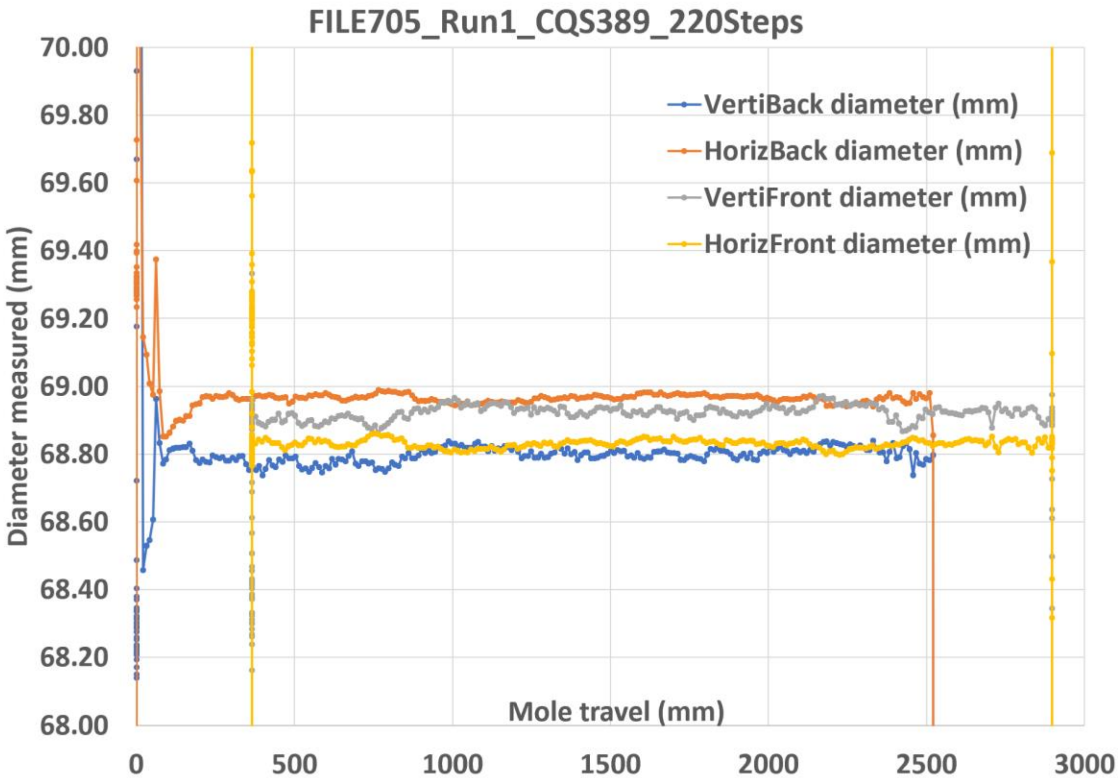


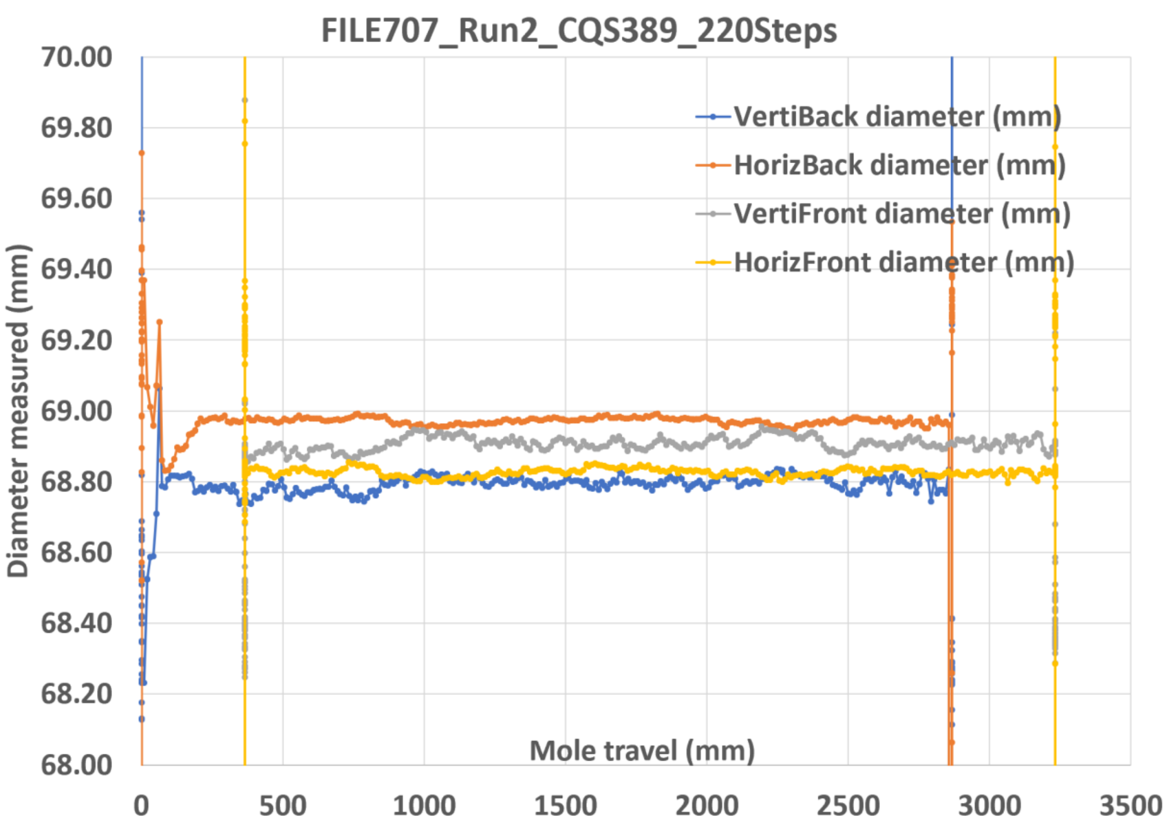
D5I107 spare dipole



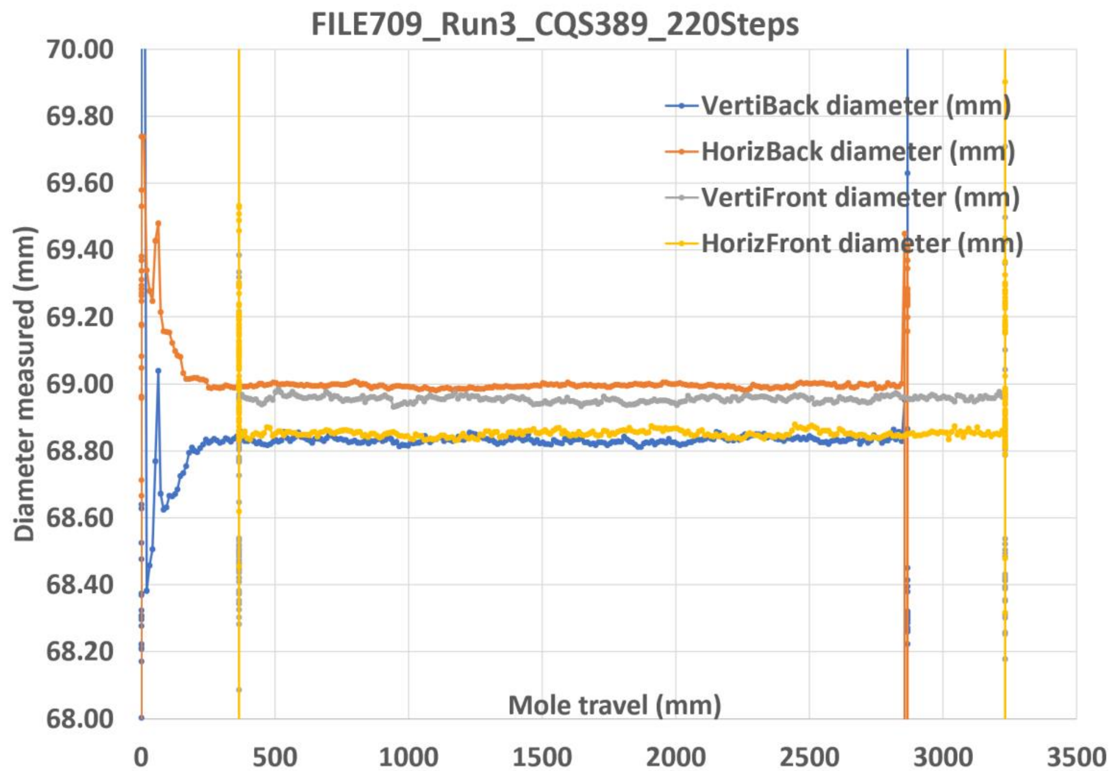


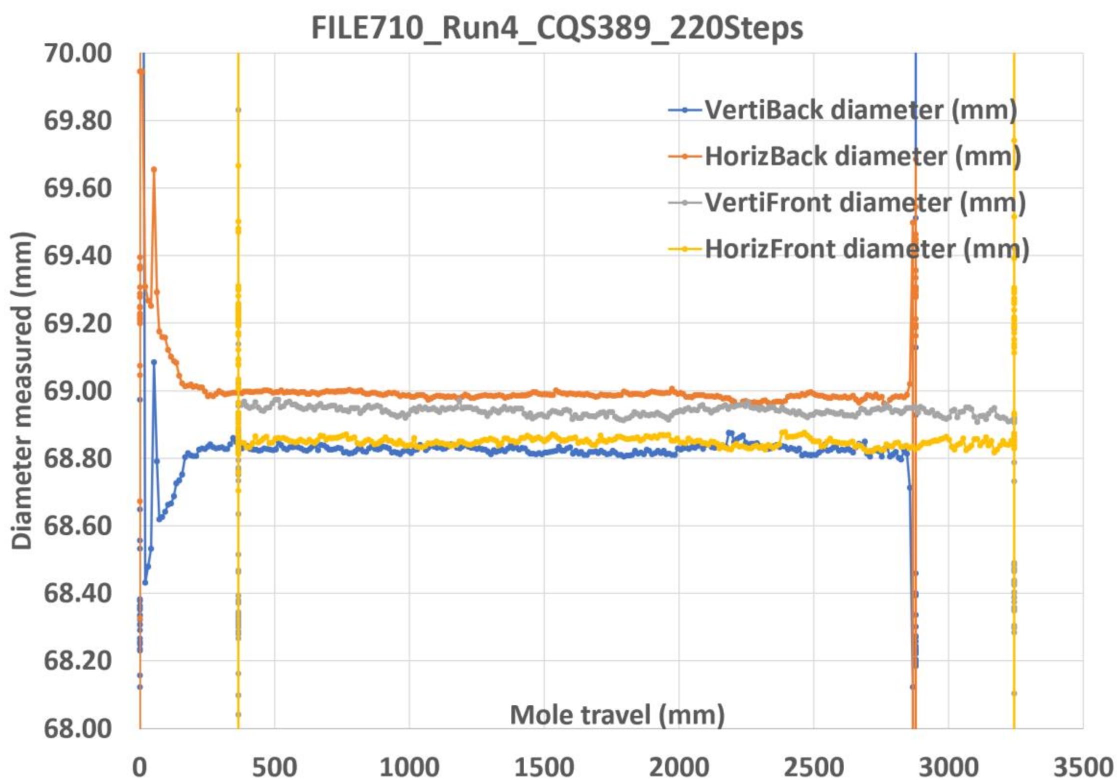
CQS389 spare CQS (Horizontal probe orientation)



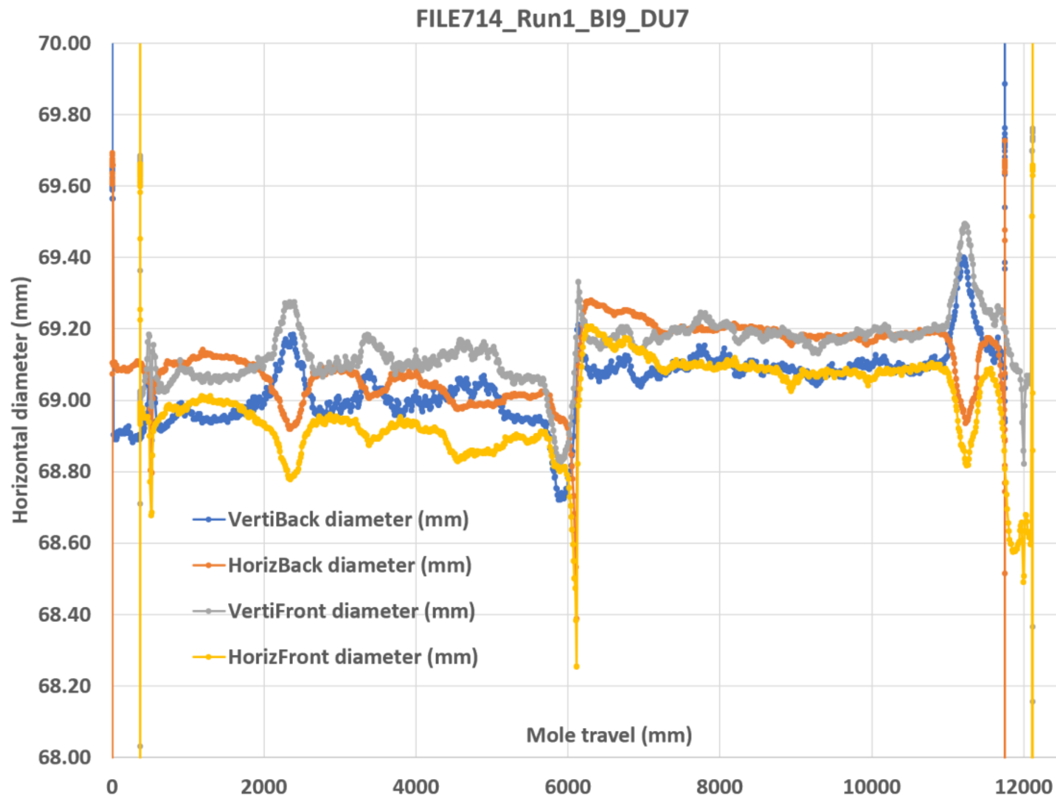


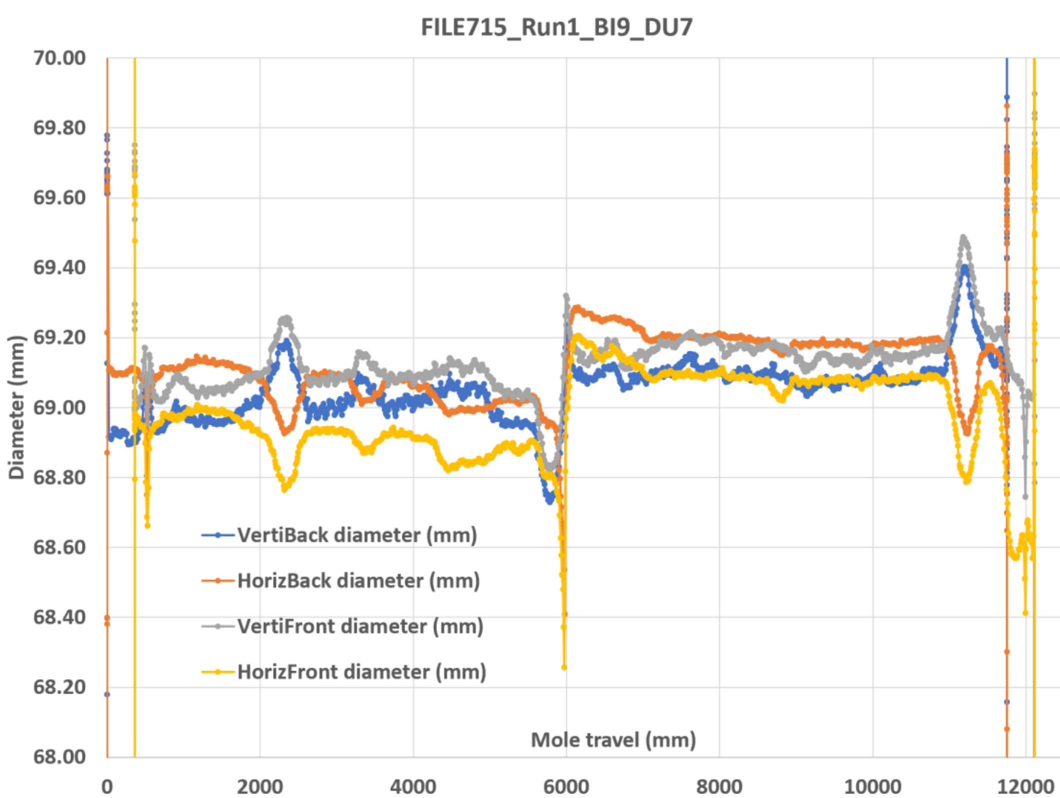
CQS389 spare CQS (45° probe orientation)



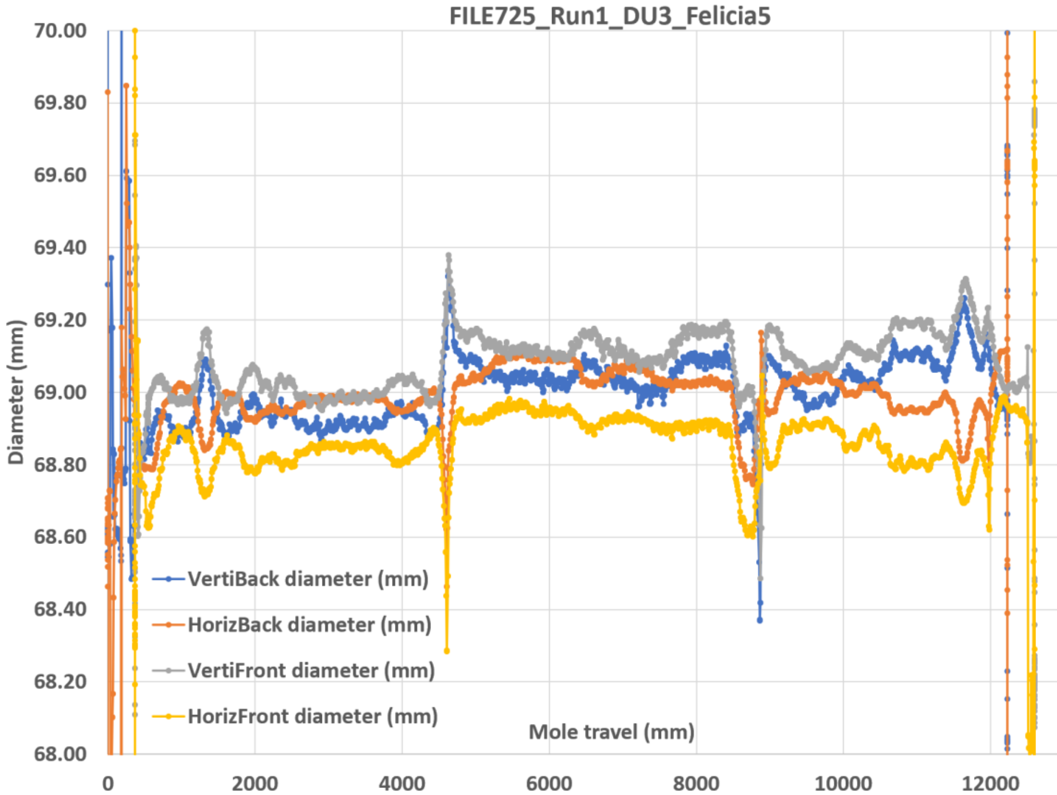


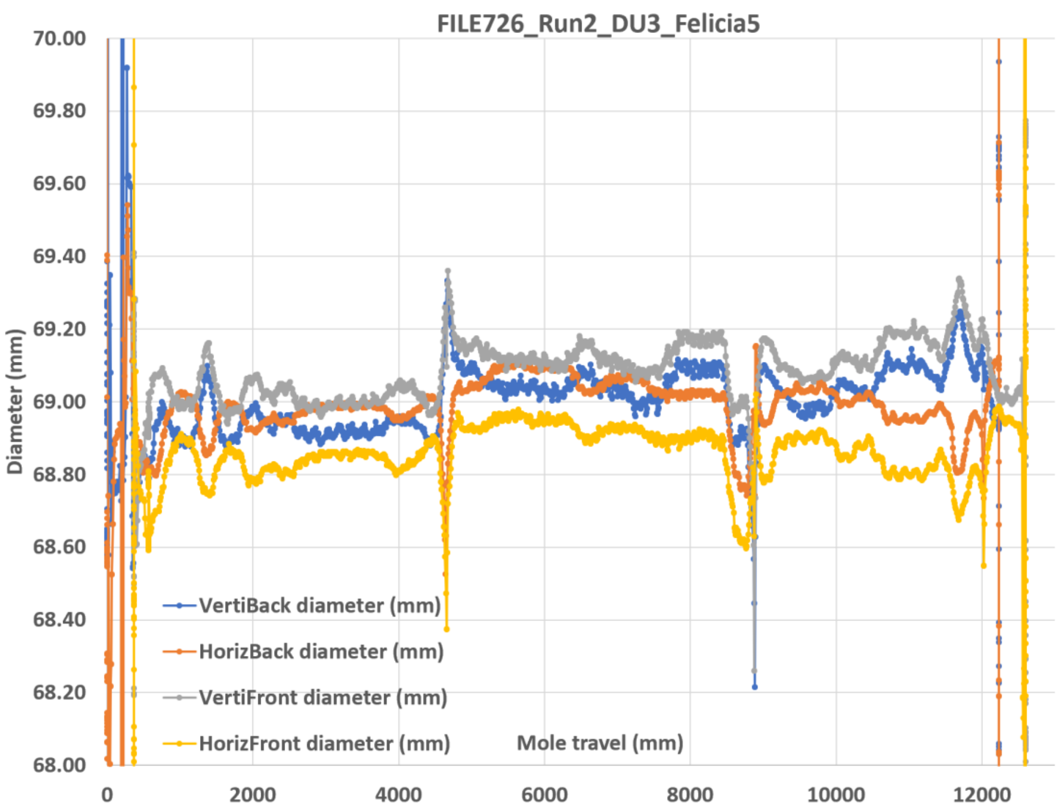
DU7-BI9 spare DU7



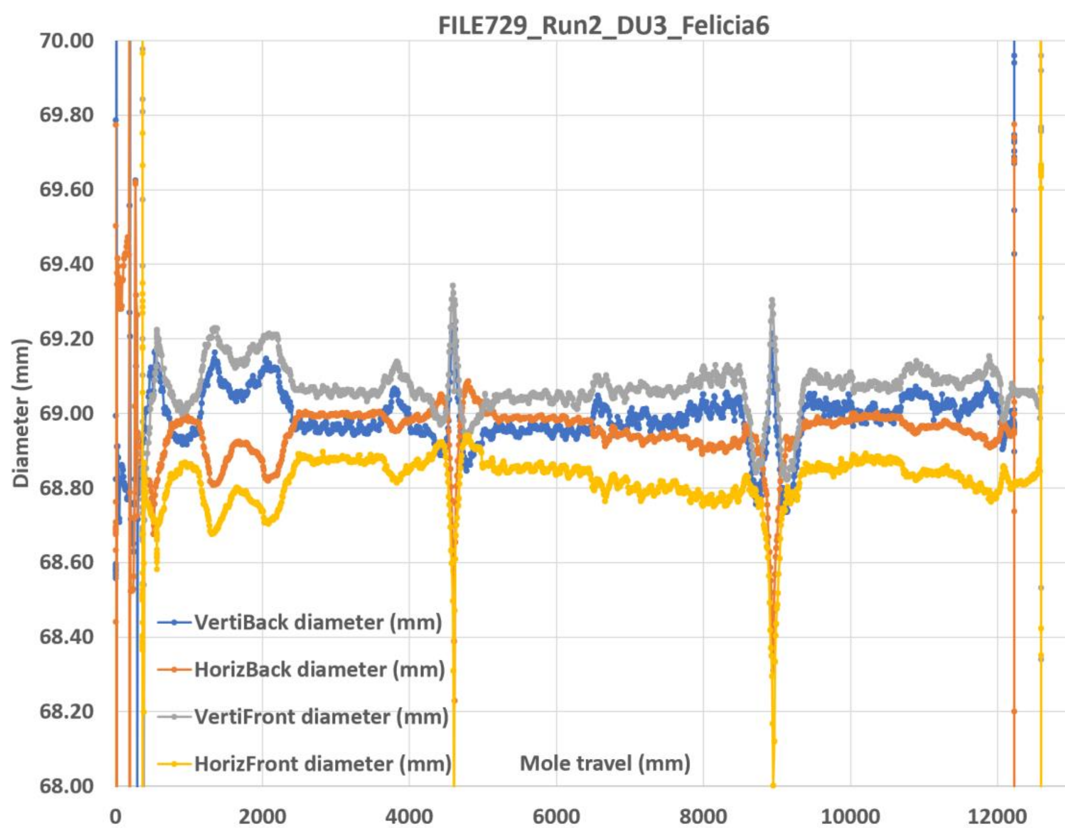


Spare DU3 Felicia 5

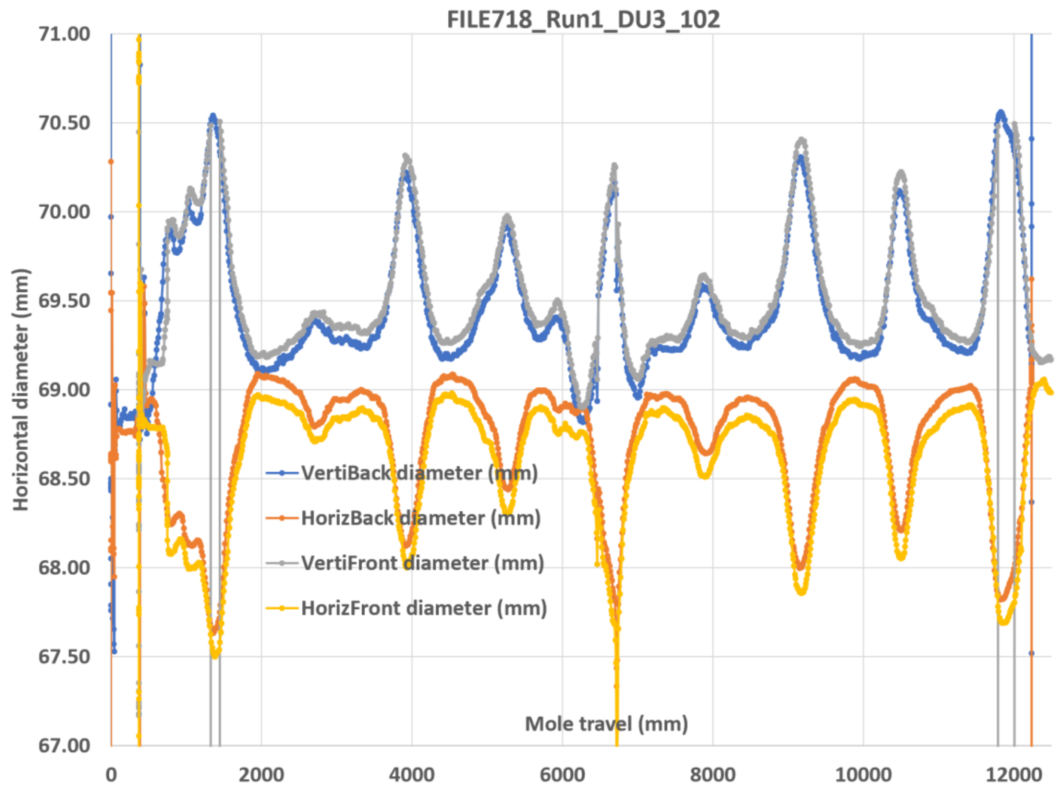


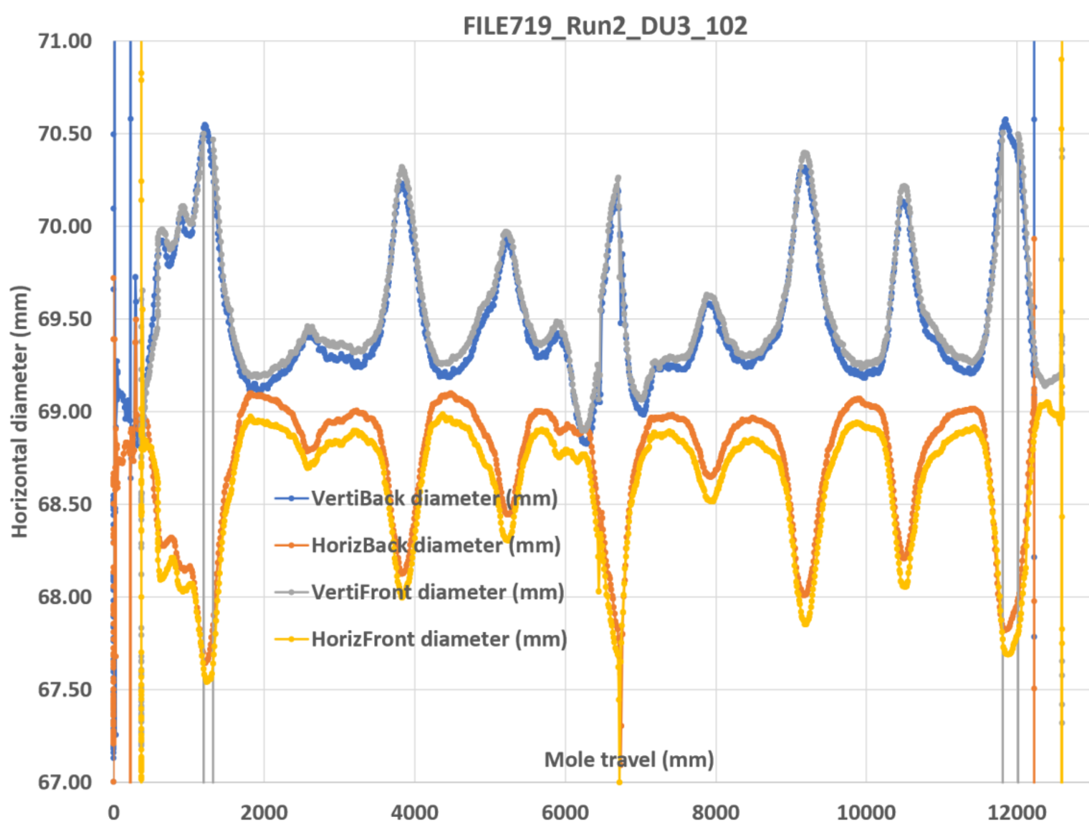


Spare DU3 Felicia 6

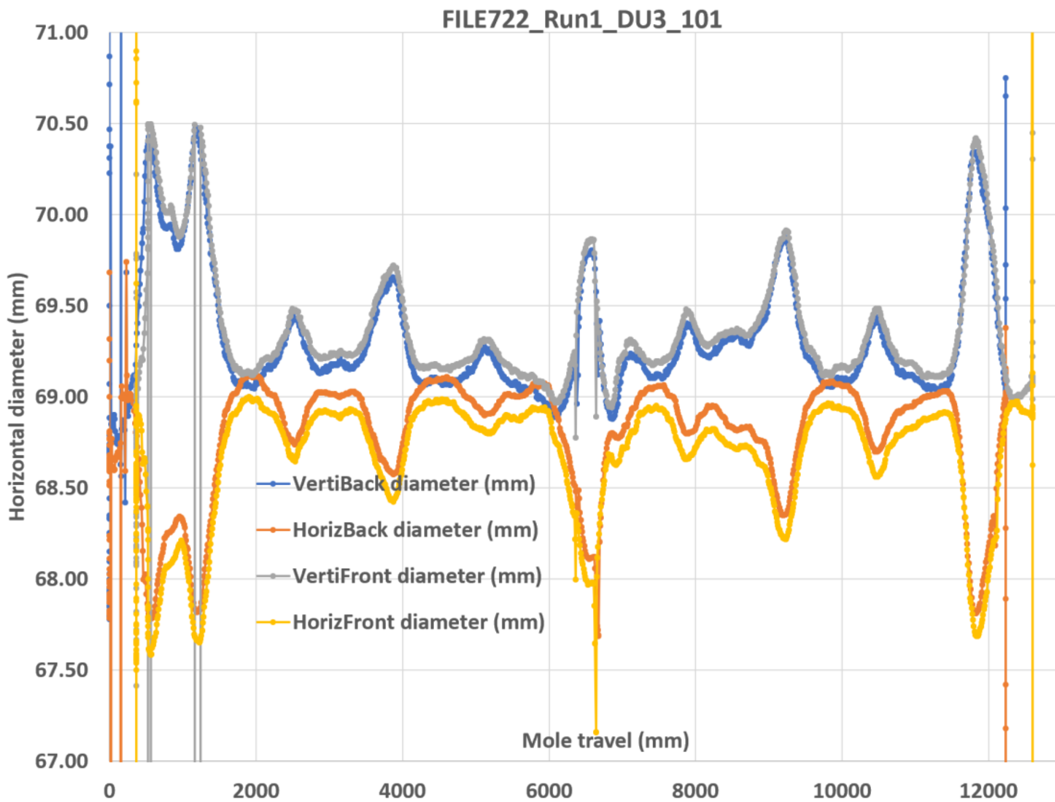


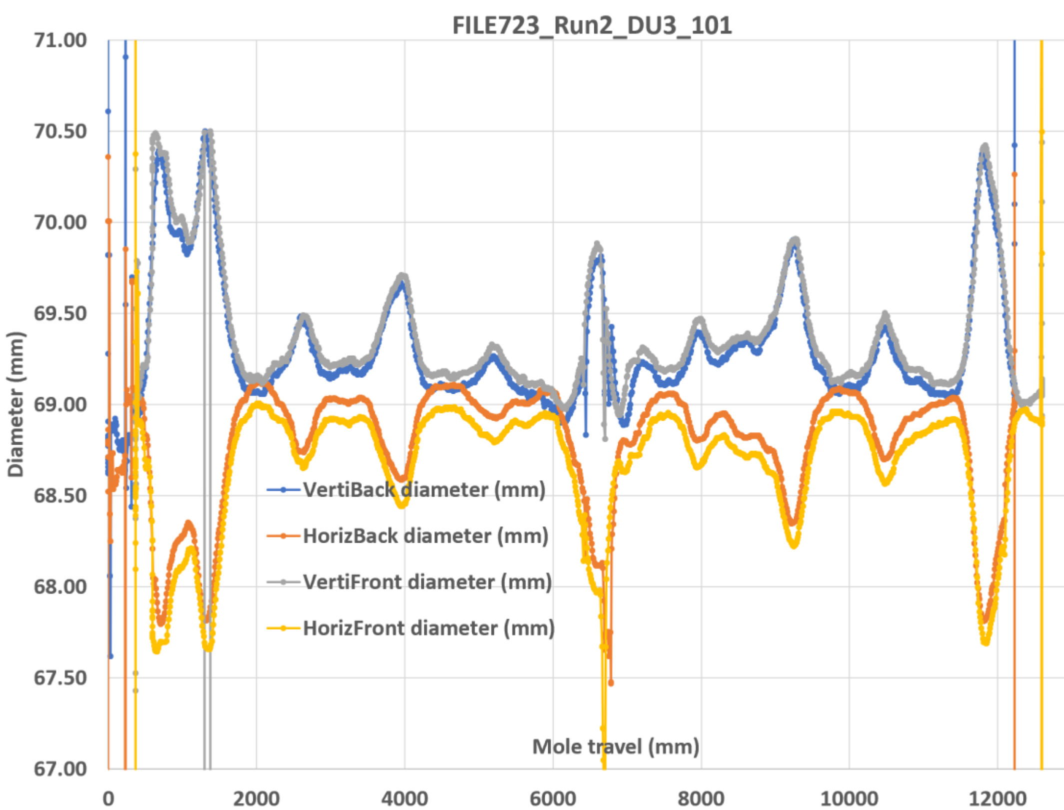
Spare DU3 102





Spare DU3 101





Appendix 3 – Analysis of the maximum dipole diameter restriction from collaring

EIC beamscreen

Evaluation of the minimum credible beampipe ID

F.Micolon – October 2022

Intro/context

- The EIC beamscreens will have to be pulled along a large set of magnet to reach their destinations
- The beamscreen OD must be chosen so the risk of interference with the minimum credible beampipe ID is limited
- This beamscreen ID must be maximized as it drives the horizontal aperture restriction
- This slideshow aims at summarizing the minimum credible beampipe OD from the tolerance and magnet fabrication technique.

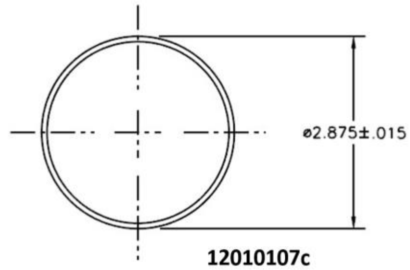
Beampipe itself

A269/A269M – 15a (2019)

TABLE 4 Permissible Variations in Dimensions

Group	Size, Outside Diameter, in. [mm]	Permissible Variations in Outside Diameter, in. [mm]	Permissible Variations in Wall Thickness,[A] %	Permissible Variations in Cut Length, in. [mm][B] Over	Under	Thin Walled Tubes[C]
1	Up to ½ [13]	±0.005 [0.13]	±15	⅛ [3.2]	0	...
2	½ to 1½ [13 to 38], excl	±0.005 [0.13]	±10	⅛ [3.2]	0	less than 0.065 in. [1.65 mm] nominal
3	1½ to 3½ [38 to 89], excl	±0.010 [0.25]	±10	3⁄16 [4.8]	0	less than 0.095 in. [2.41 mm] nominal
4	3½ to 5½ [89 to 140], excl	±0.015 [0.38]	±10	3⁄16 [4.8]	0	less than 0.150 in. [3.81 mm] nominal
5	5½ to 8 [140 to 203], excl	±0.030 [0.76]	±10	3⁄16 [4.8]	0	less than 0.150 in. [3.81 mm] nominal
6	8 to 12 [203 to 305], excl	±0.040 [1.01]	±10	3⁄16 [4.8]	0	less than 0.200 in. [5.08 mm] nominal
7	12 to 14 [305 to 356], excl	±0.050 [1.26]	±10	3⁄16 [4.8]	0	less than 0.220 in. [5.59 mm] nominal

[A] When tubes as ordered require wall thicknesses ¾ in. [19.0 mm] or over, or an inside diameter 60 % or less of the outside diameter, a wider variation in wall thickness is required. On such sizes a variation in wall thickness of 12.5 % over or under will be permitted.
For tubes less than ½ in. [12.7 mm] in inside diameter which cannot be successfully drawn over a mandrel, the wall thickness may vary ±15 % from that specified.
[B] These tolerances apply to cut lengths up to and including 24 ft [7.3 m]. For lengths greater than 24 ft [7.3 m], the above over tolerances shall be increased by ⅛ in. [3 mm] for each 10 ft [3 m] or fraction thereof over 24 ft [7.3 m], or ½ in. [13 mm], whichever is lesser.
[C] Ovality provisions of 12.2 apply.



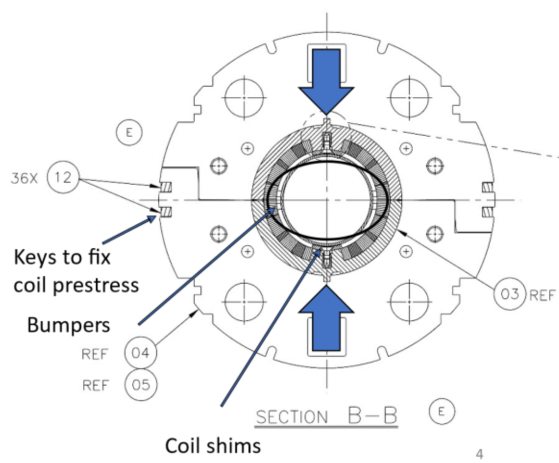
12010107c

The pipe wall thickness is specified as 0.077” (12010107)
Following the ASTM specifications above a 10% thickness variation is allowed.
So the minimum possible ID of the pipe at rest is 2.875-0.015-2x(1.1x0.077)=2.691” (68.34mm) (OD 2.86” (72.64mm))

Magnet fabrication

- During magnet fabrication, the beampipe is sandwiched in the two half yoke and gets squeezed during the vertical coil pre-stress. The squeezing is then fixed by keys.
- The coils bumper (horizontal) are located between the coil shims and limit the horizontal squeeze out.

Then the magnet is bent in shape and the shell is welded to keep the bend. The bumpers will then guide the beampipe inside the coil and impose the bend.



Tolerance stack on the vertical diameter

Minimum yoke ID (12010057) (4.7 +/ - 0.001”) = 4.699”
Maximum RX630 insulator vertical thickness (0.777 +.006/-.001) = 0.783”
Coil shim max thickness (0.121” +/-.002”) = 0.123”

Mini coil shim ID = 4.699-2x(0.783+0.123) = 2.887”

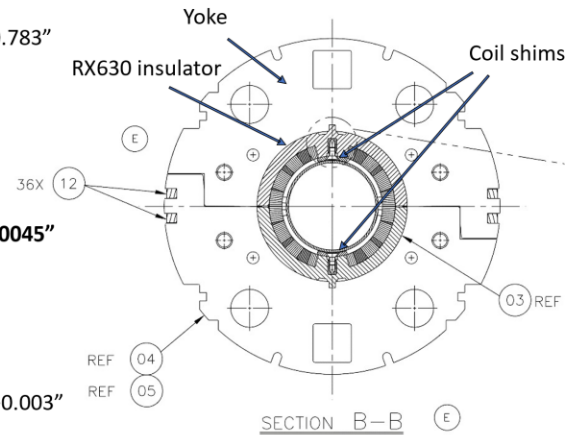
Maxi beampipe vertical OD (2.881 +/ -.015”) = 2.896”

Minimum coil shim/beampipe clearance at rest = (2.887-2.896)/2=**-.0045”**

Nominal vertical diameter squeeze = -0.029” (+.000/-.001)

Maximum interference = -0.0045-0.029/2 = **-0.019” (-0.483mm)**

(Note with a minimum beampipe diameter the rest interference is +0.003”
The maximum interference is -0.0115” is this case)



12010006

Tolerance stack on the horizontal diameter

Minimum yoke ID (12010057) (4.7 +/ - 0.001”) = 4.699”
Maximum RX630 insulator horizontal thickness (.381+/-.003”)=.384”
Coil max thickness (0.396” +/-.001”) = .397”
Coil tip Kapton cover = .0063+/-.0005 = .0068”

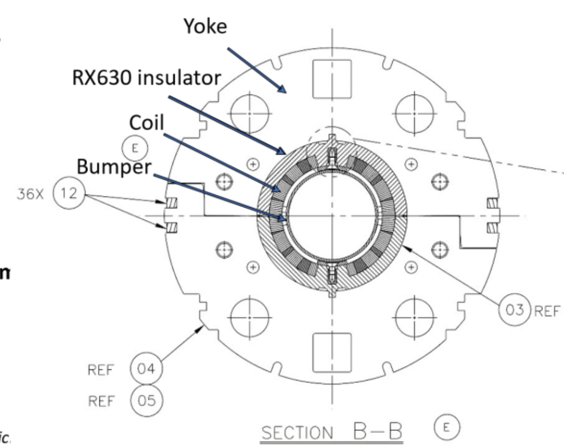
Mini horizontal coil ID = 4.699-2.(.384+.397+.0068)=3.123”

Maxi beampipe horizontal OD (3.125 +/ -.005”) = 3.130”

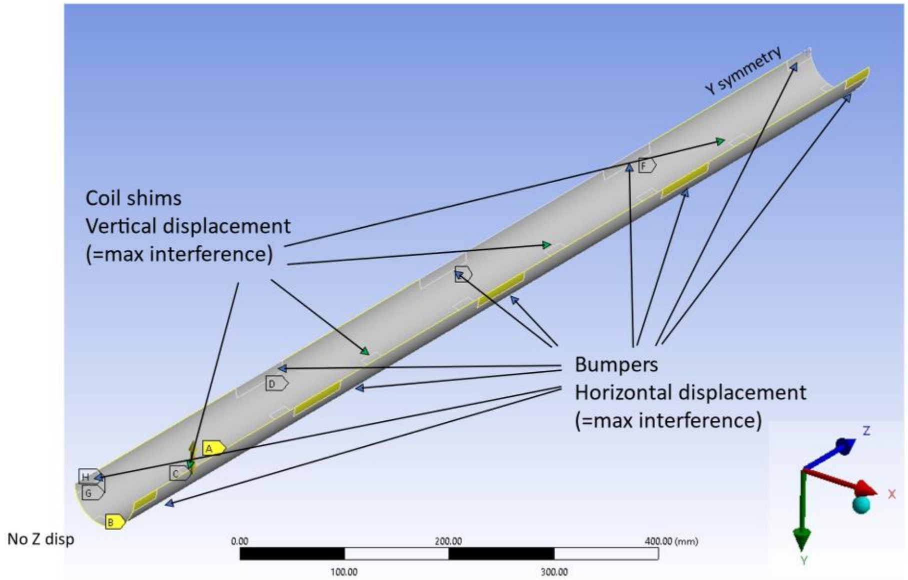
Minimum coil/beampipe horizontal clearance at rest = **-.007” (0.178n**

(Note with a minimum beampipe diameter 3.120” this interference becomes +0.0015”)

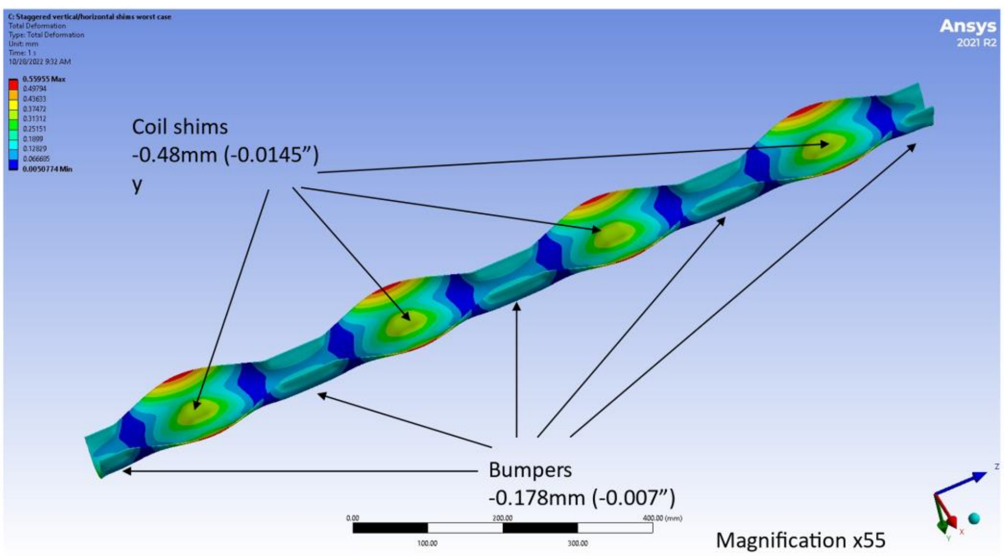
Note in a tech note from 1999 - RHIC-MD-284, the coil tip Kapton cover is given for a thic of .0045 instead of .0065 – the rest is consistent with the values determined here (max clearance is .0135” in the note, .0117” here).



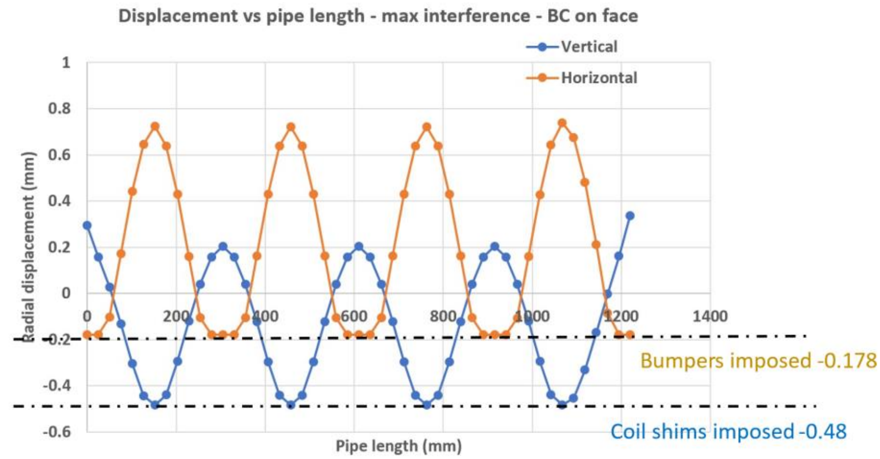
FE model – geometry and BCs



FE – model max interference

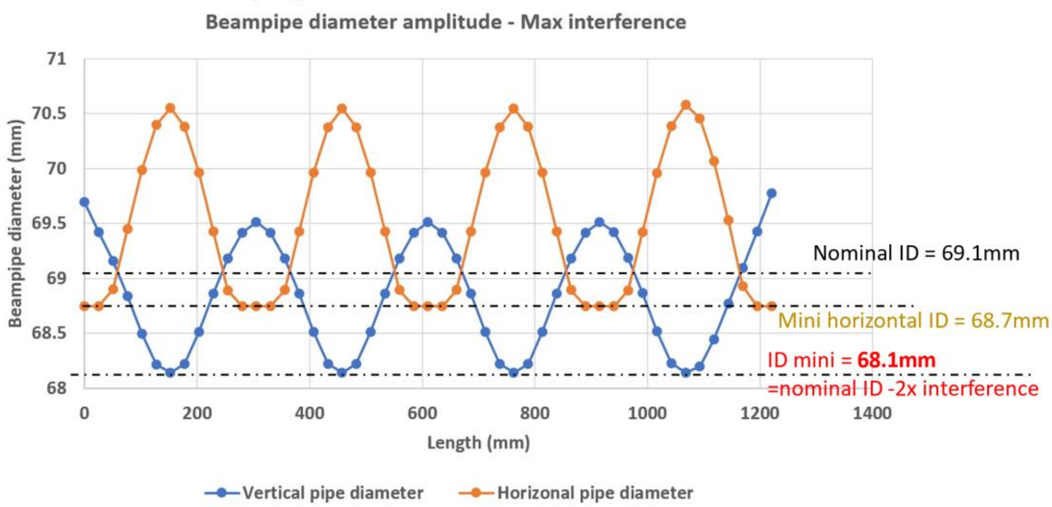


FE – model max interference



The good news is that the diameter pinch (negative radial disp) is limited to the maximum interference imposed.
→ The diameter amplitude oscillation tends to relax the pinch imposed by the coil shims/bumpers.
→ Knowing the interference (fixed by magnet design) and the pipe initial diameter is enough to get the maximum pinch

FE model – beampipe diameter

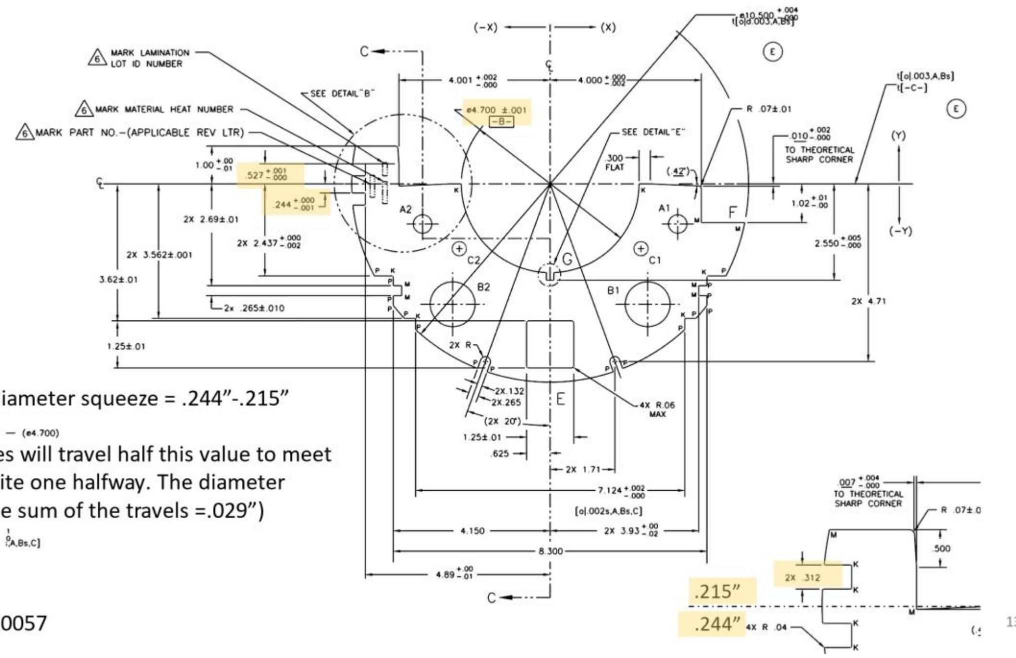


This case corresponds to the max pipe OD with max pipe thickness (to get the highest interference pinch)
IF the pipe OD reduces, the interference will reduce by the same amount and the overall pinch will remain the same.

Outlook/conclusion

- A study of the magnet tolerance was conducted to get the highest possible value of pinch of the RHIC dipole magnet beampipe.
- Summing the worst tolerance, the highest pinch is in the vertical plane and leads to a diameter reduction of ~1mm(vertical has the pipe so horizontal should be more critical)
- This is only the dipole/magnet interface. Other diameter pinch may be found at the weld on the magnet end volumes and on the dummy magnets assembly (and snakes ?).

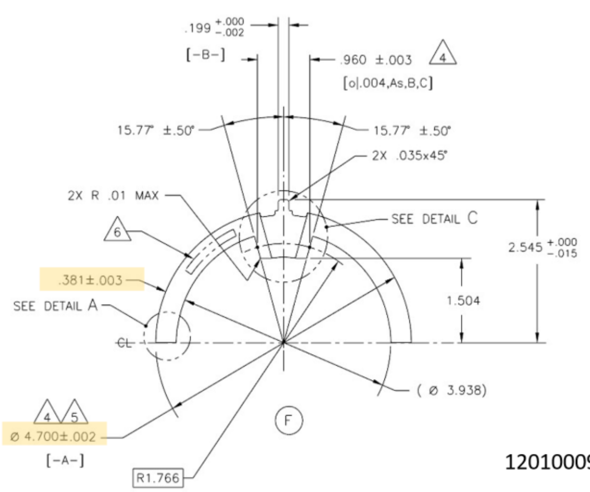
More slides



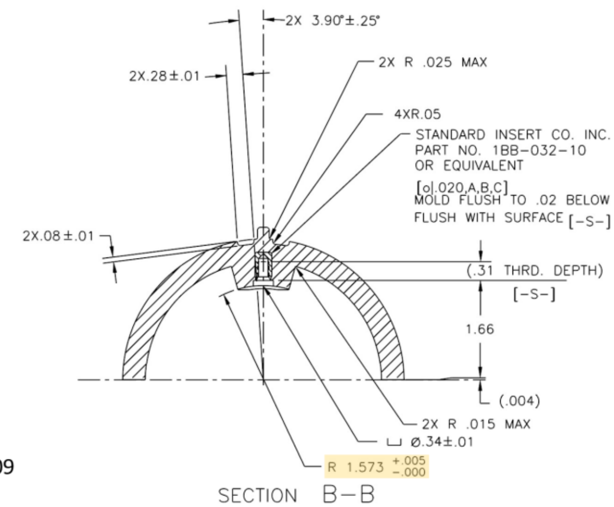
Nominal diameter squeeze = .244"-.215" =.029"

Both halves will travel half this value to meet the opposite one halfway. The diameter value is the sum of the travels =.029")

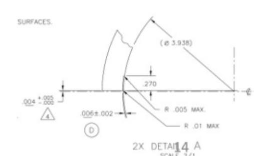
12010057

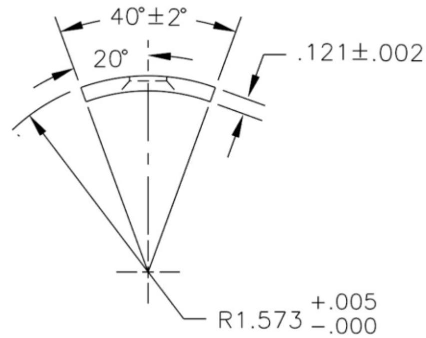


12010009

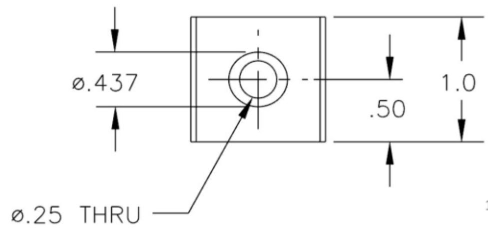


Insulator vertical thickness = (4.7+/-0.002)/2 – (1.573 +.005/-.000) = 0.777 +.006/-.001

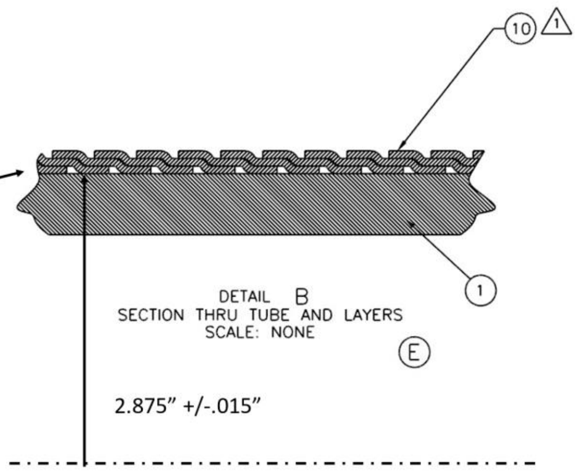




12010066



.001” (12010181-13)



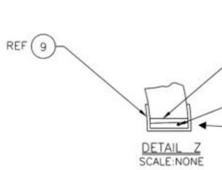
Beampipe vertical OD = 2.875 +/-.015 + 2 X(3x.001”)= 2.881” +/-.015”

2.875” +/-.015”

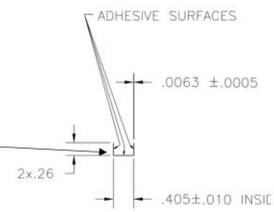
12010008
Beampipe

12010267 coil definition

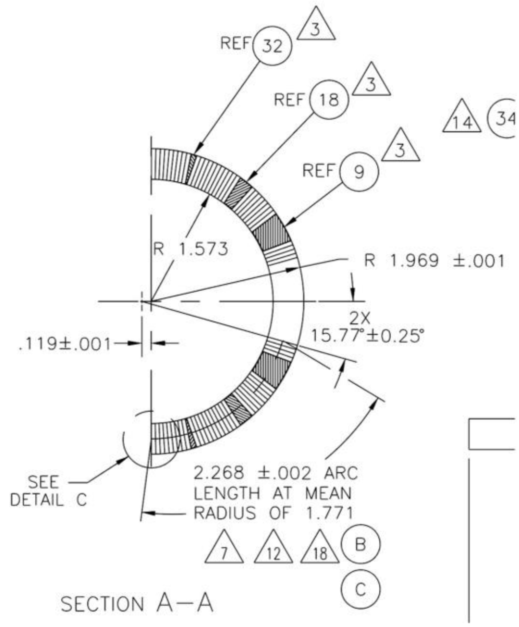
Coil thickness = 1.969+/-.001 -1.573 = 0.396 +/-.001”



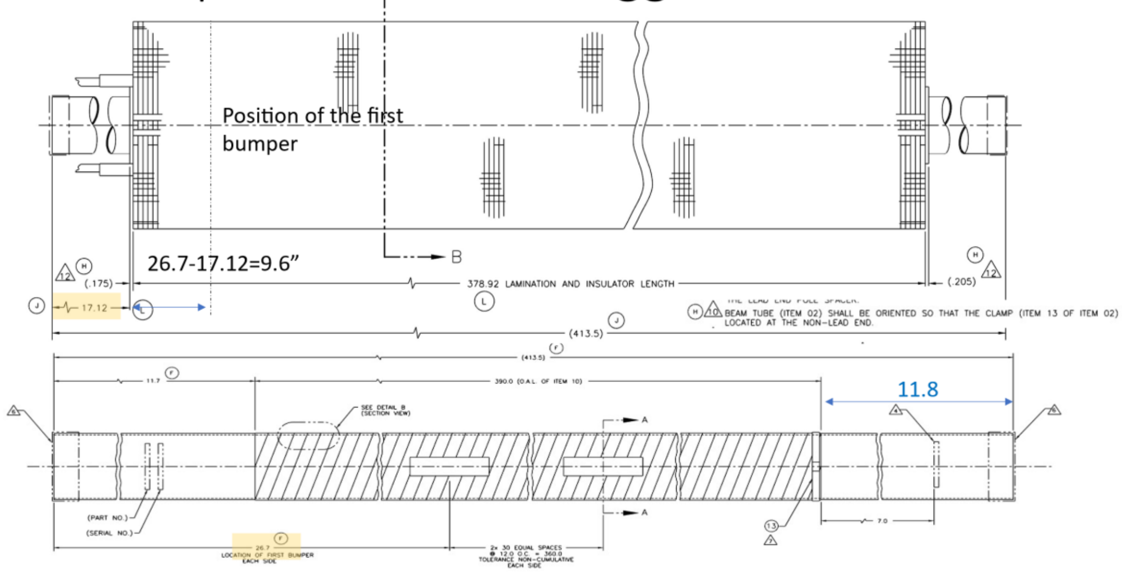
12010007

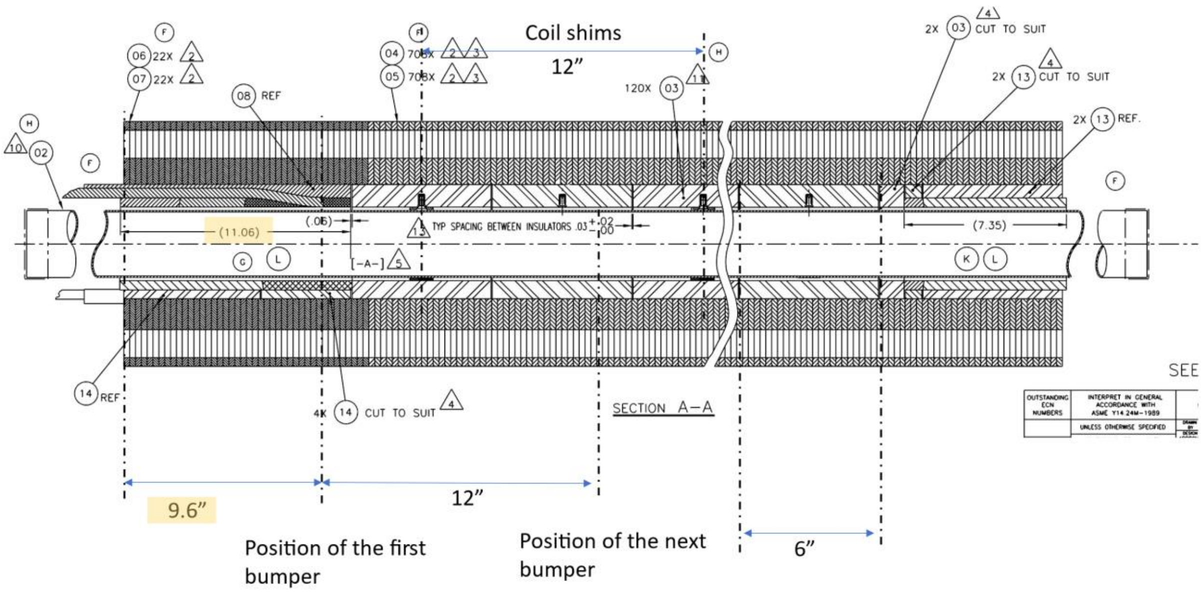


12010048



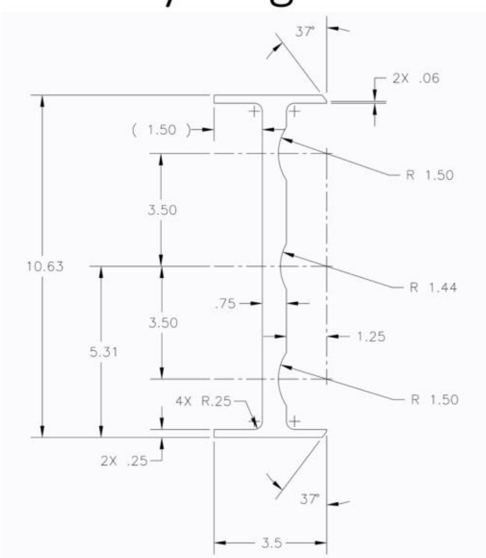
Are the bumpers/shim coils staggered ?





According to this drawing the bumpers should be located not strictly in the middle of the coil shims but slightly but at ~1.5 of the middle.
Note that the tolerance on the length of the beampipe is +/-1” and the shims/bumpers distance is not fixed by design. We will keep a central bumper between shim as a worst case for the oscillation amplitude.

Dummy magnet



01025000

Upper tube 3” th 0.065” (01025098)

Beampipe 2.875” th 0.077”

Lower tube 3” th 0.065” (01025098)