

6th Korea-Japan PHENIX/sPHENIX/RHICf/EIC Collaboration Meeting

Development of Long and High Density Flexible Cable (Bus Extender) for INTT



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Long and High Density Flexible Cable

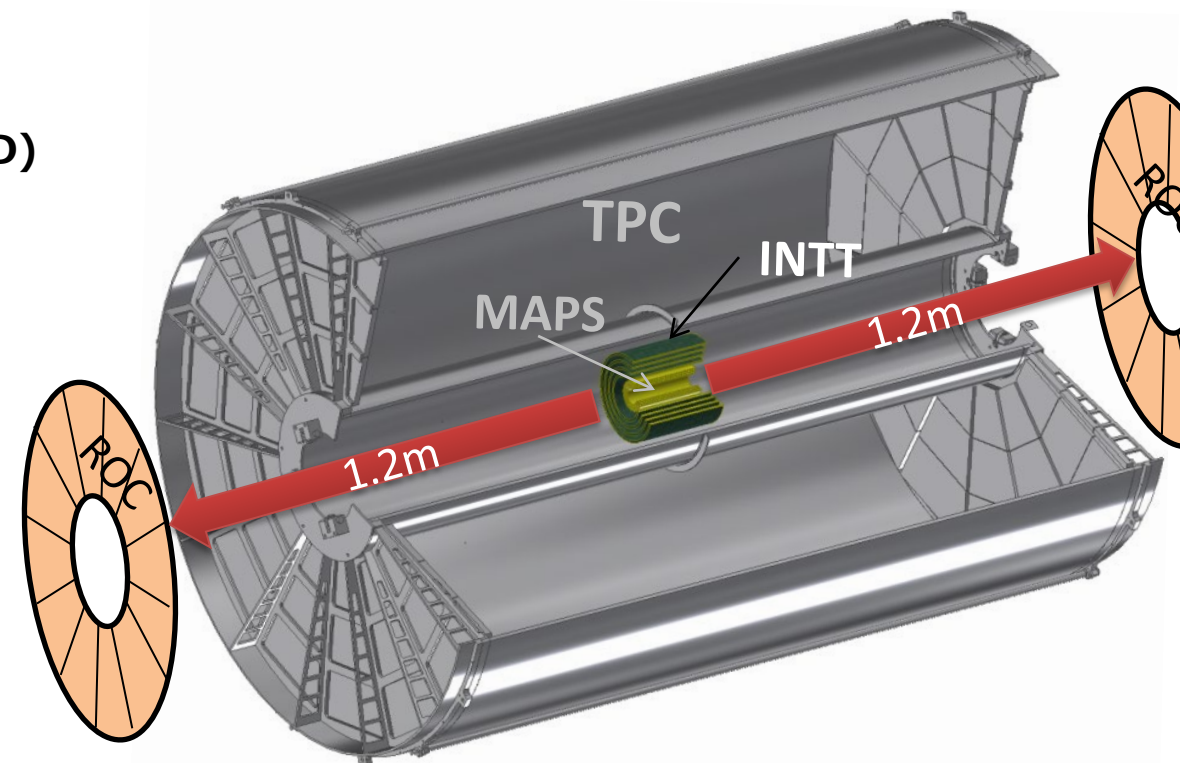


Requirements of the data cable for INTT

- Long ~ 120cm
- Dense = 62 pairs of the signal line (and power/GND)
- High speed = 200 Mbps LVDS ($Z_{diff}=100\Omega$)
- Tight space ~5cm and curving path
- (re)use the FVTX ROC

No commercial cable available in the market

- Develop the cable based on the FPC technology
 - Flexible and can be micro-fabricated
- Very long FPC is challenging
 - No fabrication machine for 120cm FPC
 - Large signal loss by 120cm during the signal transmission
 - Keep line & space precisely for whole length
 - Make the circuit open/short easily if the line width is fluctuated

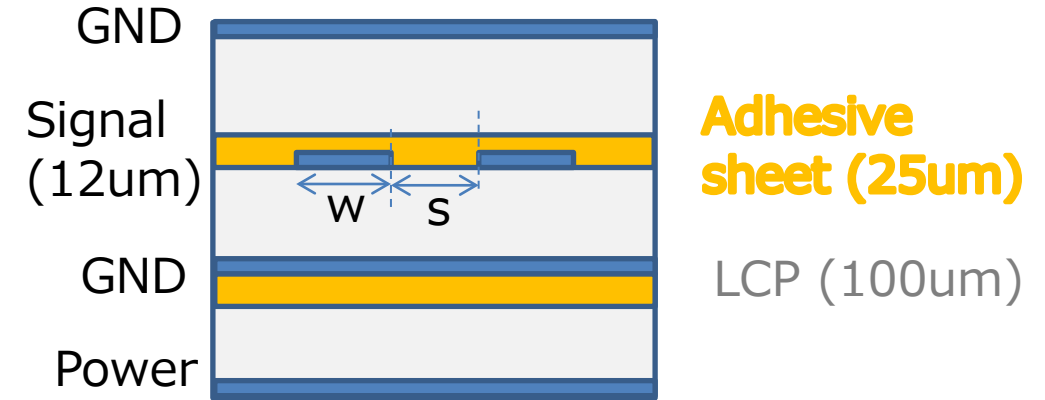


Electrical and mechanical performance studied and production procedure developed

Development of the Bus-Extender

- Cable design
 - Dimension (L x W): 120 x 5 cm²
 - Line and space : 130 & 130 μm
 - Z_{diff} : 100Ω by strip line structure
 - Signal layer is sandwiched by GND layers
 - Liquid Crystal Polymer (LCP) as substrate
 - Relatively new material for FPC
 - Less signal loss due to low di-electric constant & $\tan(\delta)$
 - Thick LCP available for Z_{diff} : 100μm

4 layers laminated by the adhesive sheet



- Prototype The design is decided based on EM-field simulation



Bus Extender Performance

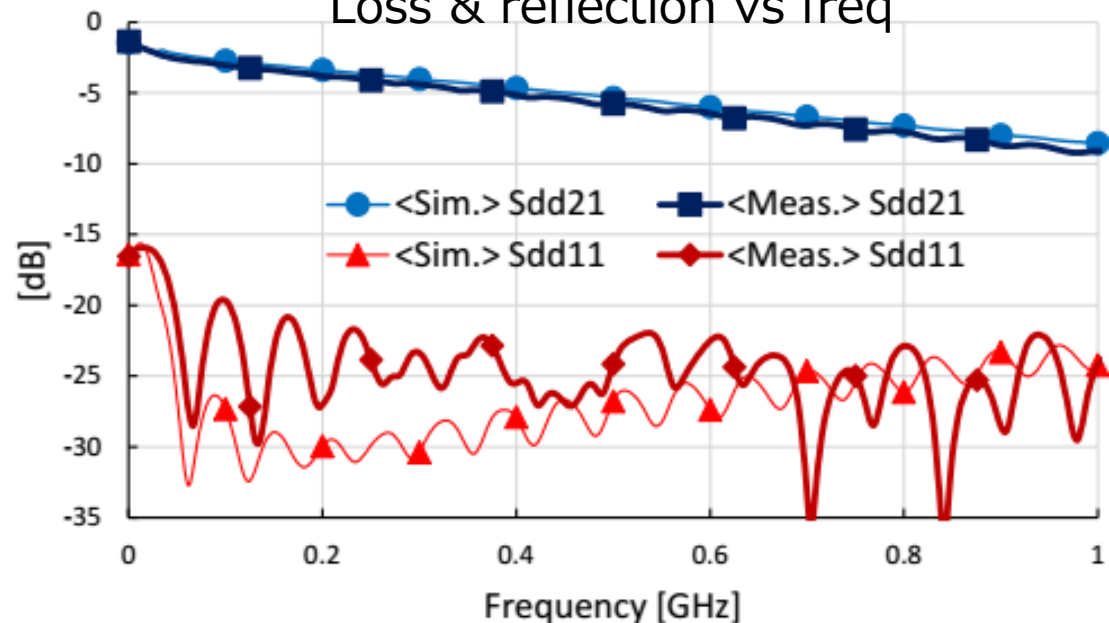
- Electrical properties
 - Signal loss vs freq. ,
 - Z_{diff} by TDR
 - Eye diagram
- Mechanical property
 - Accuracy of line & space
- Aging test
- Radiation hardness

Test bench to study properties of the single Bus-Extender

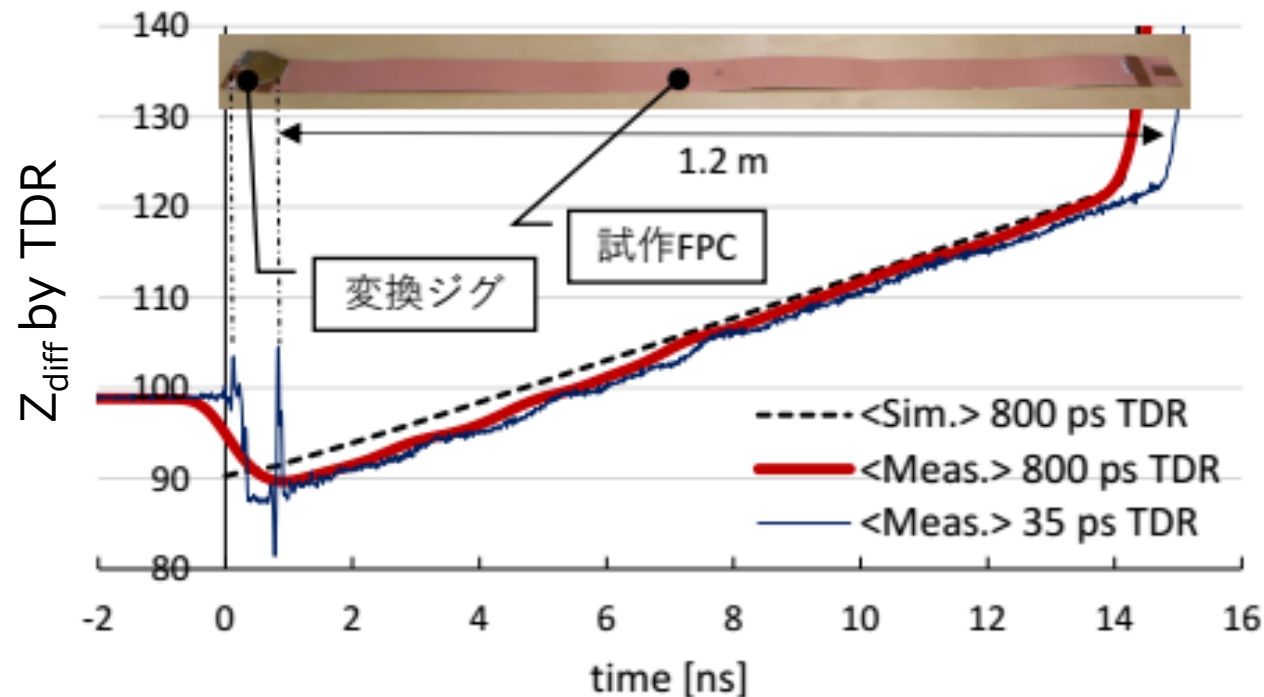


Electrical Performance

Loss & reflection vs freq



- Freq. dependence(s-parameter)
 - **Signal loss** : ~30%、
 - **Reflection**: < 10%

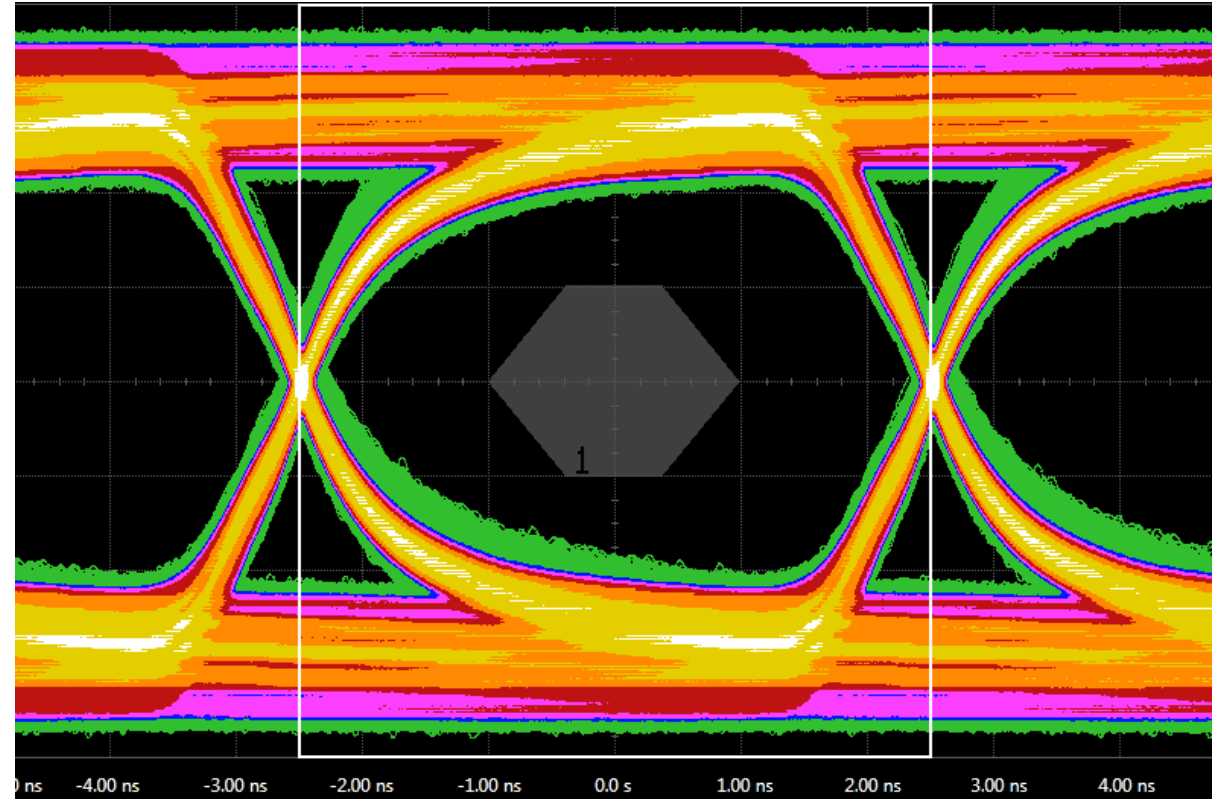
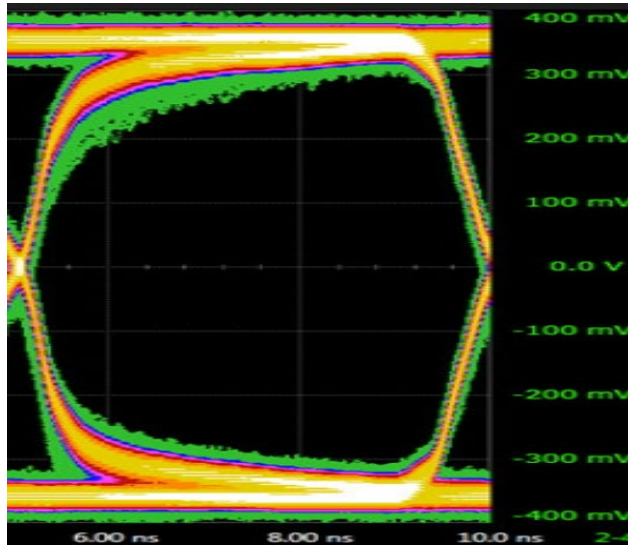


- Zdiff by TDR
 - $Z \sim 90\Omega$ (slight smaller than 100Ω)

Data is consistent with the EM field simulation

Eye diagram

Input : 200Mbps pseudo-random pulse with 500 ps rising time,

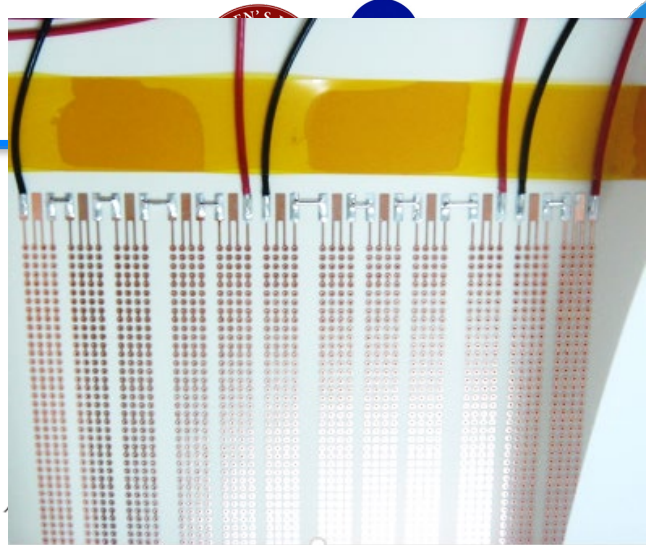
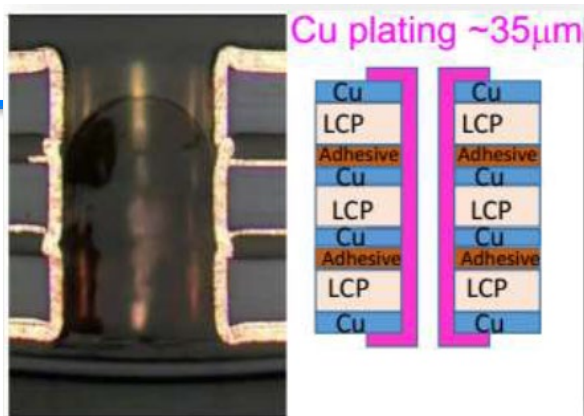


- The signal pulse is clearly separated from the mask
 - Pulse get distorted due to larger signal loss of hi-freq. component
 - Bit error rate $< 10^{-9}$

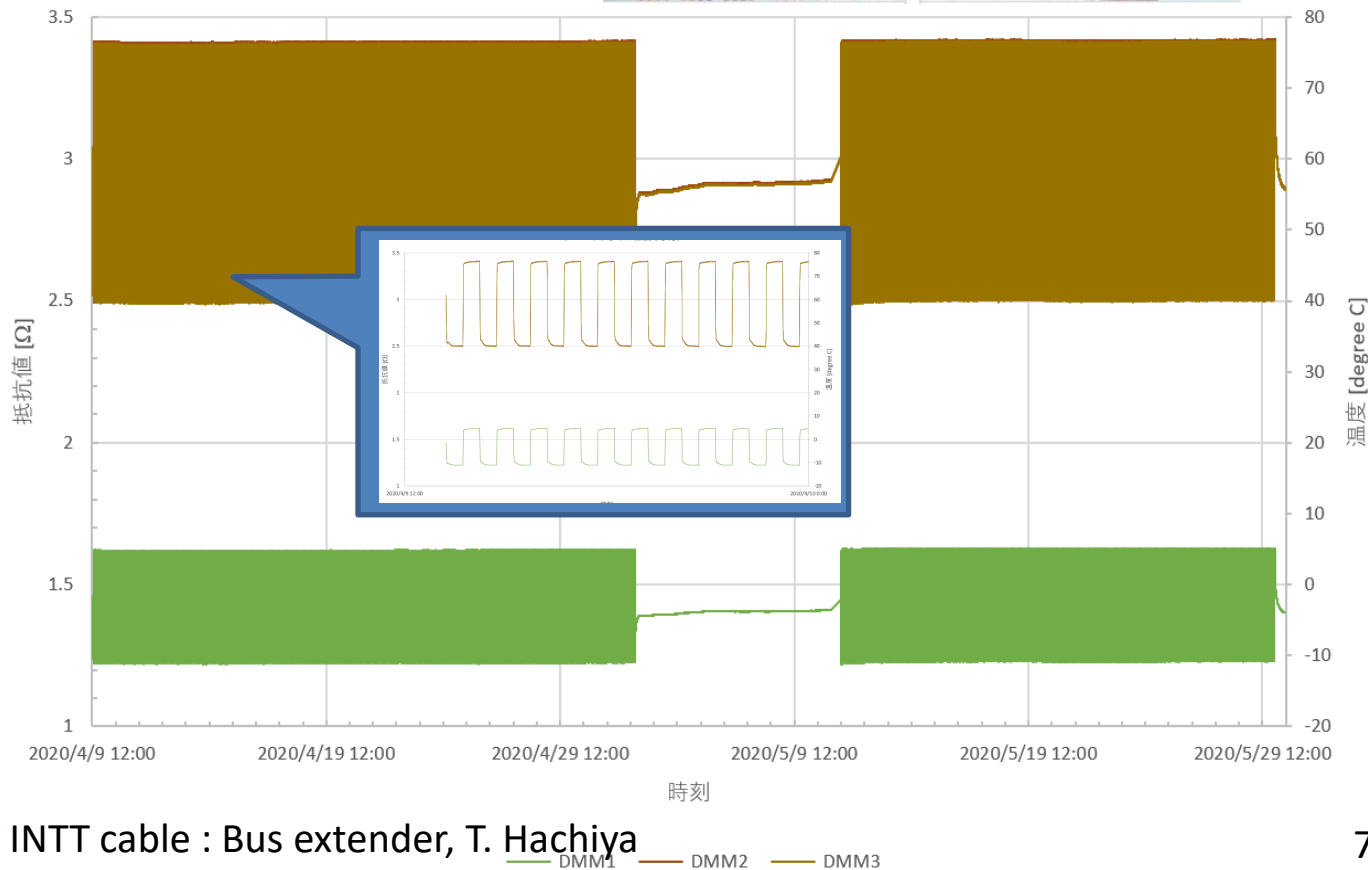
The performance of bus-extender is good enough for INTT

Aging Test

- Keep healthy at least 3 year operation
- Mechanical stress by temperate
 - LCP is expanded and shrunk
 - Thru-hole could be damaged.
- Temperature cycle
 - -15 (30min.) ~ 75°C (30min.) with 1~2min. transition.
 - 1000 cycles (40 days)
- Test FPC sample
 - 4 layers, same as bus extender
 - 400, 1000, 1000 thre-holes are daisy chained and its resistance monitored .
- Results
 - Resistances changed with temperature
 - **All FPC samples are healthy after 1000 cycles.**



スルーホール



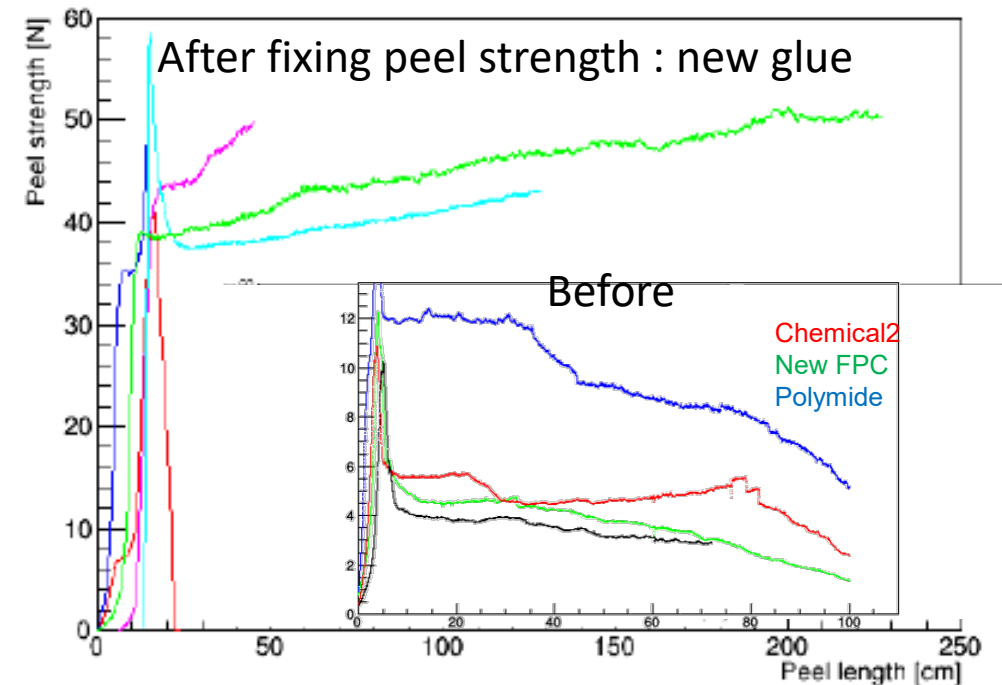
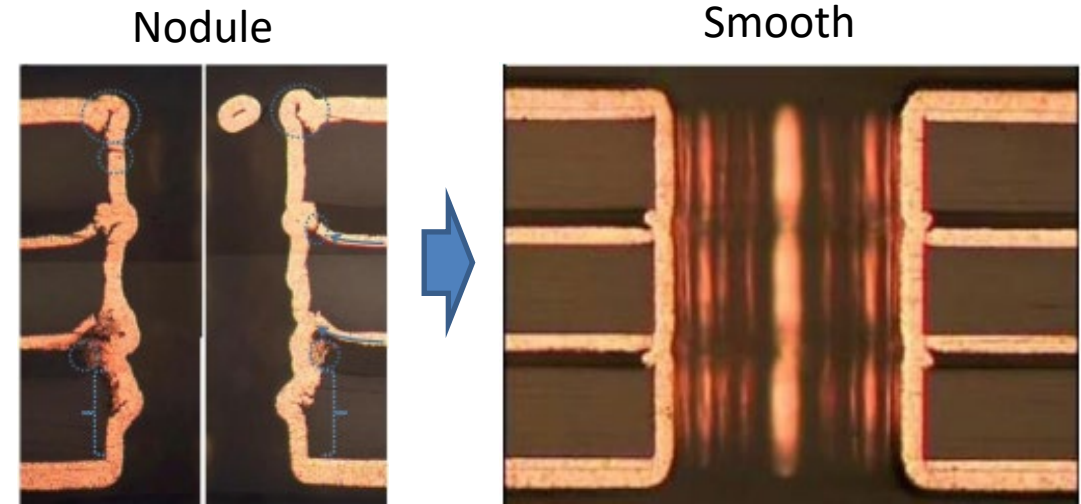
Self-test completed

- Issues solved
 - Nodule structure on Cu-plating of the thru-hole
 - Weak peel strength

The new adhesive sheet fixes the issues.

- Additional tests reported by M. Morita
 - Signal measurement with full readout chain
 - Radiation hardness test

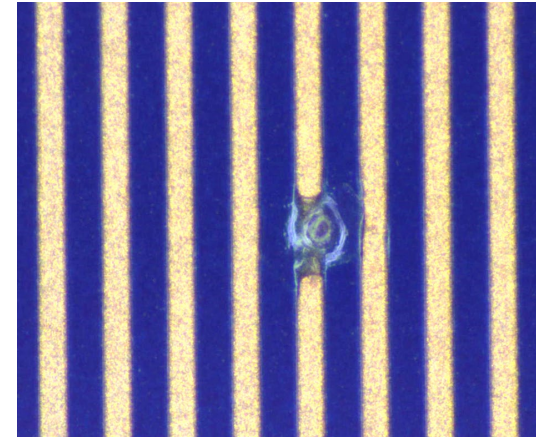
Ready for the mass production



Toward Mass production

- Improving the yield rate is necessary
 - Current yield rate was ~20~30%
 - Production parameters are best tuned
 - Pressure to make multi-layer & make thru-hole
- Inspected/discussed the production procedure with manufacturers
 - Contamination of small dusts is major cause when producing the FPC
- New procedures to remove the dust as much as possible
 - UV lights to look for remaining dust
 - Silicon roller to remove dust
- Check the continuity before laminating multiple layers

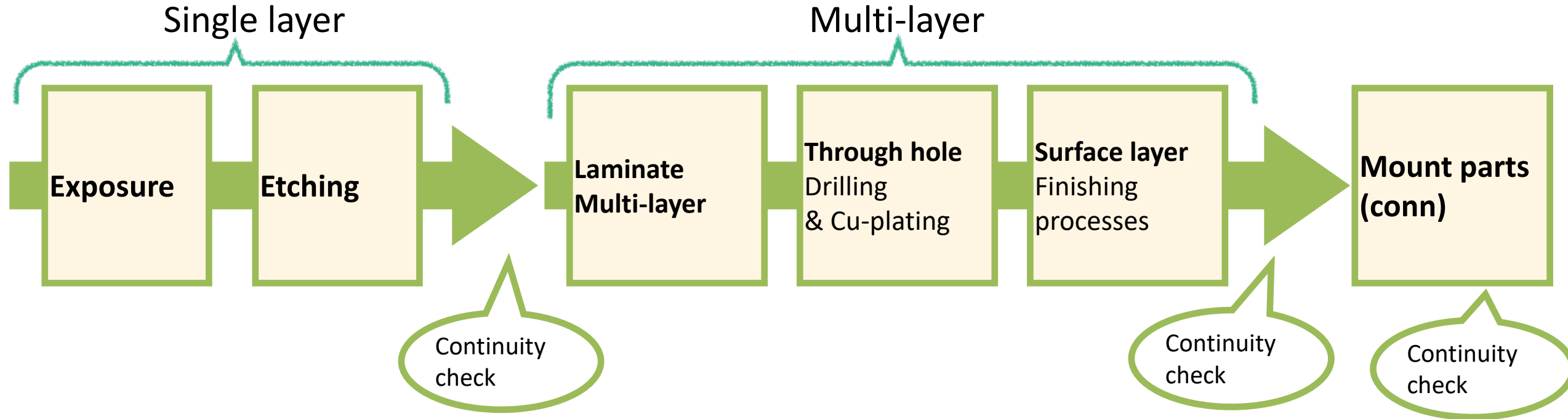
Short line by mis-exposure



Open line by mis-etching



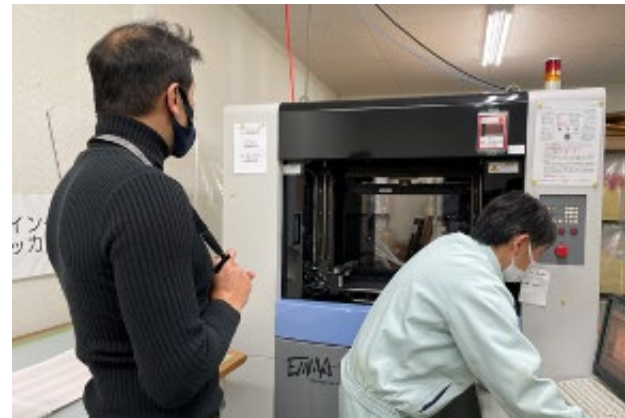
Continuity checks for the production



Three times of the continuity checks during the production

- Twice at manufacture.
- One as receiving inspection

Yield rate improved much



Flying probe tester

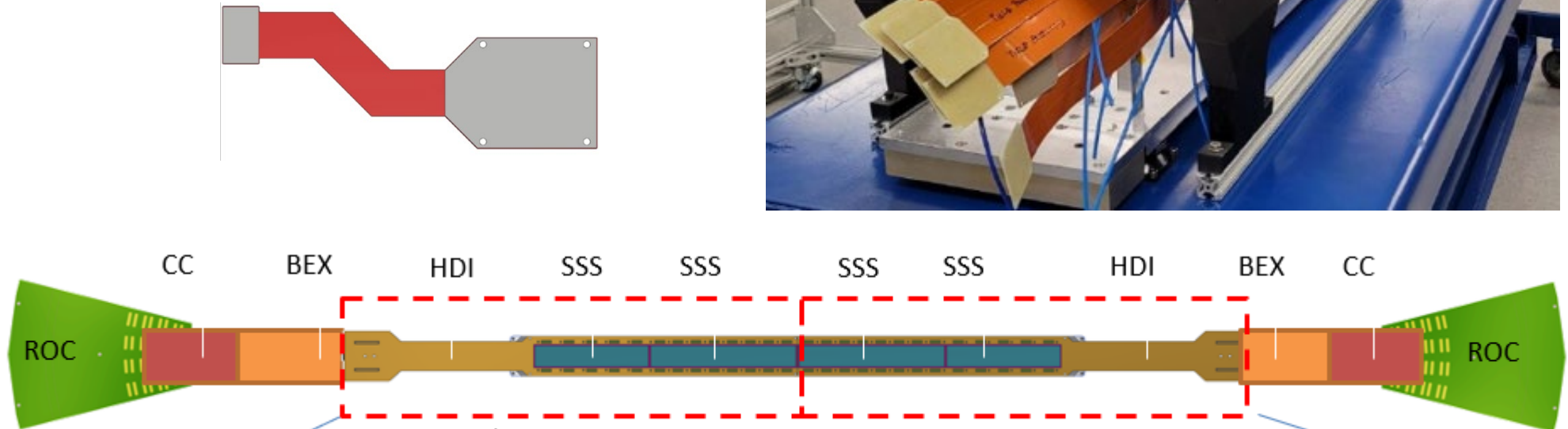
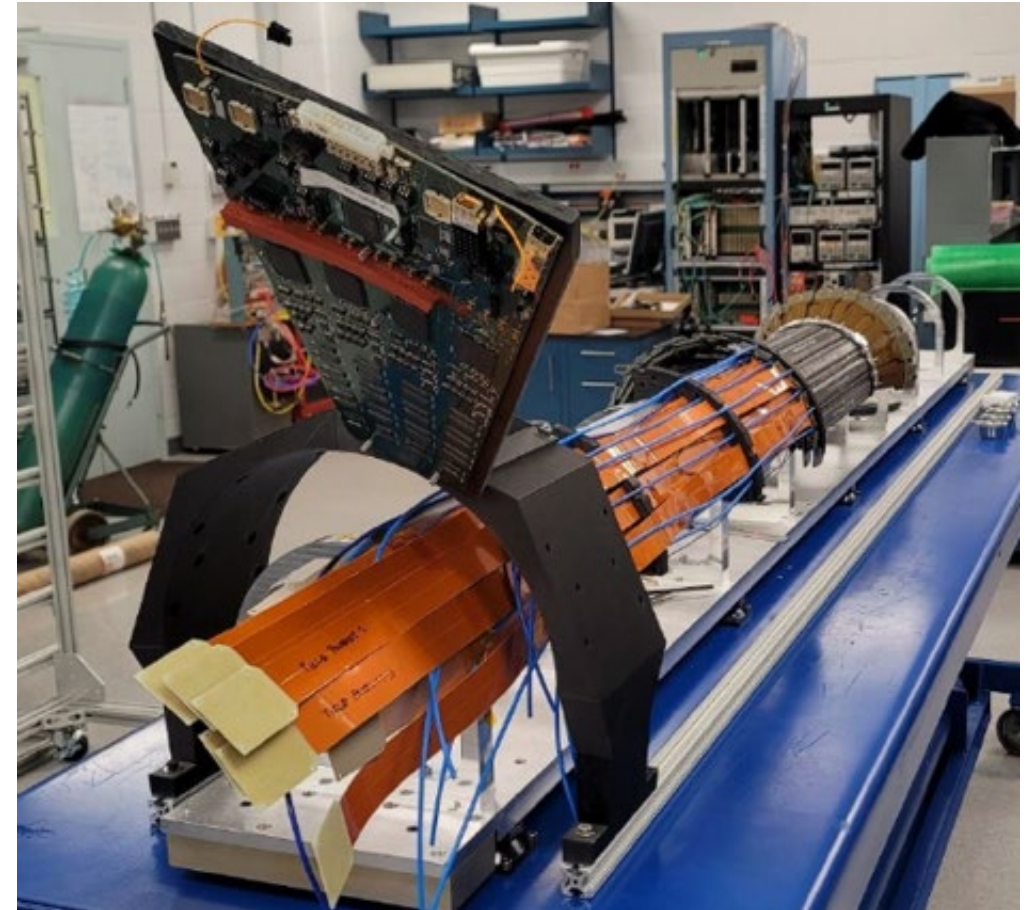


The special cable checker

Development of INTT cable : Bus extender, T. Hachiya

Bus-Extender in Barrel

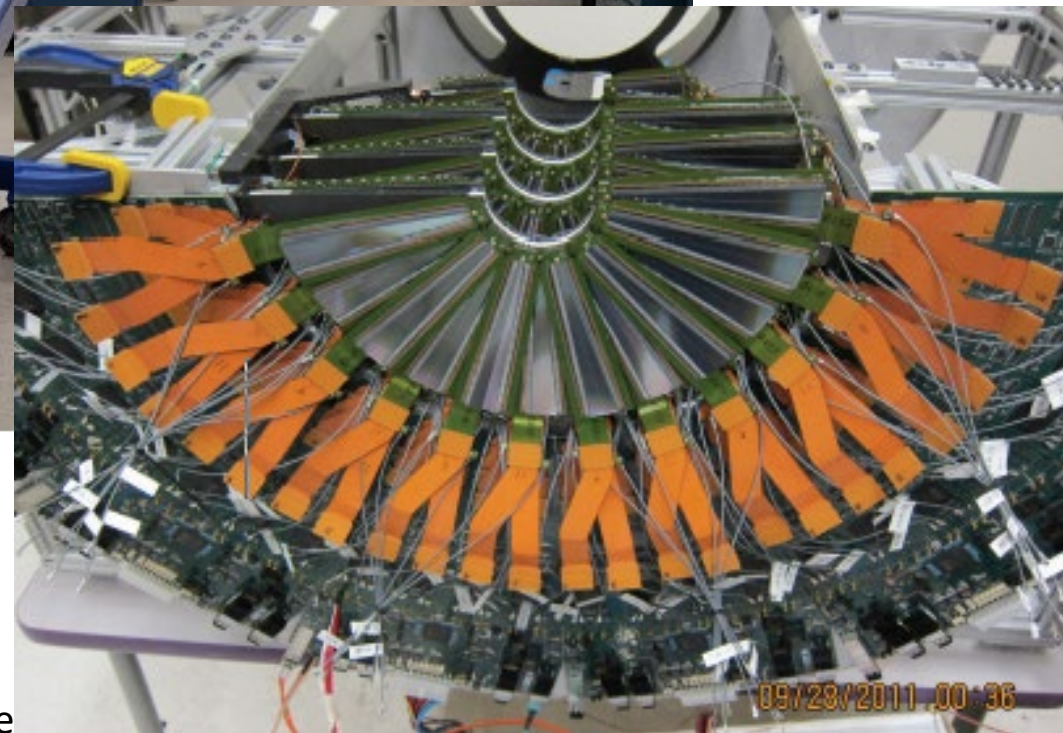
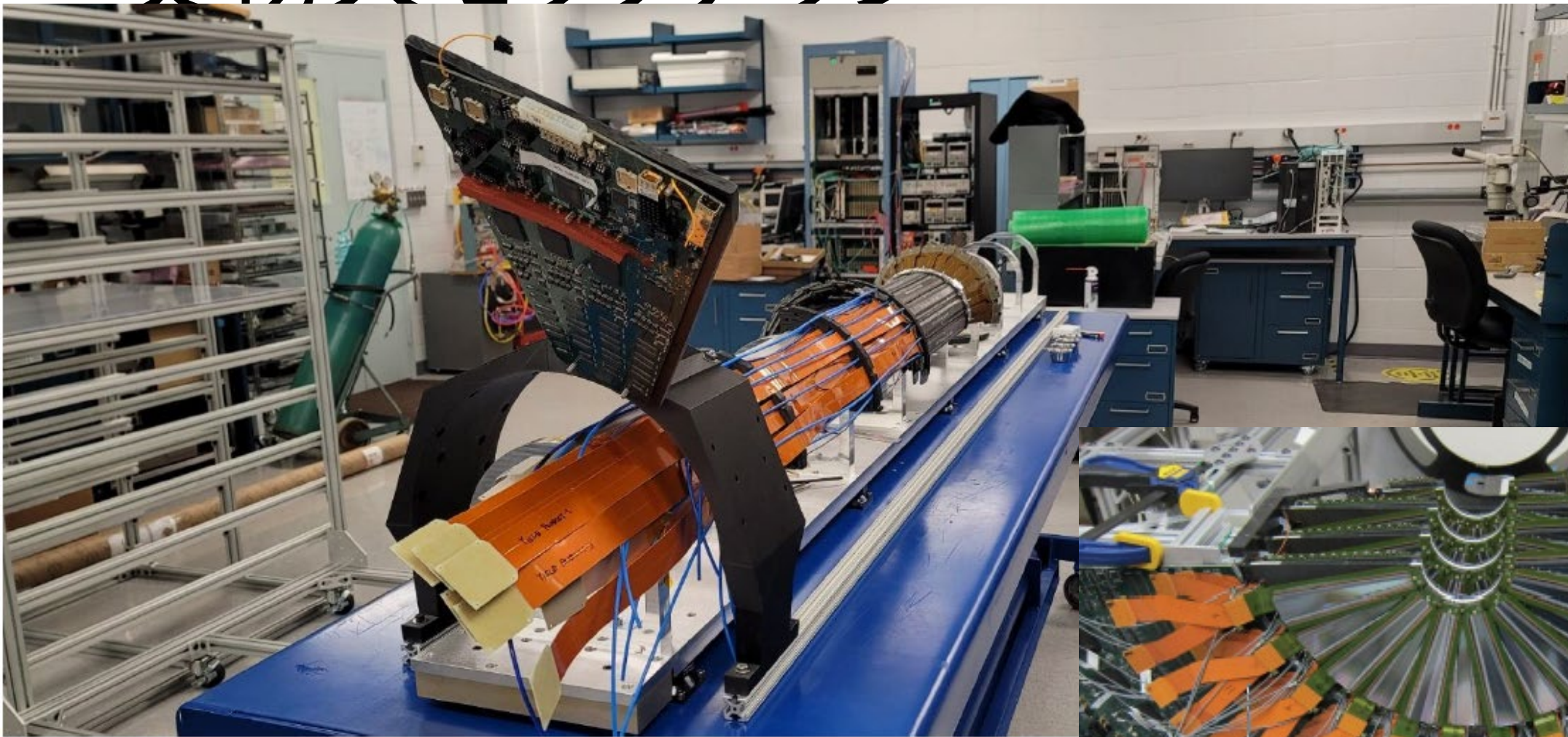
- Barrel assembly is in progress
 - Checking the interfere of the ladders
 - Adjust the length of the bus extender.
 - Optimize the shape of the conversion cable



- Bus-Extender, Long and High Density Flexible Cable, is technically most challenging part on the INTT development.
- Performance of single bus-extender is confirmed to be good for INTT
 - **Signal loss and reflection is ~30% and ~10%**
 - **Enough opening of EYE**
 - **Good mechanical strength for long term stability**
- Yield rate improved
 - **Small dust to be removed**
 - **Another production is running to evaluate the yield rate with new procedure**
- Ready for the mass-production
 - **Final length of the bus-extender under consideration**
 - **Expect to be slightly shorter**
 - **Improve the yield rate.**

- backup

実物大モックアップ

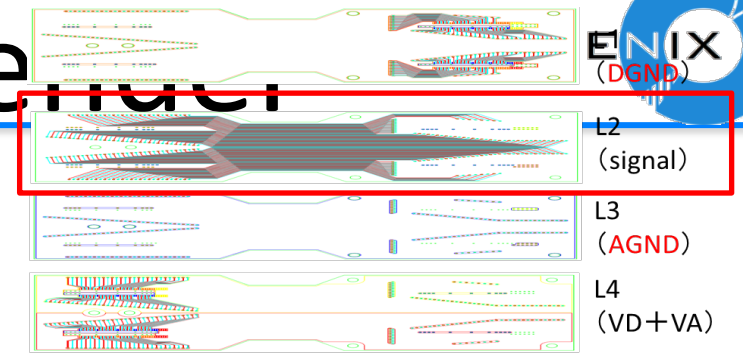


- HDI(実物)、エンドリング(実物), BE(試作・実物)

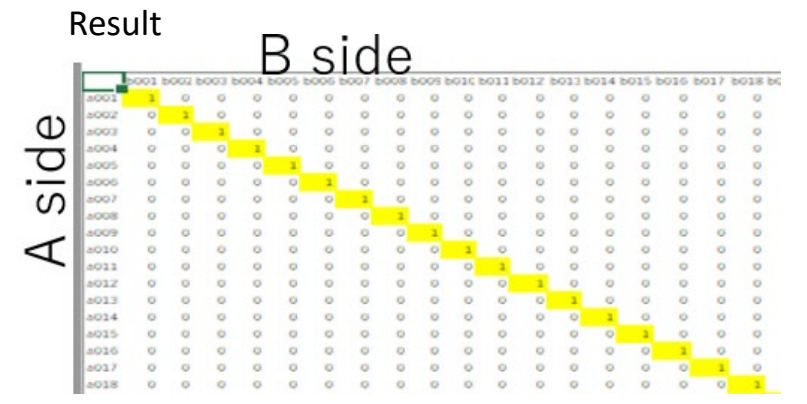
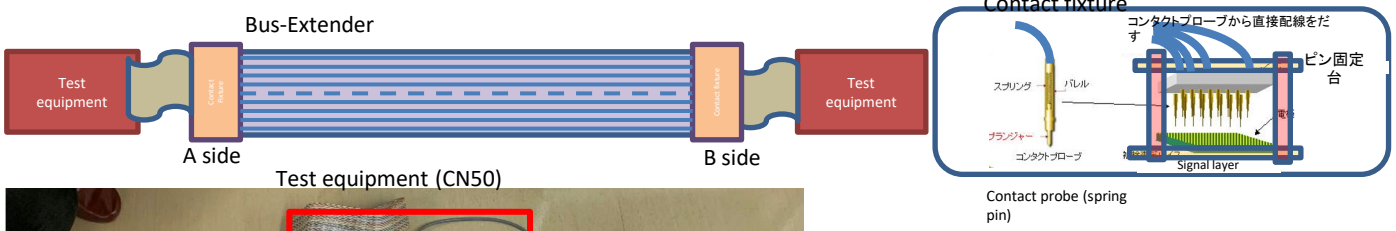
Continuity check of Bus-extender



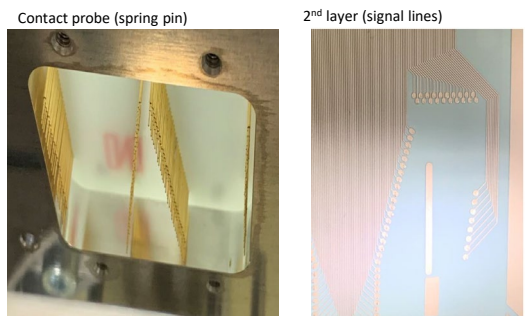
- Yield rate issue
 - Yield rate is low because some signal lines gets short/open.
 - There could be one short/open line per the extender (out of 124 lines)
 - Check the continuity of all signal lines at L2 (signal) layer during the production
- Fixture & test equipment is almost ready to use
 - CN50 : Harness checker
 - Continuity of all signal lines is tested
- This setup will be used



Test setup



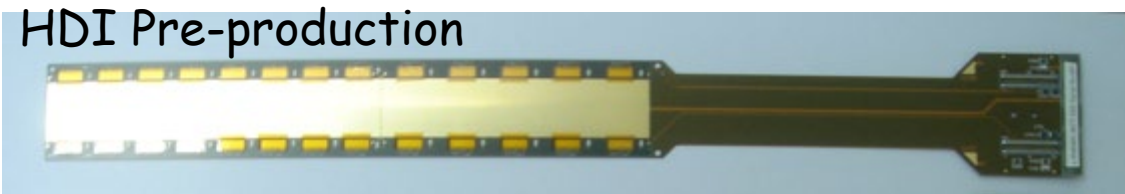
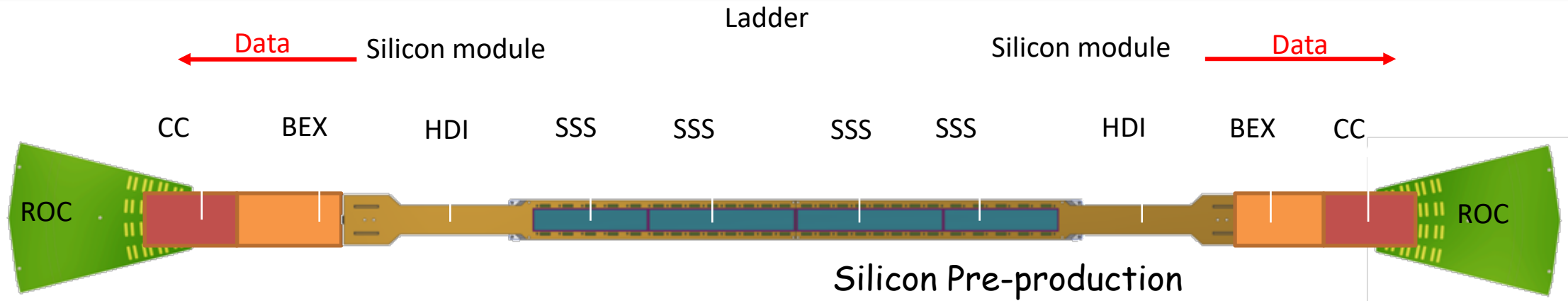
1: connected (short),
0: disconnected(open)



Setup for the produced bus-extender



Executive Summary of INTT Components



Silicon Pre-production



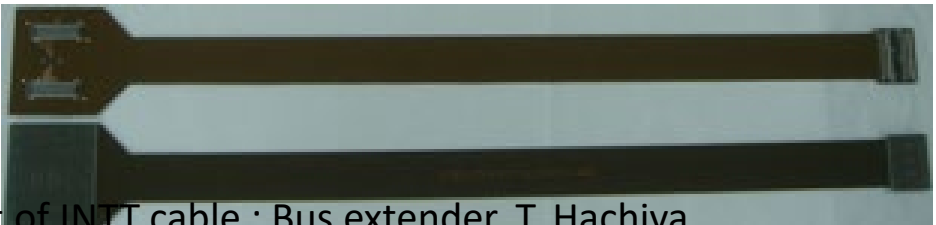
FPHX Production



1.2 m Bus Extender (BEX) Prototype-II



Conversion Cable (CC) Pre-Production



長尺FPCの製造過程



露光

エッチング

積層



露光マスクの配線パターンを
転写(クリーンルーム)

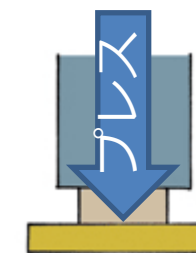


エッチング液のシャワーを通過
不要な銅箔をはがす



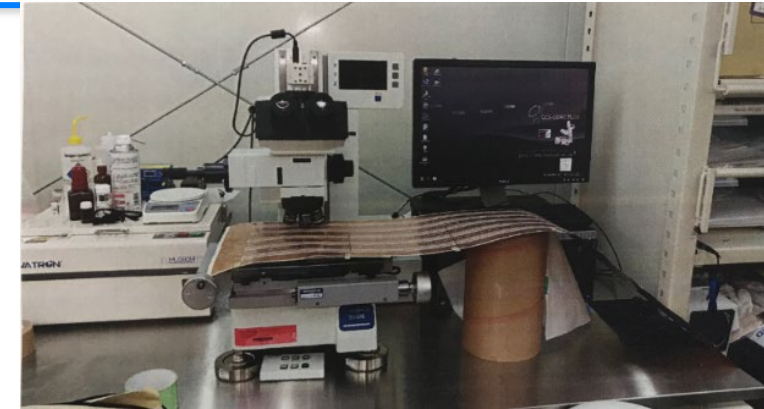
単層FPCを接着剤で
張り合わせる。
高温で圧接する

- 製造装置の限界から長尺FPCの積層は、複数回に分けてプレスする
 - 一度のプレスで50cm程度。 3回プレスが必要。
 - プレス間の区切れ目が信号伝送に影響するか？



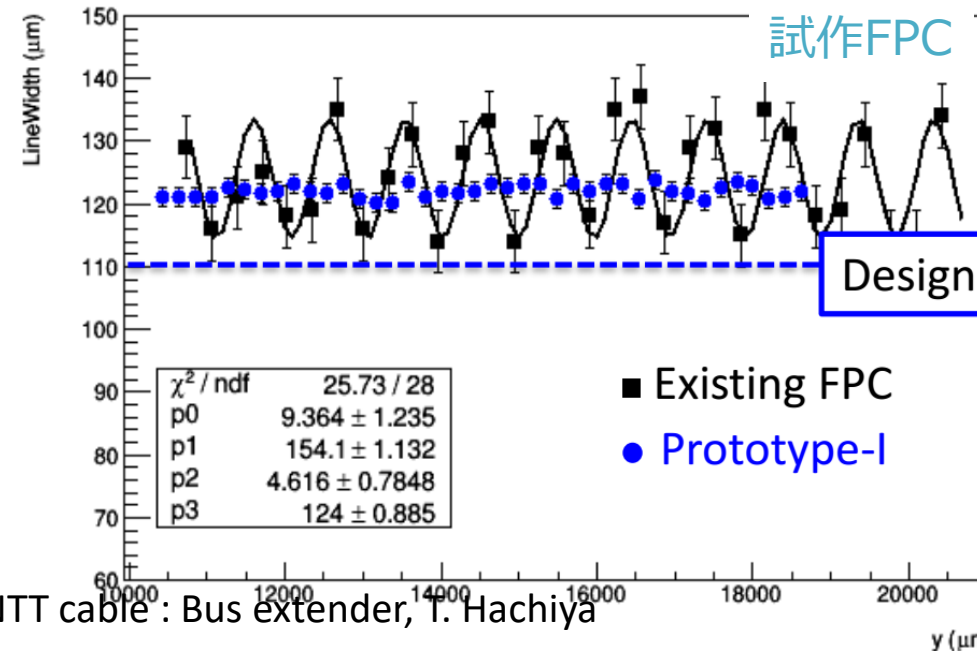
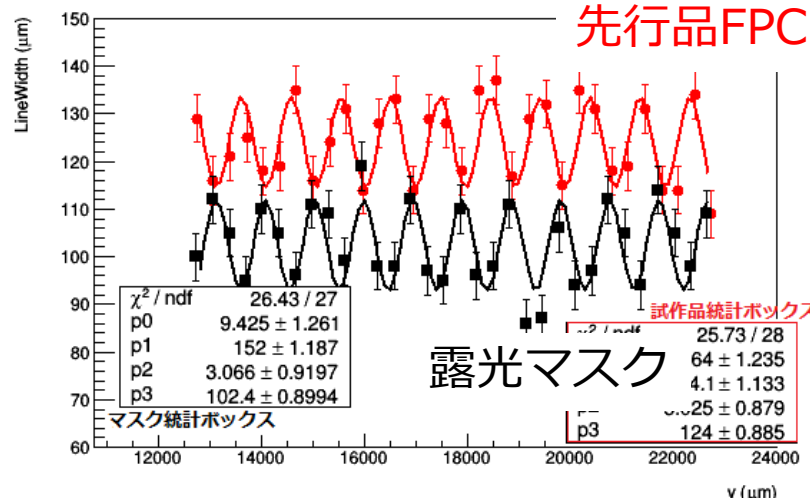
製造特性の測定

- 均一な高密度配線技術の検証
 - 従来の製造限界を超える微細加工
 - 100umの配線での歩留り向上
- 従来品にあった問題を解決
 - 露光マスクの製作精度が原因
 - マスクプリンタを変更することで改善した

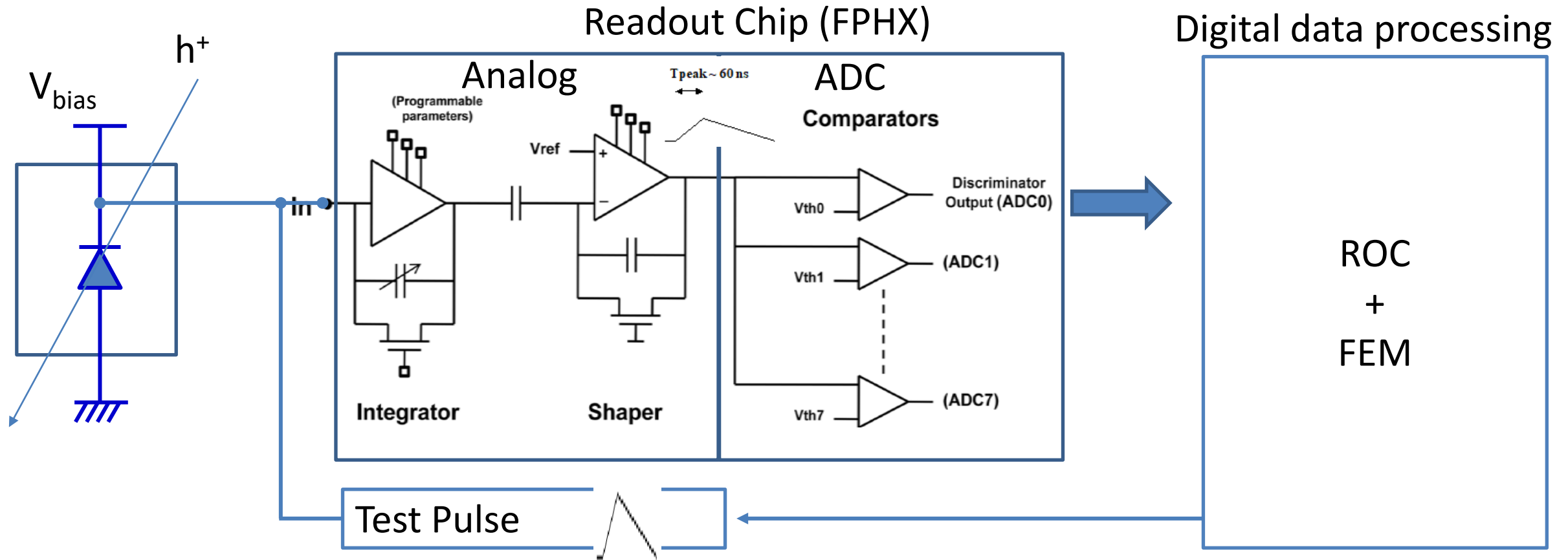


新マスクによる改善後：配線精度±3um

従来品の配線精度±15um



Sensor + Readout Schematics



- Performance is studied using:
 - Charged particle by beam test, cosmic ray and RI sources
 - Test pulse for Readout electronics

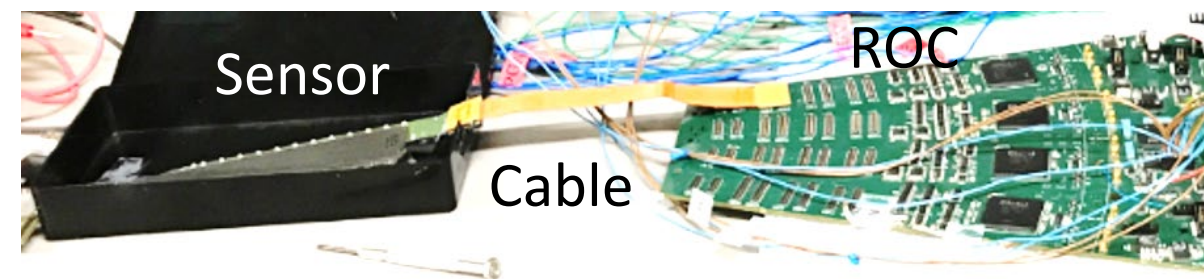
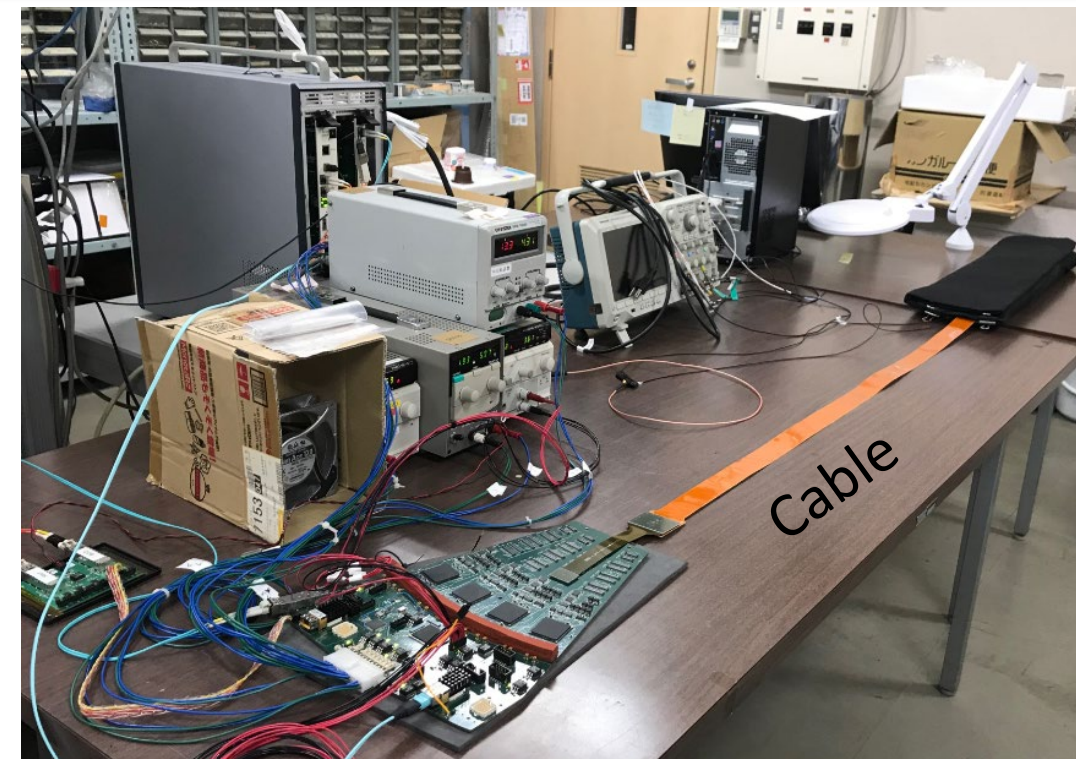
Bus-Extender = Very long data

cable

- Use the same technology with FVTX: FPC
- Status
 - Design completed
 - Prototype tested at FNAL beam test
 - Performance looks OK
- Issues
 - Remain in the production

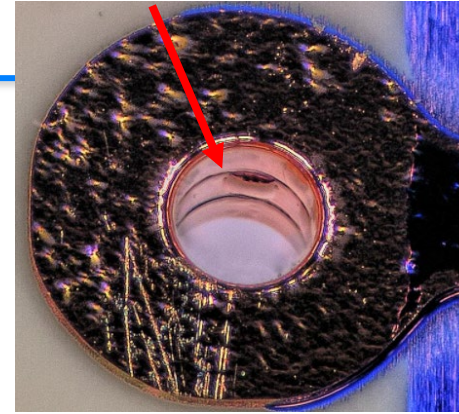
	FVTX	INTT
Length	10~30 cm	120cm
Layer	7	4
Signal	62 pairs (LVDS)	62 pairs
Power	V-a, V-d, GND	V-a, V-d, GND
Substrate	Polyimide	LCP

Impe There are some remaining issues

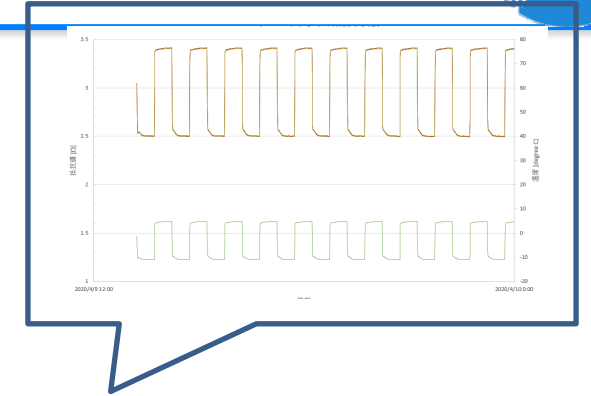


Through hole issue

Small bump with new glue



Resistance is changing with temperature

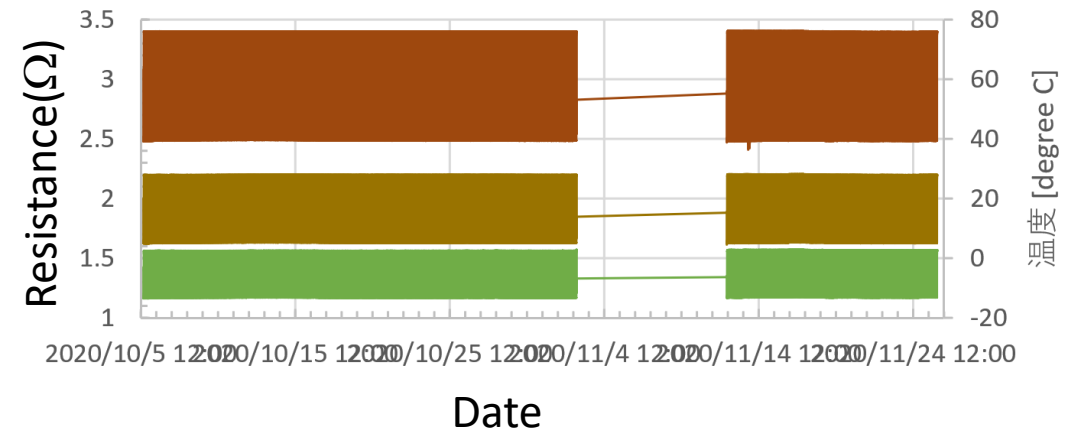


- Issue:
 - Through hole issue was once fixed with new glue
 - Nodules and cracks with previous glue were disappeared
 - We recently found there are small bump with new glue
 - The cross section of the hole shows that LCP pushes the surface
 - To confirm if it is OK or not, we performed the thermal shock test again

Thermal shock test (same as before)

- Setup
 - -15 (30min.) ~ 75°C (30min.) with 1~2min. transition.
 - 1000 cycles (40 days)
 - Monitor the resistance of the through holes where 400, 600, 1000 holes are daisy chained respectively
- Result:
 - All chains are healthy after 1000 cycles.
 - No change by the visual inspection before and after the test

Thermal shock test result



Visual inspection of the hole

