$\overline{\mathrm{P}}$anda-MVD - note 009

First prototypes of low mass cables for the pixel detector of the MVD

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17/04/2012

Abstract

The high expected hit rate and the triggerless readout determine a large amount of data to be transmitted continuously from the MVD. In addition, the strict layout and material budget constraints require the investigation of low mass signal transmission cables based on aluminum, to be used inside the MVD volume up to the optical links.

This note presents the results from the tests of the first aluminum cable prototypes. 1 meter long folded differential cables have been realized using both laminated aluminum and aluminum deposition. Cables with different track layout have been prototyped and tested to study the digital signal transmission as a function of the data rate.

1 Introduction

Due to the asymmetric layout of the Micro Vertex Detector (MVD) of the $\overline{\text{P}}$ANDA experiment, all the services of the MVD must be routed outside the detector only in upstream direction. This poses a significant problem especially for the six hybrid pixel disks, in which the services will be routed first along the beam pipe in downstream direction and then brought to the outer radius and stretched backwards, passing between the MVD and the Central Tracker of the experiment. The amount of material introduced by the services and in particular by the cabling is significant. To limit the material budget it is therefore mandatory to investigate the feasibility of cables based on aluminum, which allows advantages with respect to copper in terms of radiation length [1].

Various prototypes of aluminum data cables, realized with differential aluminum microstrips laid on an insulator support, have been studied in terms of digital signal transmission as a function of the data rate.

The technique employed is the analysis of the eye diagrams, obtained superimposing all the bits in a sequence and triggering on the edges of the ideal recovered clock. The diagrams are analyzed for their main features, namely the jitter, the eye width and the height [2]. In Fig. 1 is shown the picture of a generic eye diagram with the relevant quantities. Additionally, the Bit Error Rate (BER) evaluation has been also performed.

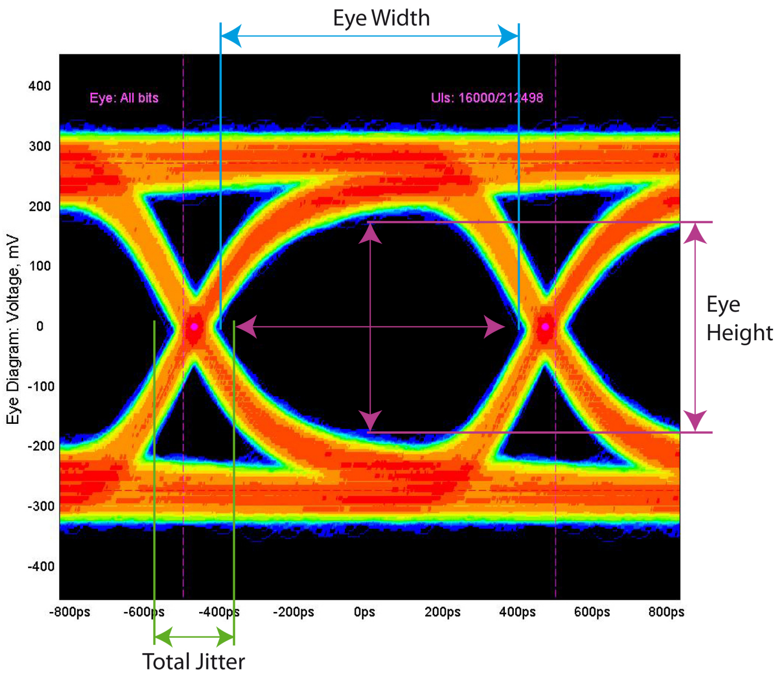


Figure 1: Example of an eye diagram and its main features.

2 The aluminum cable prototypes

The cable prototypes feature a single microstrip pair, 1 meter long, arranged in a folded layout. Two different technologies have been exploited: laminated aluminum, manufactured at the CERN technology department, and aluminum deposition, manufactured at the Techfab company in Italy. The samples have a similar layout, but differ in the properties of the dielectric material and of the aluminum strips. In the CERN samples, the insulator is a commercial DuPont composite sheet (Pyralux), made of a polyimide film coated on both sides with a proprietary acrylic adhesive for an overall thickness of about 50 µm. An aluminum layer 15 µm thick is laminated on both sides of the support. The aluminum on the front side is etched in the final layout by means of a mask; on the back side, the metal layer acts as the ground plane.

The Techfab prototypes feature microstrips 7 µm thick over a 50 µm kapton layer. On the backside a continuous aluminum ground plane is also deposited [3]. Fig. 2 shows a section of the microstrip cables with the geometrical parameters of prototypes from both CERN and Techfab.

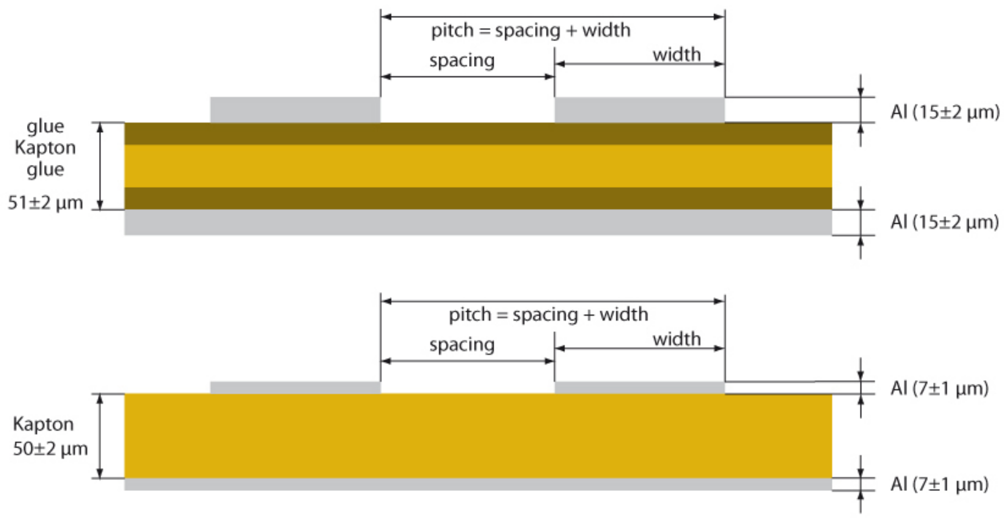


Figure 2: Geometrical parameters of microstrips prototypes. Top: CERN samples (laminated aluminum). Bottom: Techfab samples (aluminum deposition).

The CERN prototypes were manufactured in three different track widths: 100 µm, 150 µm and 200 µm; in each case the spacing between the tracks is equal to the width and the differential pair pitch is therefore 200 µm, 300 µm and 400 µm, respectively.

The Techfab samples were originally produced in a single layout with 150 µm wide tracks (300 µm pitch); however, these prototypes were found to be difficult to connect with wire bonding. Therefore a second batch of cables was produced, using an Al/Si 99/1 alloy instead of pure aluminum; this allowed an improvement of the reliability of the wire bondings, at the expense of the adhesion of the ground layer. The cables of the second batch have a track width of 200 µm for a resulting pitch of 400 µm.

With both technologies the layout of the samples was designed to obtain a differential impedance of about 100 Ω.

3 The experimental setup

To test the folded microstrip prototypes the testing board shown in Fig. 3 has been developed. The board is equipped with a 65lvds100 transmitter, which features a 2 Gbit/s data rate upper limit. The transmitter acts as a buffer and uses Low-Voltage Differential Signaling (LVDS) levels (common mode of 1.25 V and voltage swing of a single phase of 350 mV).

The microstrip prototype is connected at its ends to the board using wire bondings. The ground contact is obtained by means of an epoxy conductive glue between the backside of the cable and ground pads on the board.

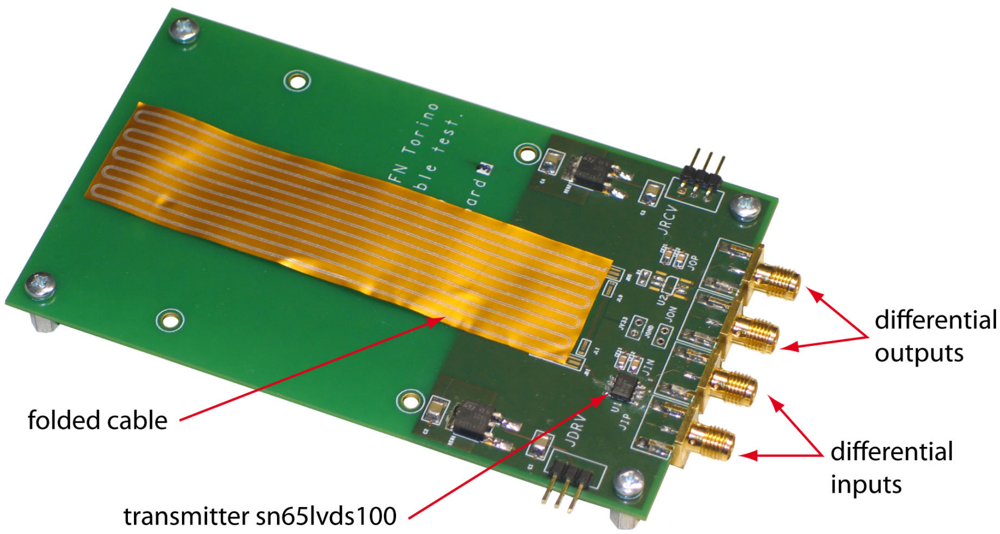


Figure 3: Test board for folded aluminum microstrips.

The complete experimental setup is shown in Fig. 4. It comprises the Agilent N5980A pattern generator and Bit Error Rate Tester (BERT), the test board and the Tektronix DPO 70604 digital oscilloscope with a 6 GHz bandwidth.

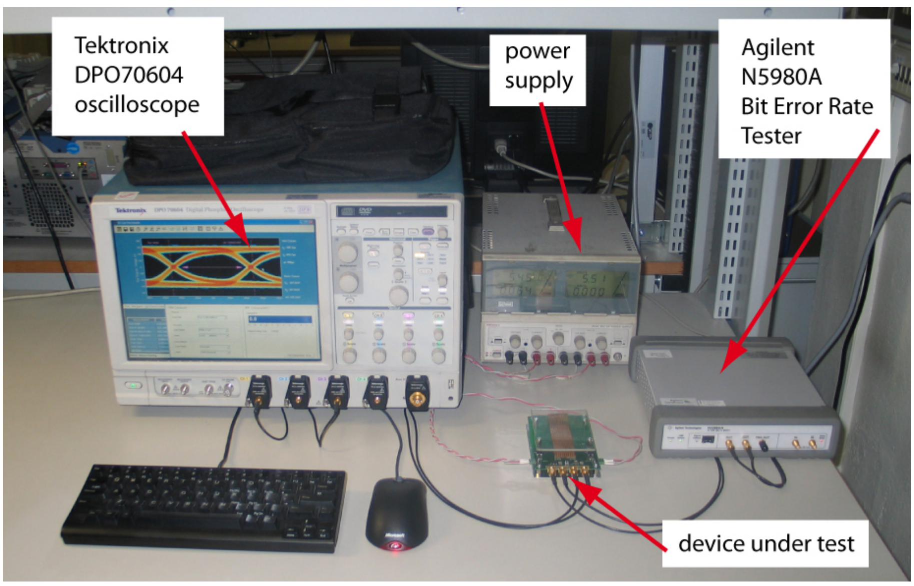


Figure 4: Experimental setup for aluminum microstrips tests.

The BERT produces LVDS pseudorandom patterns following various configurations ($2^7 - 1$, $2^{15} - 1$, $2^{23} - 1$, $2^{31} - 1$); the data rate can be chosen among a series of standard protocols listed in Tab. 1.

Standard protocol	Data rate [Mbit/s]
OC3 (Optical Carrier 3x)	155.52
OC12 (Optical Carrier 12x)	622.08
FCx1 (Fiber Channel 1x)	1062.5
GBE (Giga Bit Ethernet)	1250
FCx2 (Fiber Channel 2x)	2125

Table 1: Standard protocols of signal transmission available on the BERT.

The LVDS pattern generated in the BERT is sent to the testing board; the buffer reshapes the signal and feeds the microstrip under study. The output signal from the strip can be either sent back to the BERT for a bit error rate evaluation or sent to the oscilloscope for the waveform study and the analysis of the eye diagram.

4 Results

Eye diagram measurements have been performed on nine CERN laminated prototypes (three per each of the track widths) and on two Techfab samples [4]. The total jitter and eye height have been measured as a function of data rate, for the five standard protocols available on the BERT equipment. The results are shown in Fig. 5 and 6.

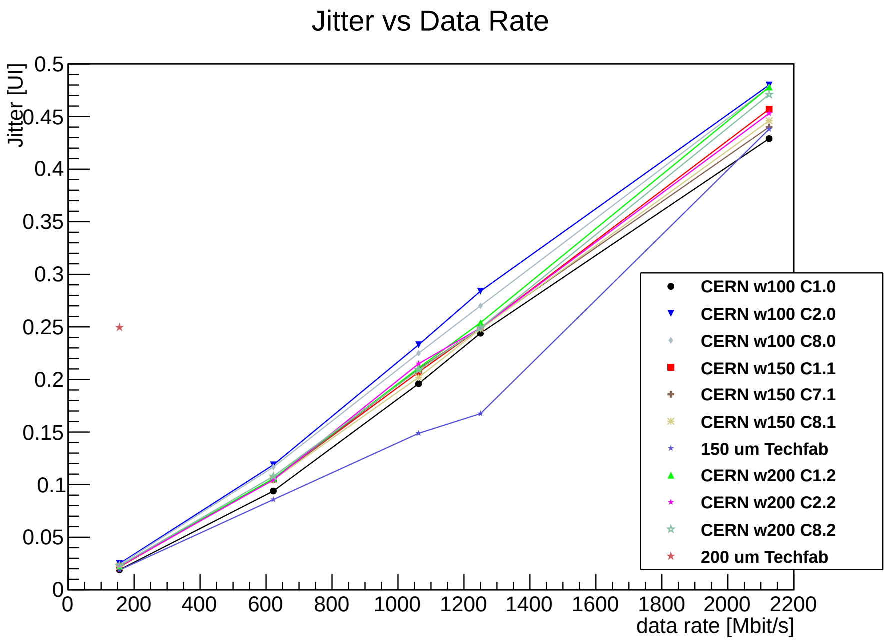


Figure 5: Total jitter as a function of data rate for aluminum microstrip prototypes. Nine samples from CERN (three per each track width) and two Techfab samples are shown.

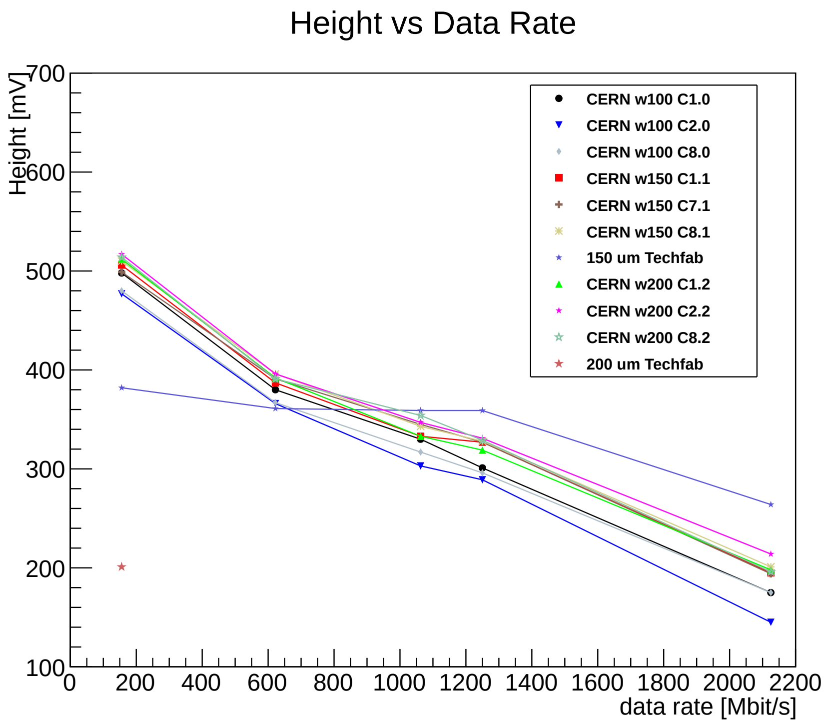


Figure 6: Eye height as a function of data rate for aluminum microstrip prototypes. Nine samples from CERN (three per each track width) and two Techfab samples are shown.

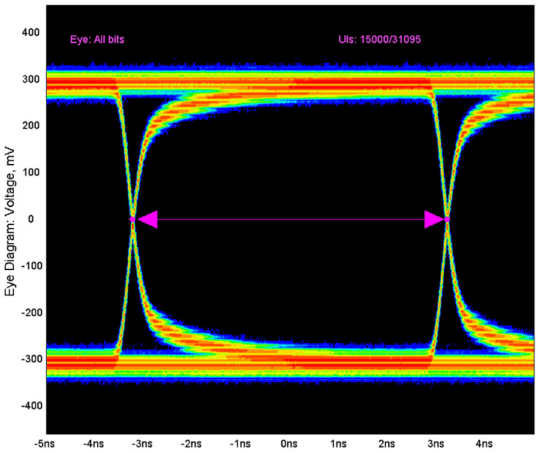
The behavior of the nine CERN prototypes is similar. It shows a clear worsening with the increase of the data rate; no obvious relationship appears between electrical performances and track width. Assuming that a safe limit for total jitter is 30% of the Unit Interval (0.3 UI), the cables can be used up to a data rate of about 1.2 Gbit/s.

The jitter value of the Techfab 150 µm prototype is lower than that of the CERN samples at most data rates; additionally, the height shows smaller variations within the explored frequency range. On the contrary, the 200 µm Techfab cable shows a very high jitter and the eye diagram measurement fails completely at all data rates but the lowest; this is probably due to the high linear resistance of the Al/Si alloy tracks.

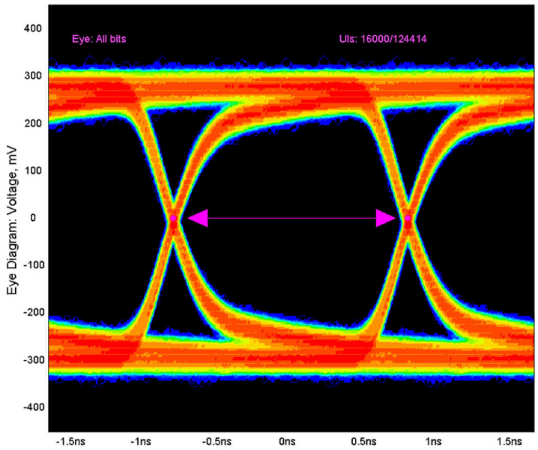
Additional tests have been carried out to evaluate the statistical uncertainties and the effects of the environment. A CERN sample featuring 150 µm track width was measured 15 times on different days, at the five available data rates. The variation on the total jitter is in the order of 3÷4 ps, while the error on the eye height varies between 6 and 9 mV.

In Fig. 7 the eye diagrams of one CERN microstrip prototype are shown. The eye is still open at the maximum data rate used in this experimental setup, although the jitter reaches 45% of the Unit Interval.

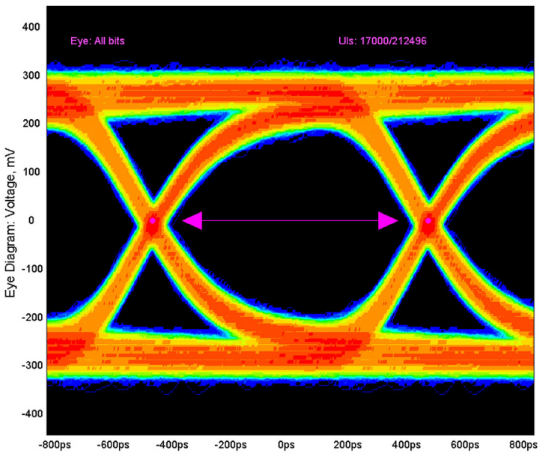
Bit Error Rate evaluations have been performed on one Techfab sample (track width 150 µm, pure Al) and on two CERN samples (track width 150 µm and 200 µm), at the data rates of 155.52 Mbit/s and 2125 Mbit/s. The test duration was 5 hours in each case and no errors were found; at the two data rates, the number of bits transmitted faithfully is 2.8×10^{12} and 3.8×10^{13}, respectively.



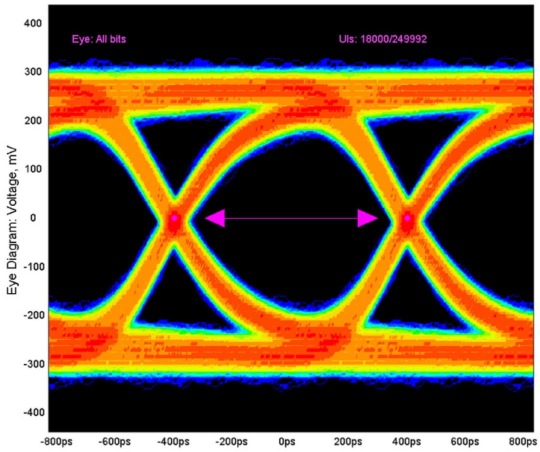
Data Rate 155.52 Mbit/s



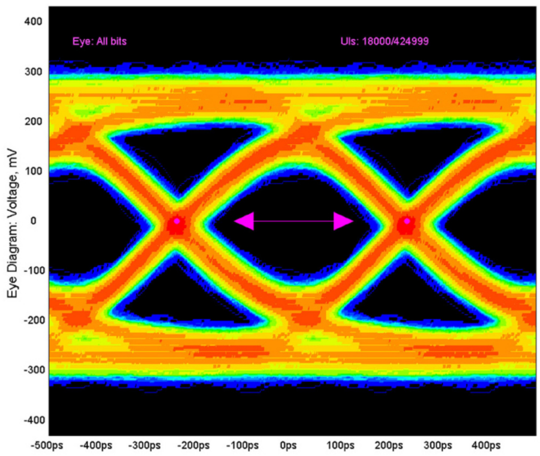
Data Rate 622.08 Mbit/s



Data Rate 1062.5 Mbit/s



Data Rate 1250 Mbit/s



Data Rate 2125 Mbit/s

Figure 7: Eye diagrams of a CERN 100 µm cable, at five different data rates.

5 Irradiation test

To study radiation damage effects on the kapton and the glue, two CERN samples (track width 150 µm and 200 µm) were irradiated with neutrons at the TRIGA Mark II research reactor at LENA in Pavia. The irradiation time was calculated to reach an equivalent fluence of 2×10^{15} n_{1MeVeq} / cm^2; the fluence was evaluated using the NIEL scaling hypothesis, taking into account the neutron cross section for carbon, which is the main element of the Kapton layer [5] [6] [7]. Eye diagram jitter and height were measured before and after the irradiation and the results are reported in the Fig. 8 and 9. After the irradiation a small increase in the height is measured on both samples; similarly, the jitter is slightly reduced at most data rates. Therefore the neutron irradiation does not reduce the data rate range in which the cables can be used safely.

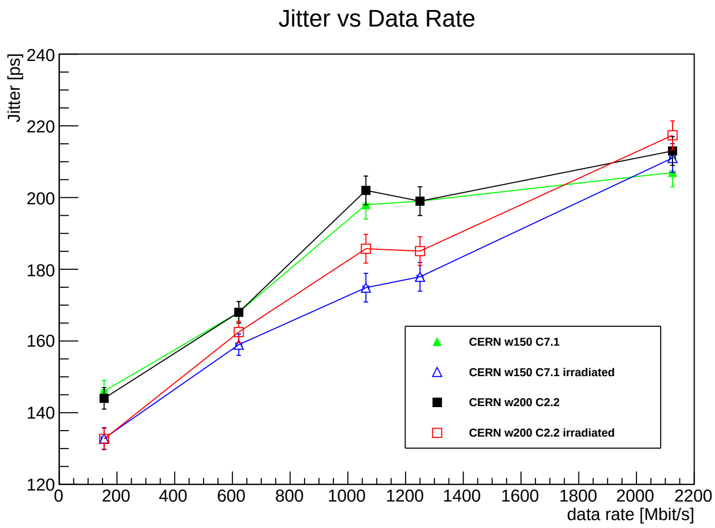


Figure 8: Total jitter before and after neutron irradiation for two CERN prototypes.

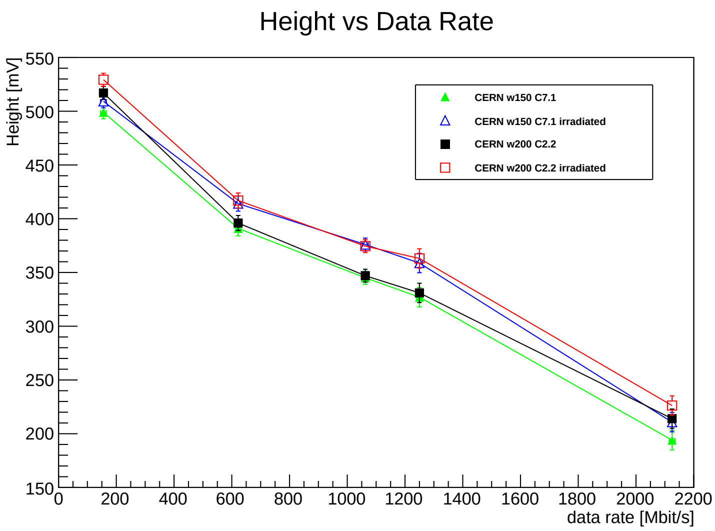


Figure 9: Eye height before and after neutron irradiation for two CERN prototypes.

6 Conclusions

The first prototypes of aluminum microstrips have been built and tested up to a data rate of about 2 Gbit/s. Two different technologies have been compared: laminated aluminum and aluminum deposition.

The cables manufactured at CERN show similar trends of the eye diagram parameters, regardless of the track width. The total jitter remains below the critical value of 30% of the Unit Interval up a data rate of about 1.2 Gbit/s and reaches 45% of the Unit Interval at the maximum data rate.

The 150 µm cable manufactured at Techfab shows slightly better electrical performances with respect to the CERN samples, at the expense of the worsened reliability of the wire bondings. The mechanical properties can be improved using Al/Si tracks; however in this case the electrical performances are completely unacceptable, making laminated aluminum the only reliable technique.

Neutron irradiation tests performed on two samples show no remarkable variations in the behavior of the cables, suggesting that kapton and glue layers do not suffer significant radiation damage up to the applied fluence. Further tests with proton irradiations are ongoing to evaluate the effects of Total Ionizing Dose.

References

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