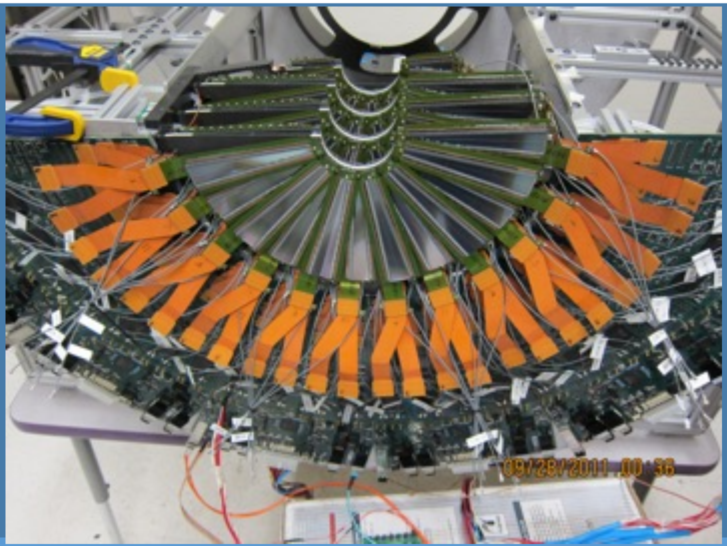
Development of INTT Conversion Cable Using μ-Coaxial Cable Technology

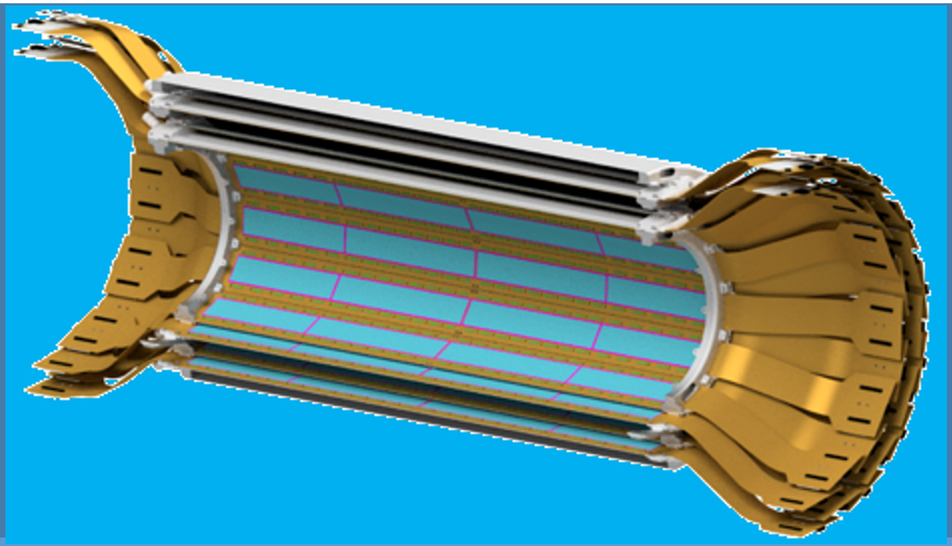
RIKEN/RBRC
Itaru Nakagawa
for INTT Team

FVTX



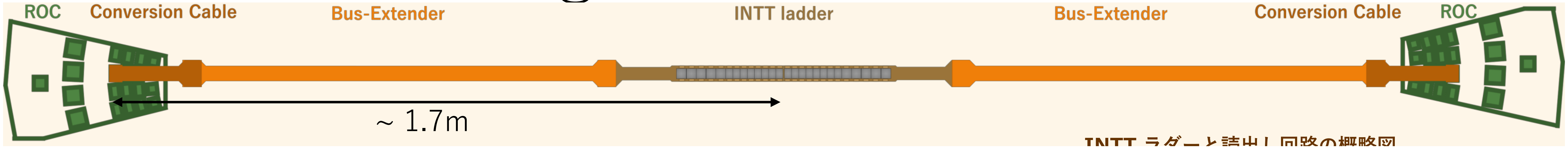
- **Disk Type**
- 4 Layers
- Silicon Strip Sensors
- 1M Channels
- FPHX Readout Chip
- FPHX-ROC-FEM-DCM-II

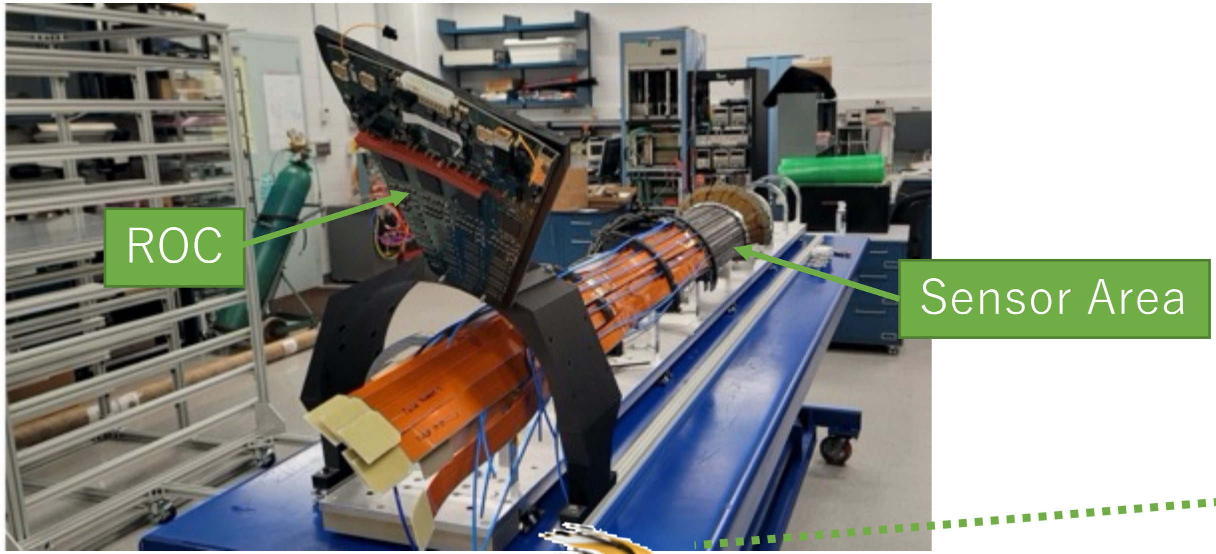
INTT



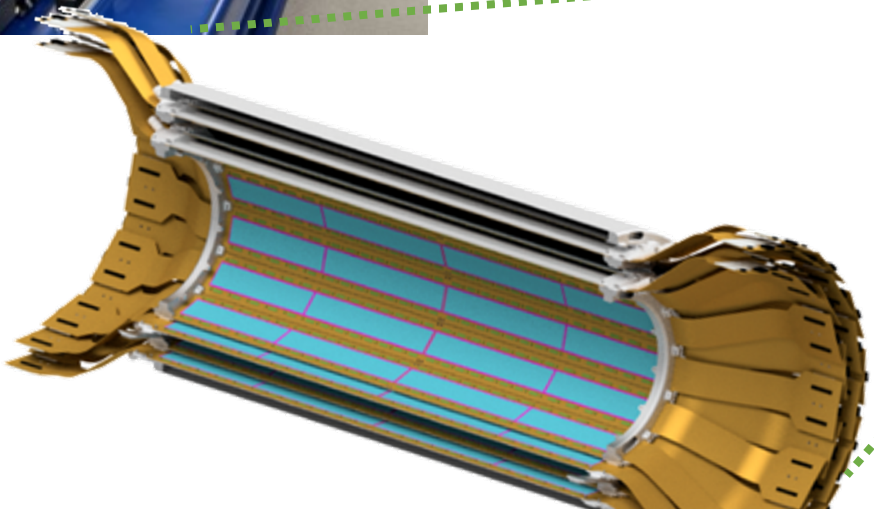
- **Barrel Type**
- 2 layers
- Silicon Strip Sensors
- 37k channels
- FPHX Readout Chip
- FPHX-ROC-FELIX

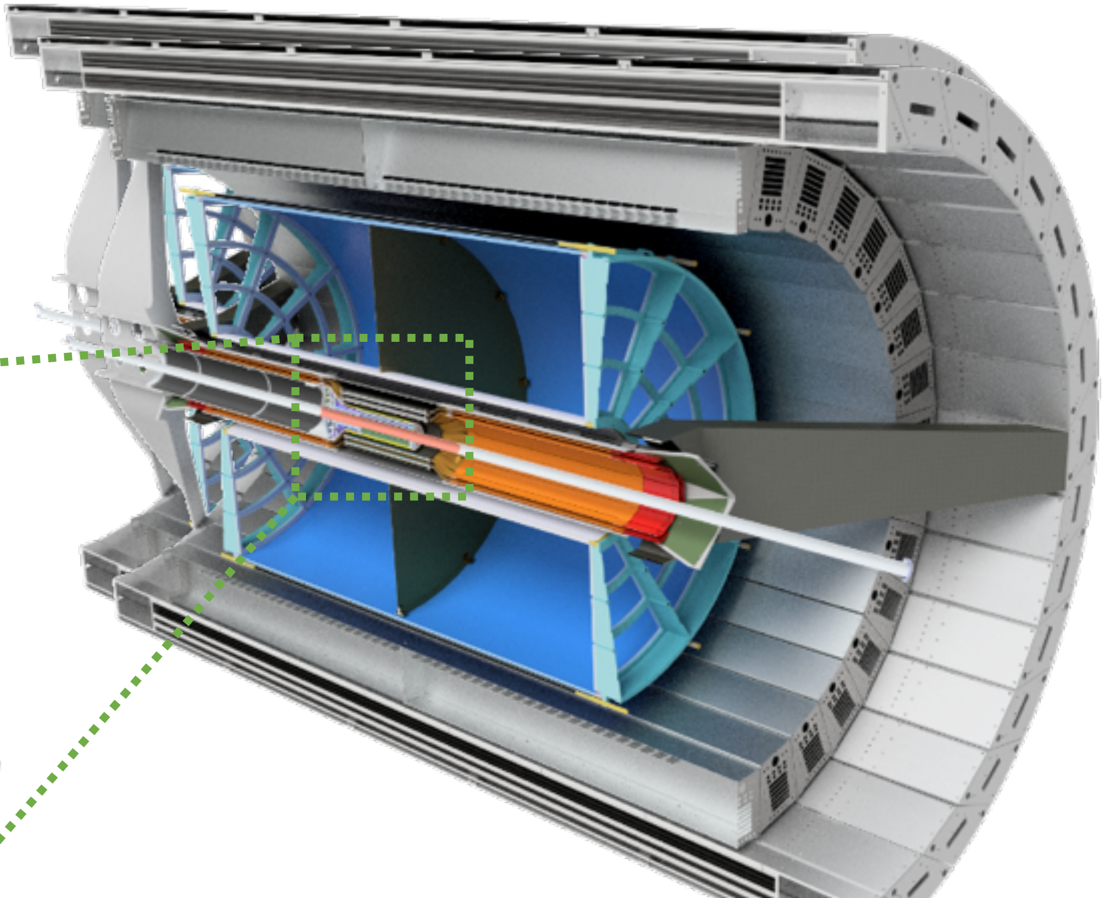
Technical Challenge ~ INTT Readout Cable ~



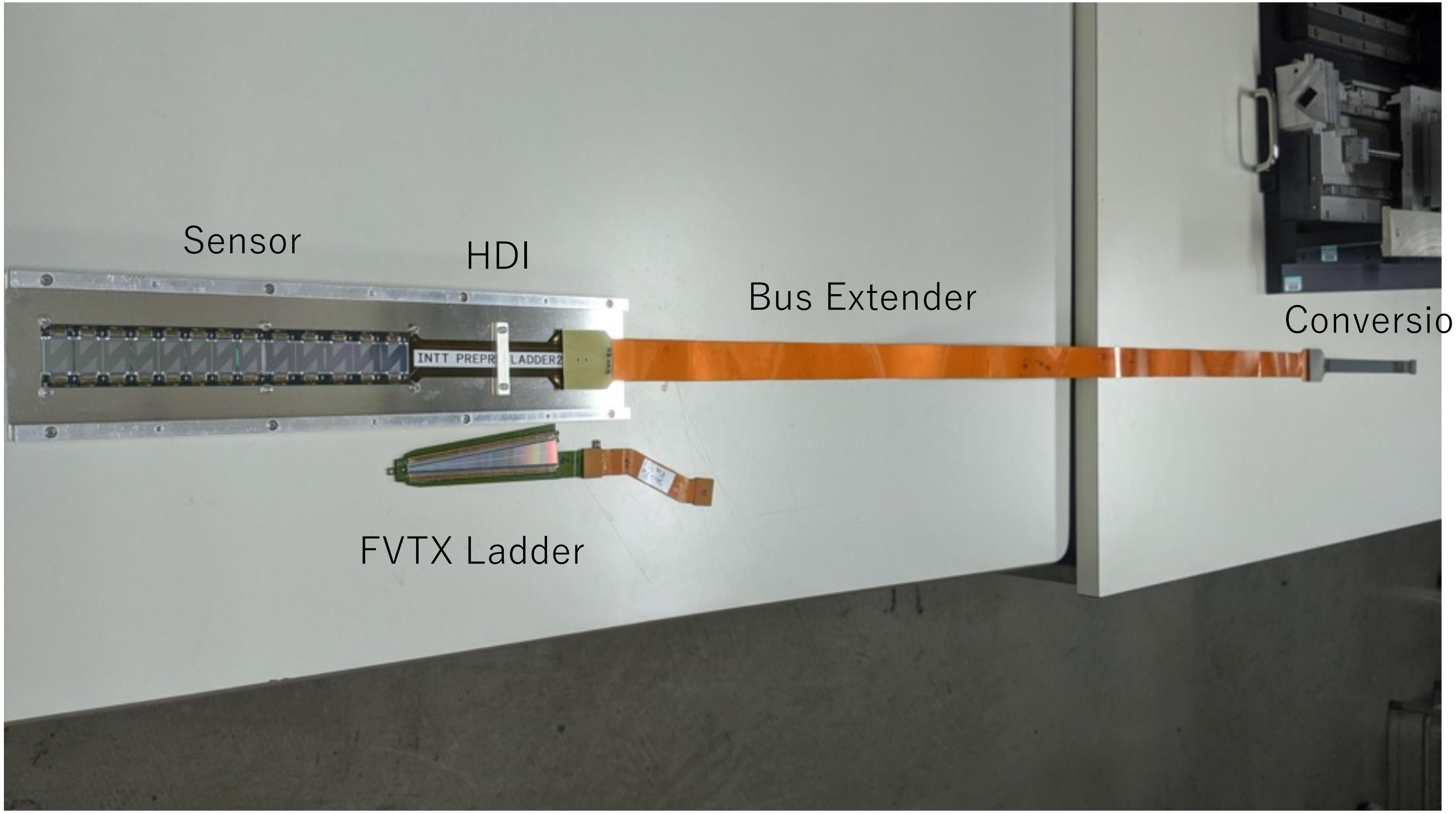


INTT Barrel Mock-Up

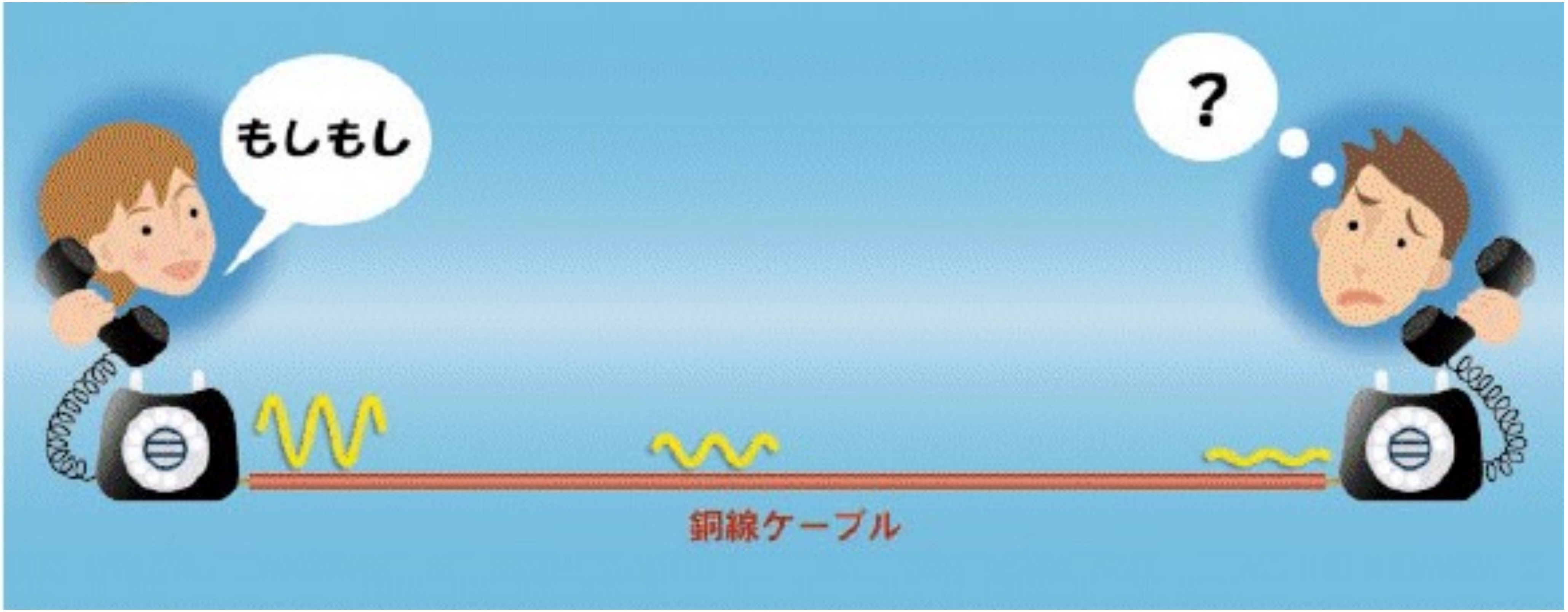




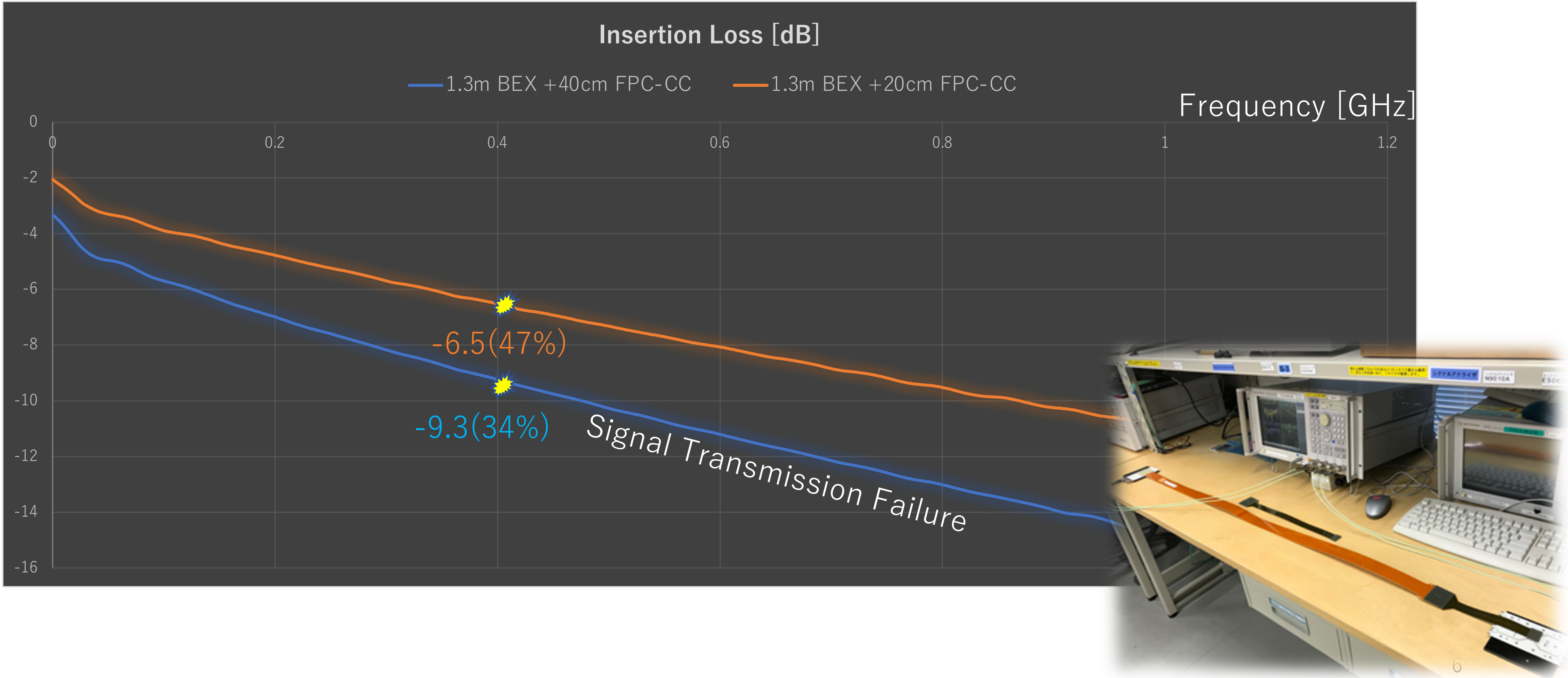
INTT Readout Cable Chain



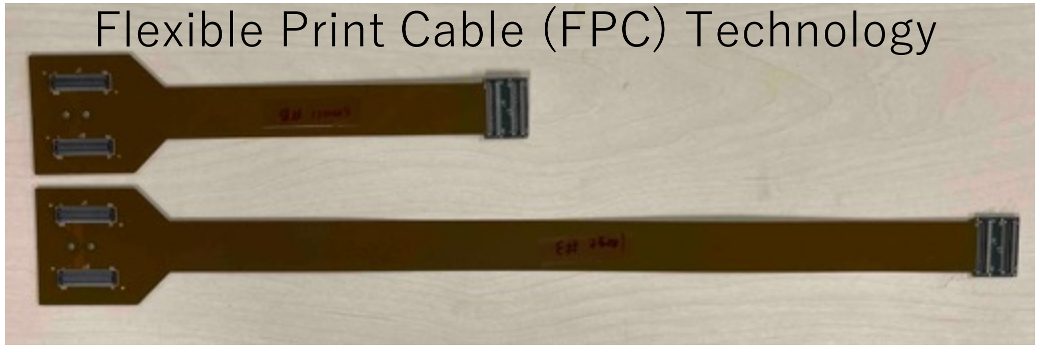
Signal Transmission Performance



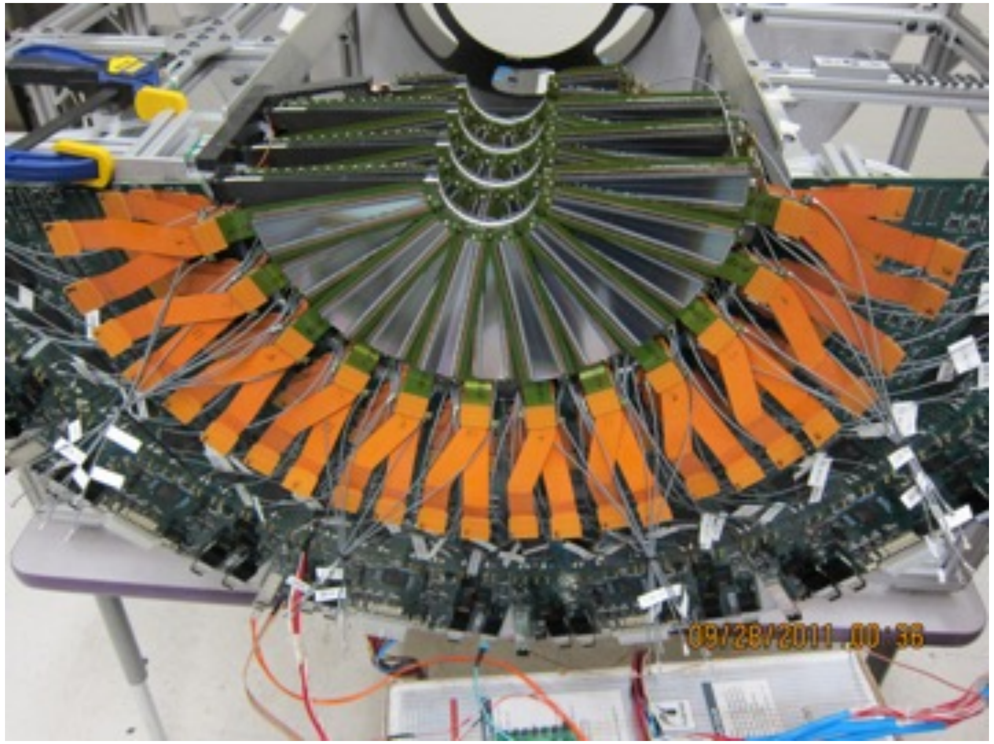
Insertion Loss Limit

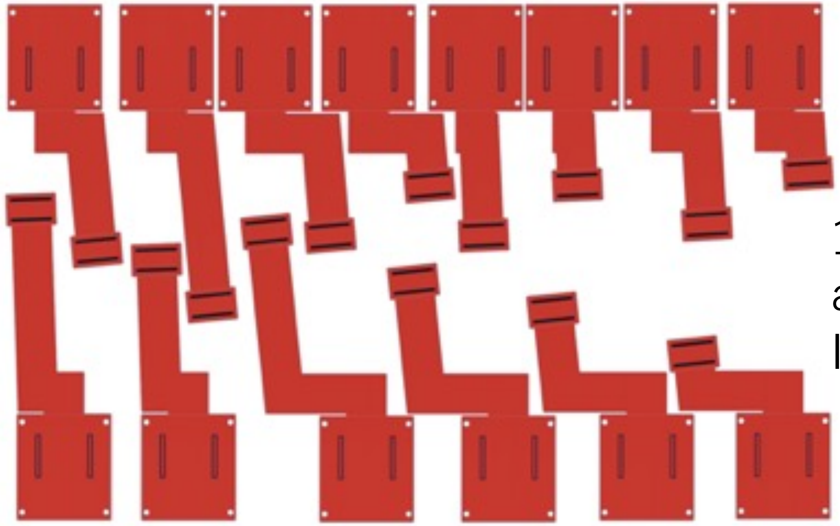


Conversion Cable using FPC Technology

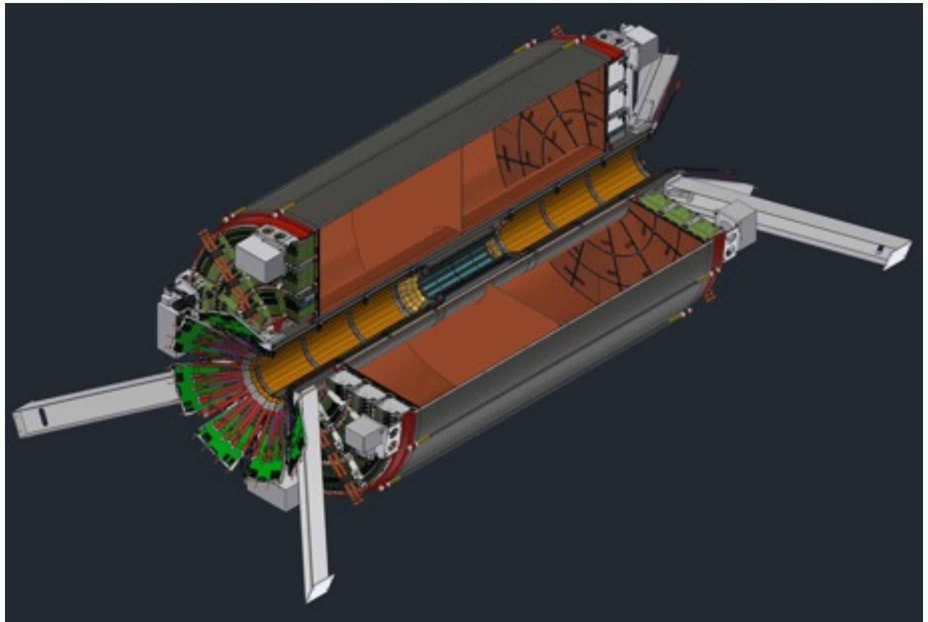


FVTX



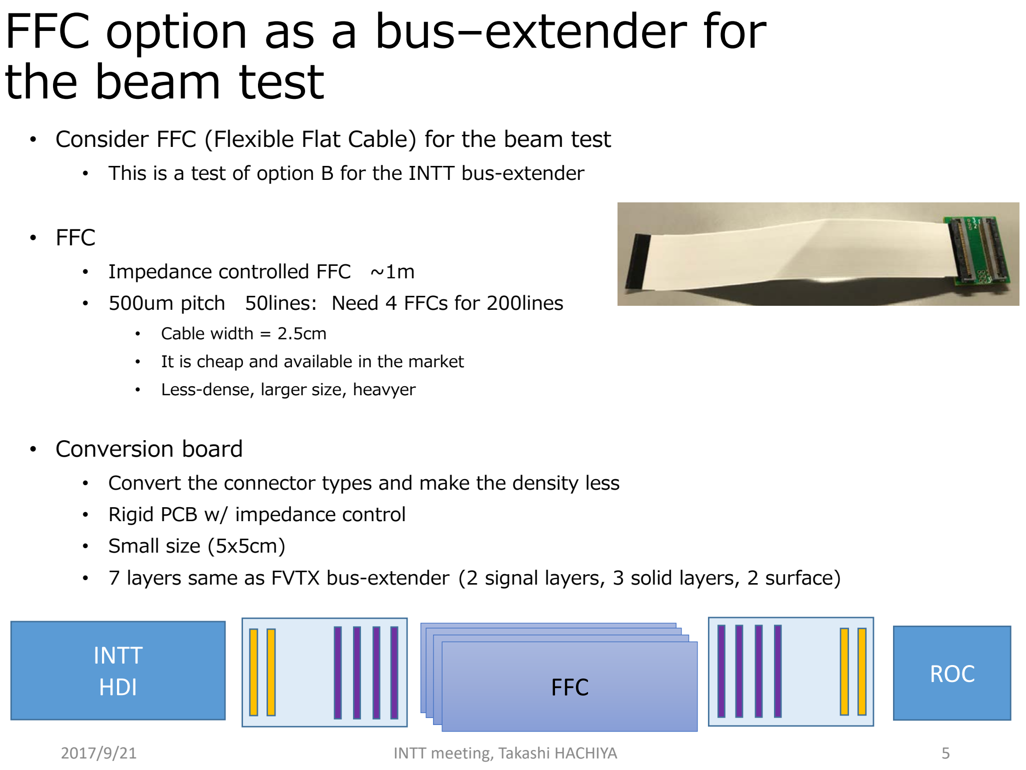


14 Different Types are required for INTT



Risky in many sense f.i. cost, spares, mis-design, etc.

Technology Choices

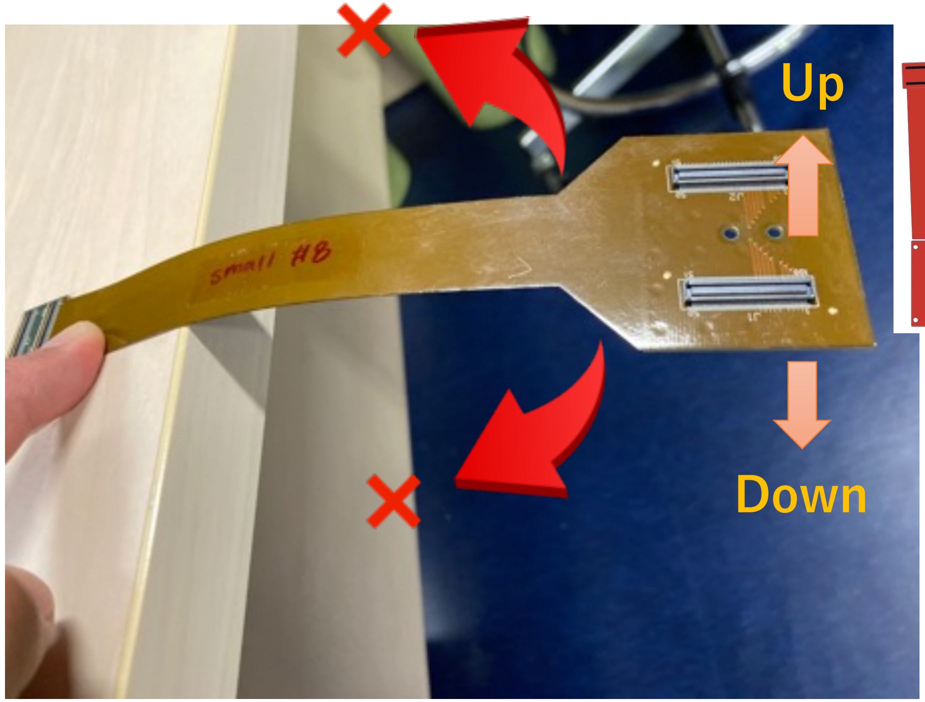


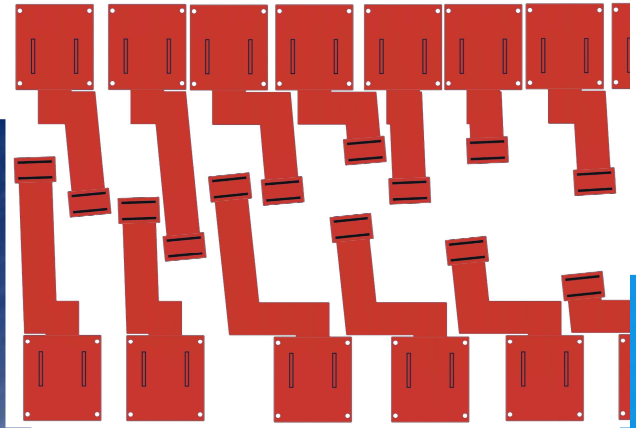
1. Flexible Print Cable (FPC)
2. Flat Flexible Cable (FFC)
3. Micro-Coaxial Cable (MCC)

	FPC	FFC	MCC
Line Pitch [um]	60	500	250
Shield	Shielded	Not Shielded	Shielded
Flexibility	2D	2D	3D

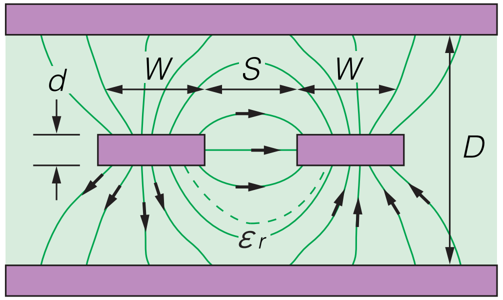
Advantage in the flexibility

😰 No flexibility in left/right resulted in multiple different designs → 2 D flexibility





Micro-coaxial cable

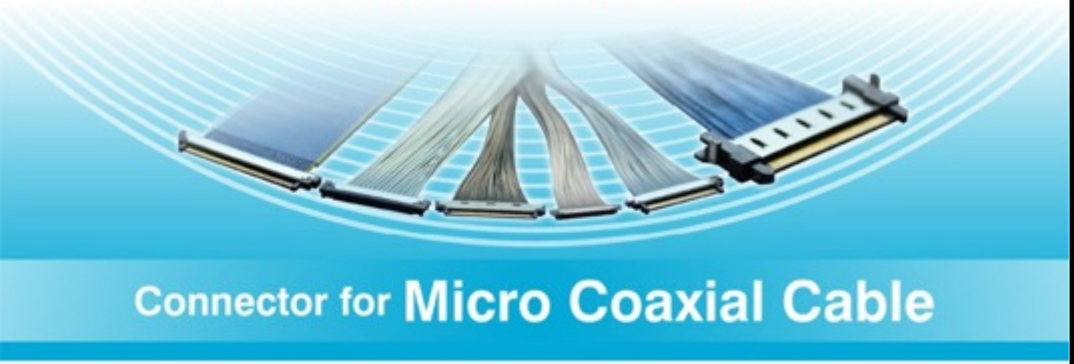


😀 Flexible in 3 dimensions and thus only 1 simple design cable can connect any ROC port. → 3D flexibility
😀 All cables can be made in 1 single length.

Micro-Coaxial Cable

KEL CORPORATION

Industry-leading small and thin connectors

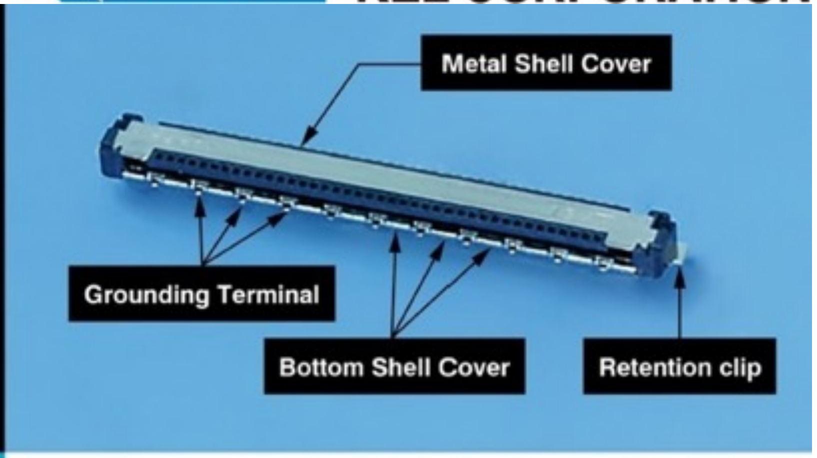


- Down sizing
- Anti-noise measures
- Reliability
- Flexibility
- Twist durability

This series of connectors provide best solution for those who face some challenges in downsizing, anti-noise measures, and reliability, as well as those seeking for a cable with superior flexibility and twist durability.

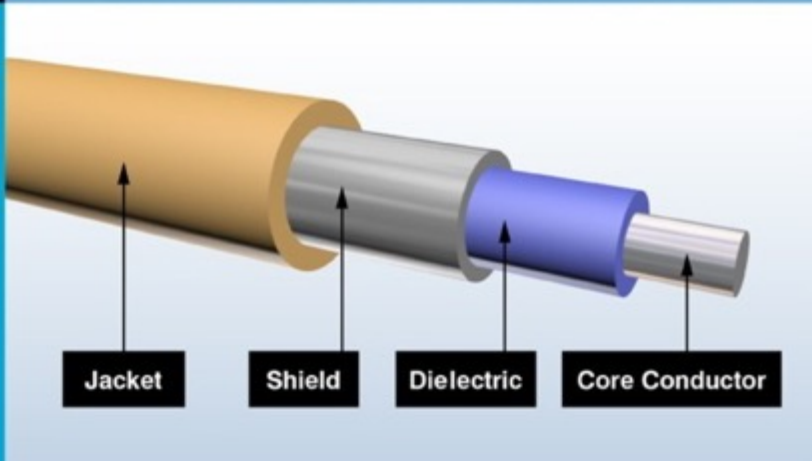
Grounding of PCB Side Connectors

Each series also provided with a ground terminal, metal shell cover and the bottom shell cover is has become a form surrounding the connector, we have to ensure the noise measures and product strength.



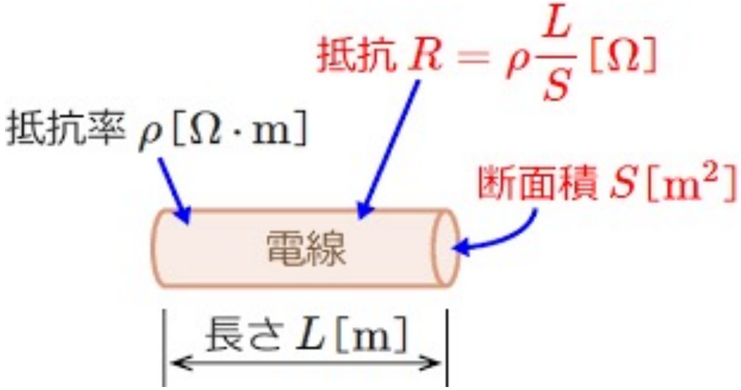
Micro Coaxial Cable Structure

In spite of the extremely thin cable, one by one has become in coaxial structure, and excellent transmission characteristics. Has a high flexibility and twist durability, repeated bending, is the cable that was blessed with strong features to twisting.

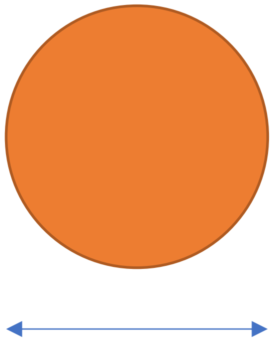


https://www.kel.jp/feature/coaxial_lp_1

Potential Risk?



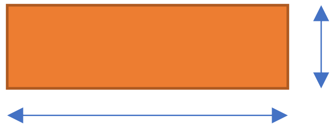
- Coaxial Cable



40 ~ 50 μm

Cross section S =1256 ~ 1962 μm²

- FPC



9 μm

60 μm

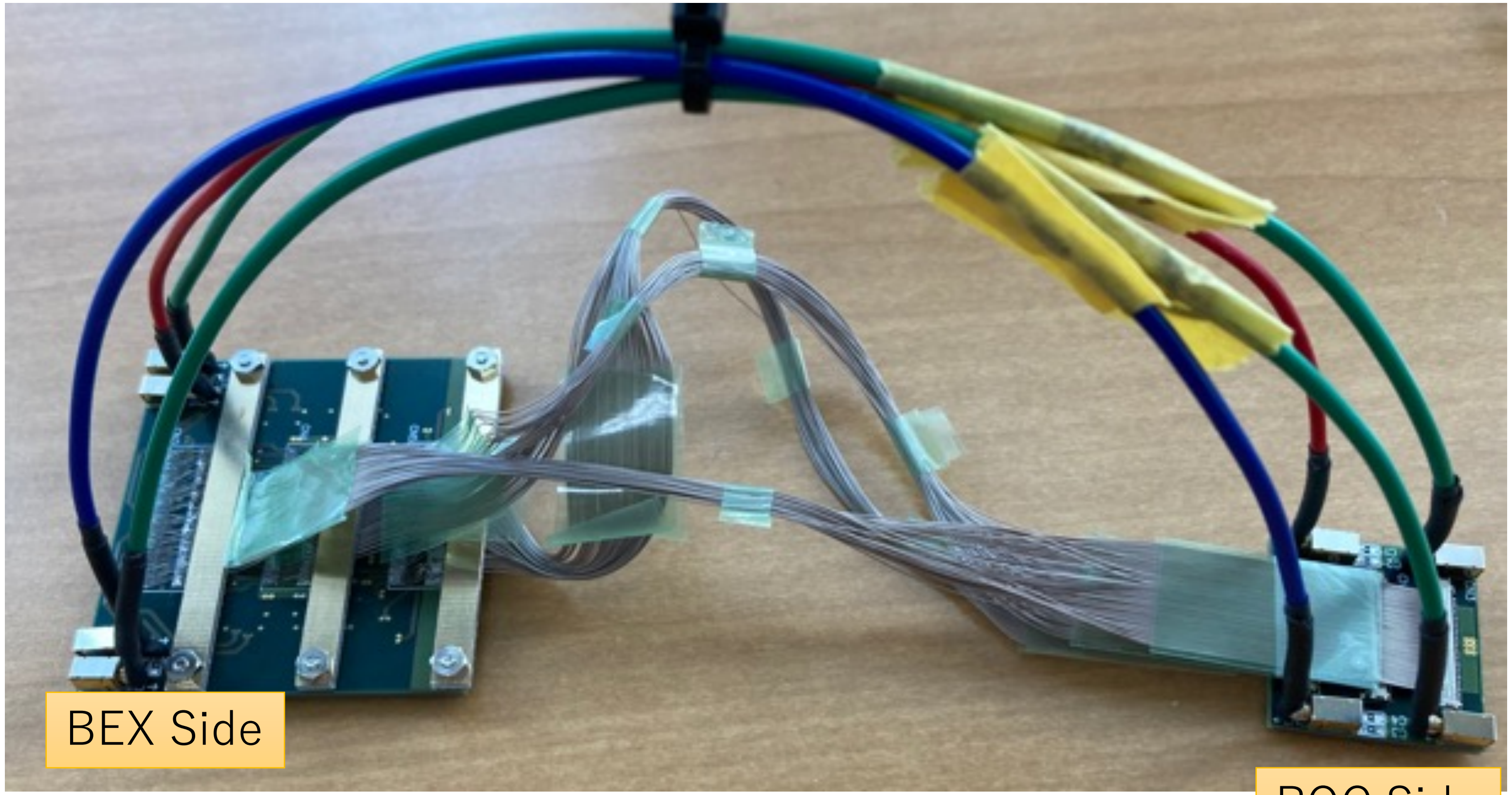
Cross section S =540 μm²

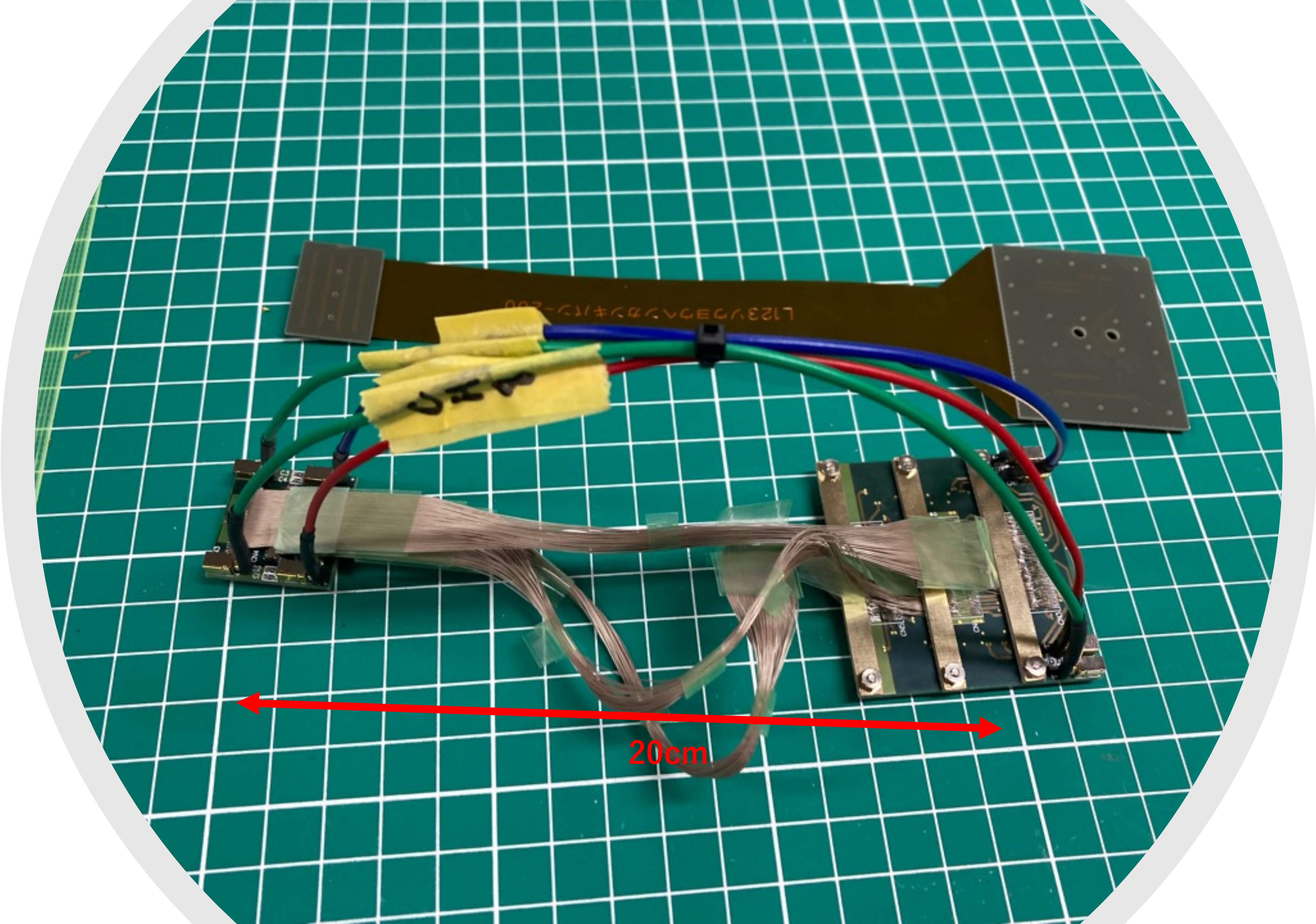
Factor of 2 to 3 larger cross section compared to FPC. Things are not complicated, but the signal attenuation can be expected to be relaxed intuitively.

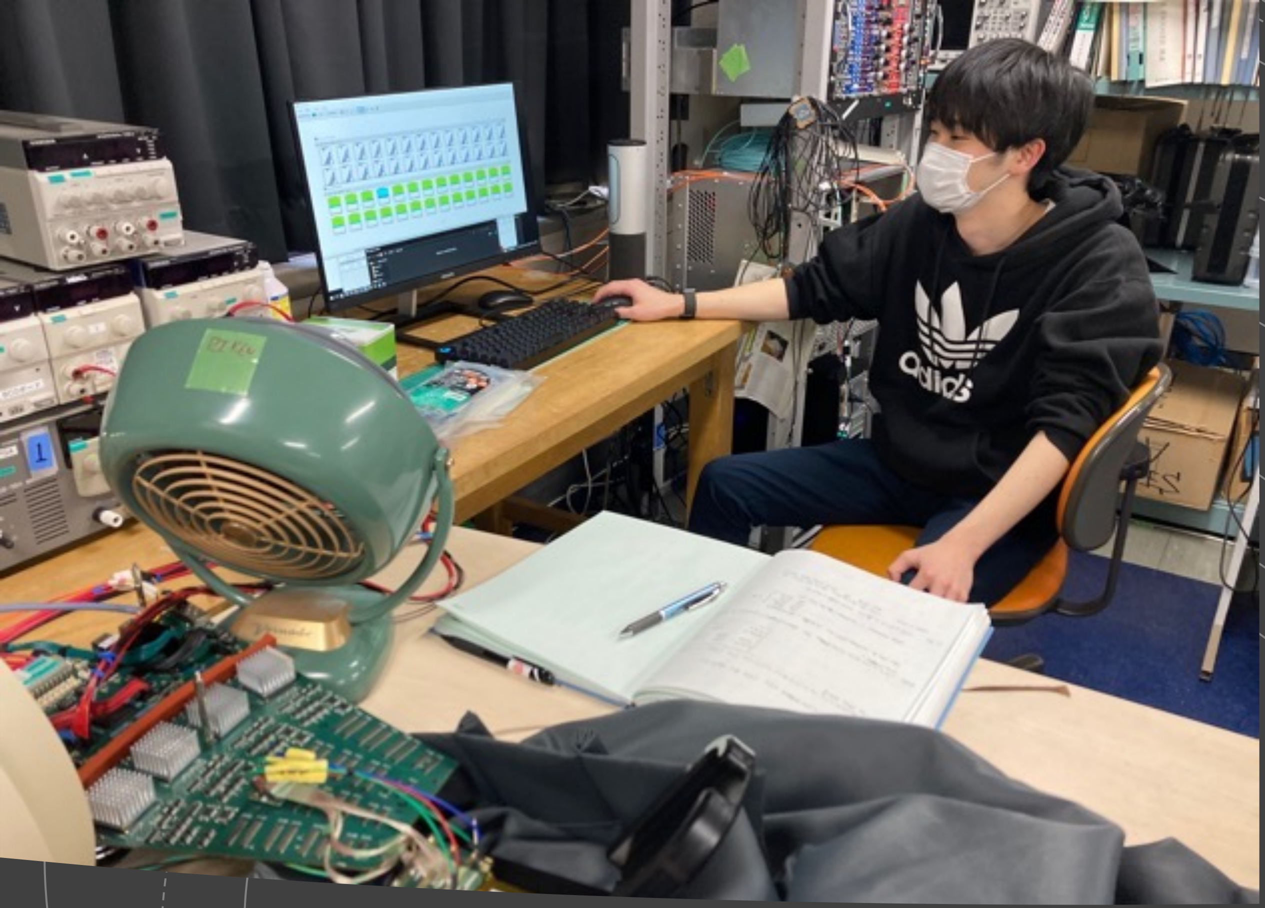
m-Coax Conversion Cable Protoype-I

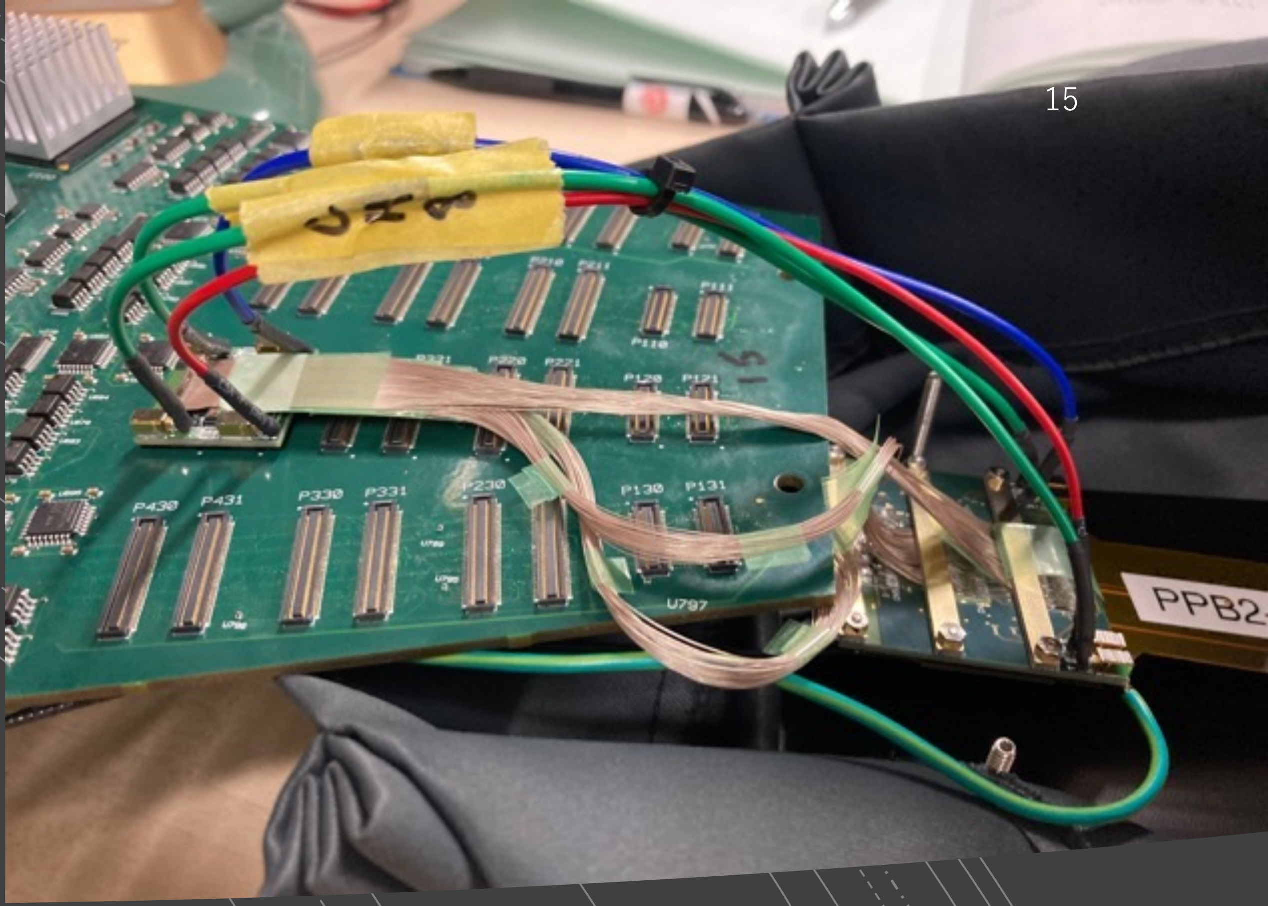
Delivered in December, 2021

μ-Coax Conversion Cable Prototype-I




20cm

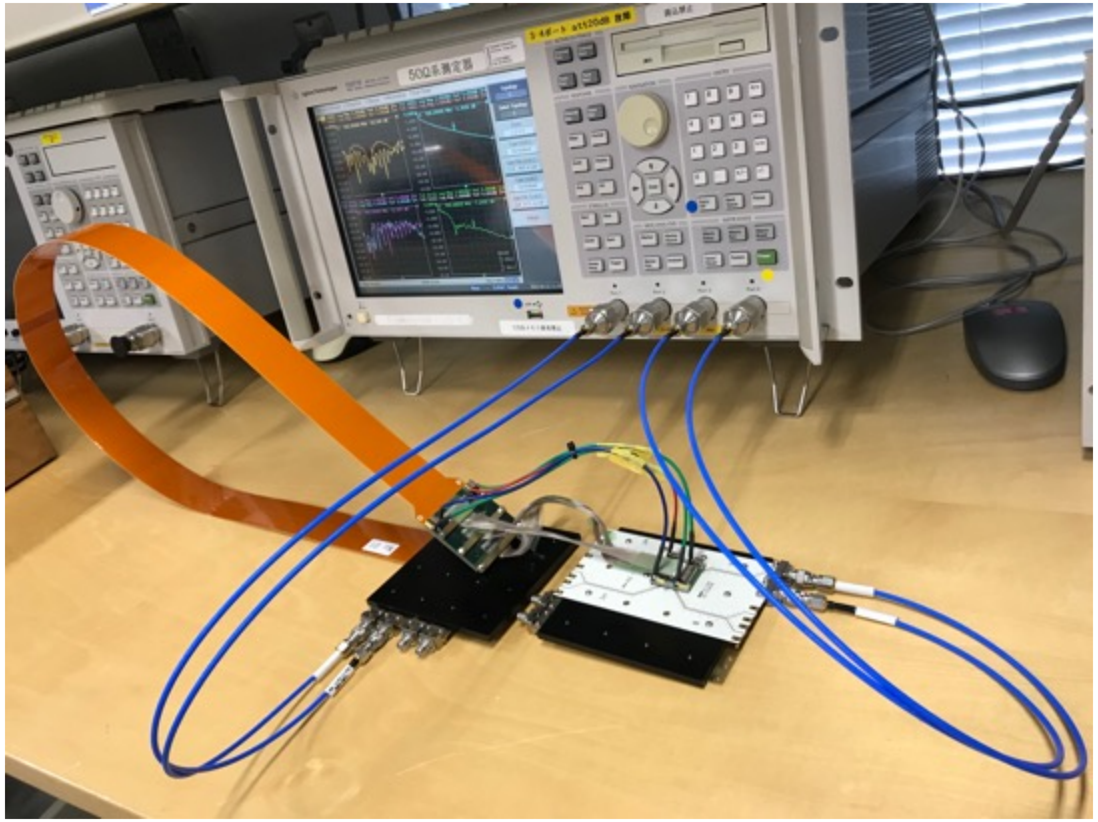




Performance Check

- After some iteration between Hayashi-REPIC to fix mixed up channels, we confirmed satisfactory data taking.

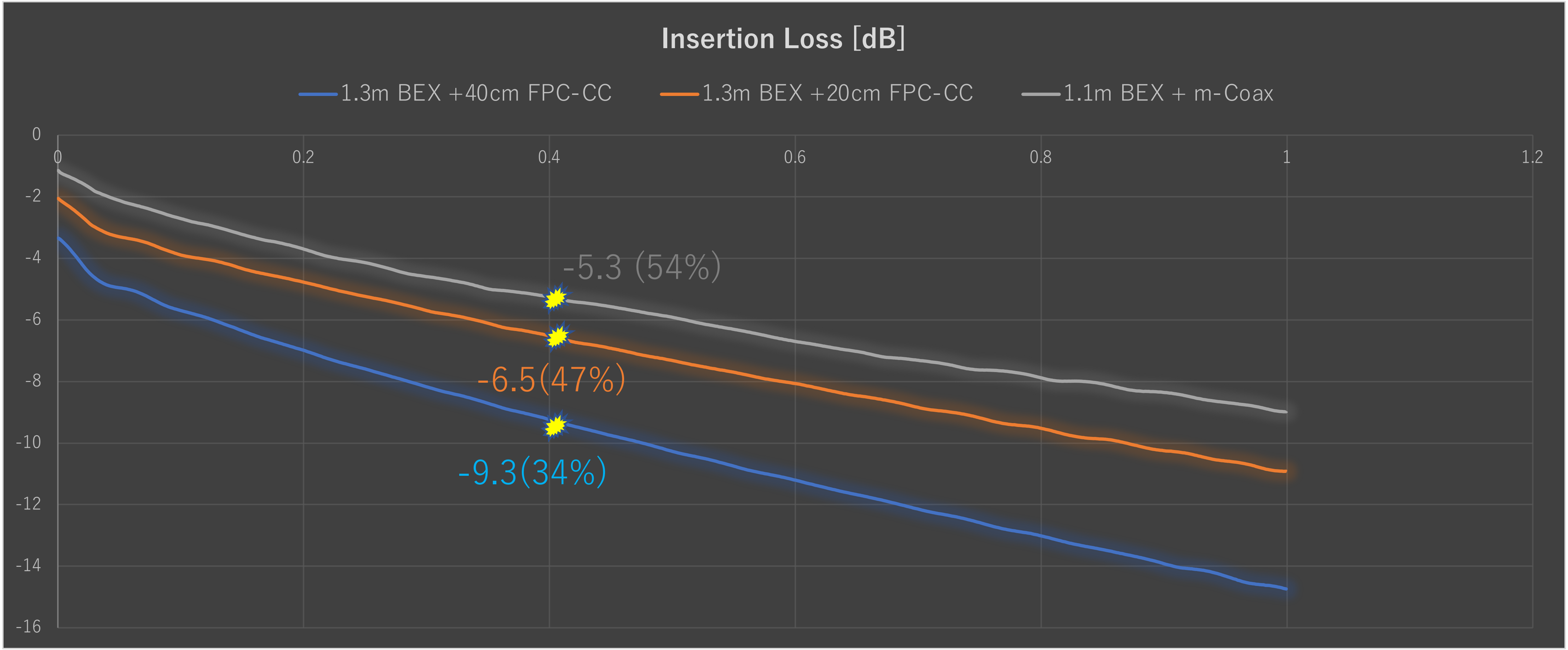
Bus Extender + Conversion Cable Chain



2021/8/4
1.3m Bus Extender + FPC Conversion Cable

2022/2/21
1.1m Bus Extender + μ-Coax Conversion Cable

Insertion Loss

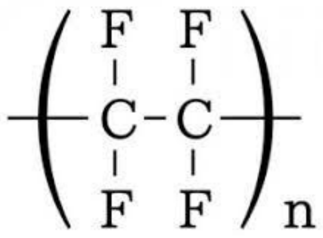


OK, the insertion loss is moderate than FPC as intuitively expected.

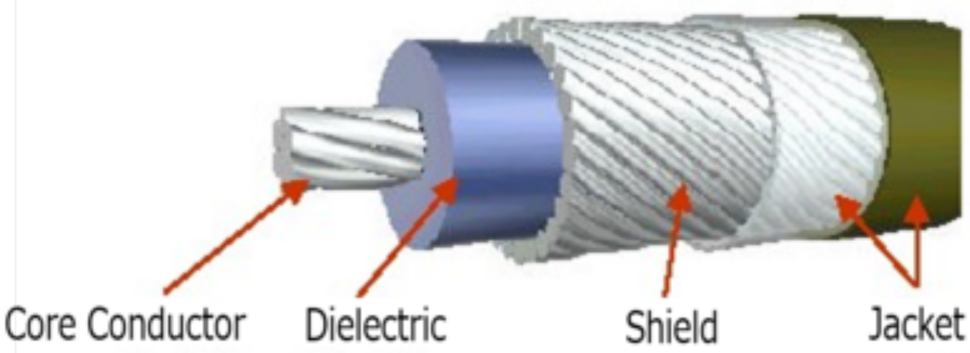
μ–Coax Cable Structure and Material

2. Construction and material　Material Breakdown of micro-Coax

Item		Unit	Specified Value
Inner conductor	Material	-	Silver plated Copper Alloy wire
	AWG size	-	44
	Stranding	No./mm	7/0.02
	Dia.(approx.)	mm	0.06
Insulation	Material	-	PFA
	Thick.(nom.)	mm	0.037
	Dia. (approx.)	mm	0.134
	Color	-	Black
Outer Conductor	Material	-	Tinned copper alloy wire
	Type	-	Wrap(Right-hand lay)
	Strand Dia. (approx.)	mm	0.02
Jacket	Material	-	PFA
	Thick.(nom.)	mm	0.025
	Dia. (Max.)	mm	0.22(0.23)
	Color	-	Brown , Green



PTFE 化学式

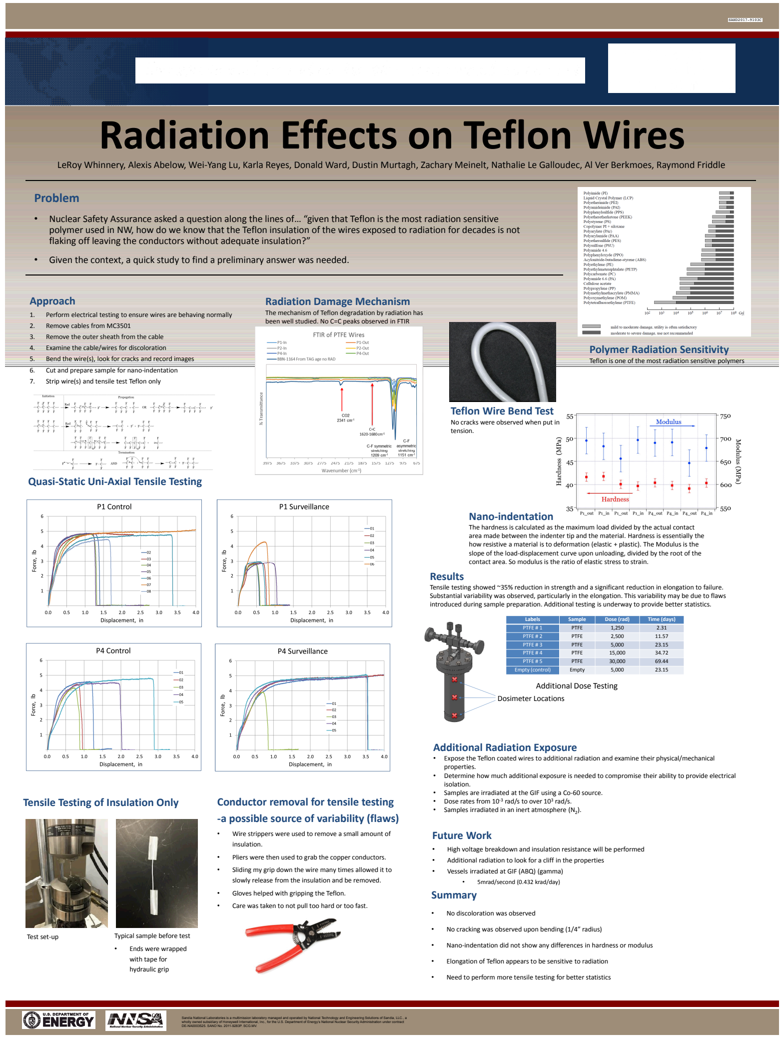


PFA（フッ素樹脂）=**パーフルオロアルコキシアルカン**
四フッ化エチレン・パーフルオロアルコキシエチレン共重合樹脂

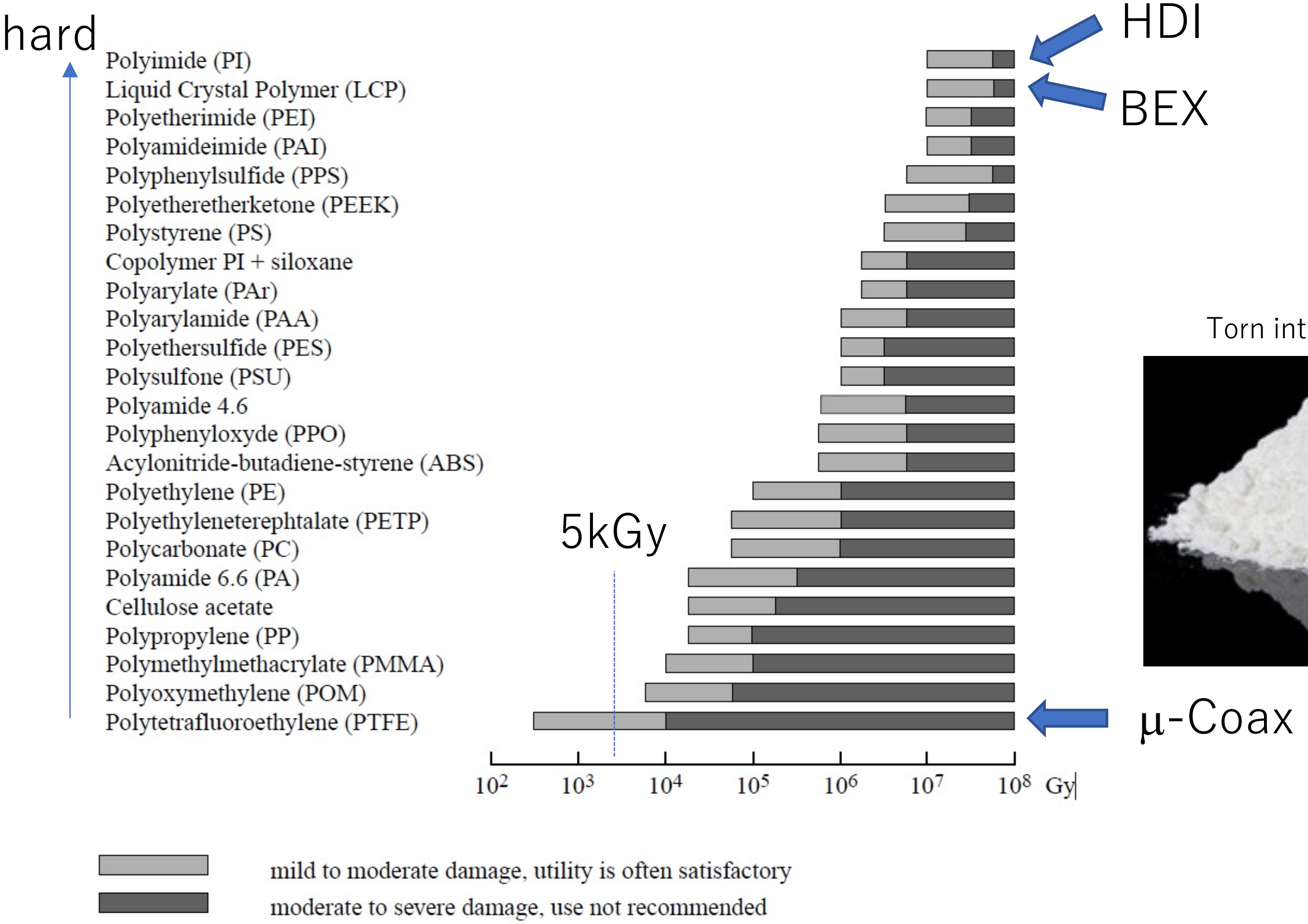
http://www.diced.jp/~KAZU/syousya.txt.htm

Radiation Hardness of Fluoropolymer

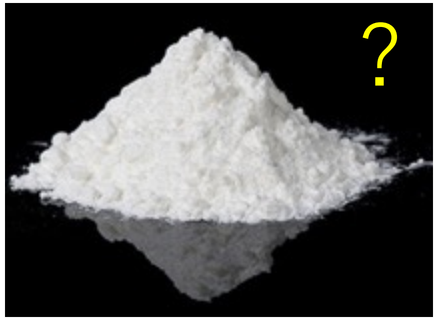
https://www.osti.gov/servlets/purl/1467983



Dielectric material



Torn into pieces?

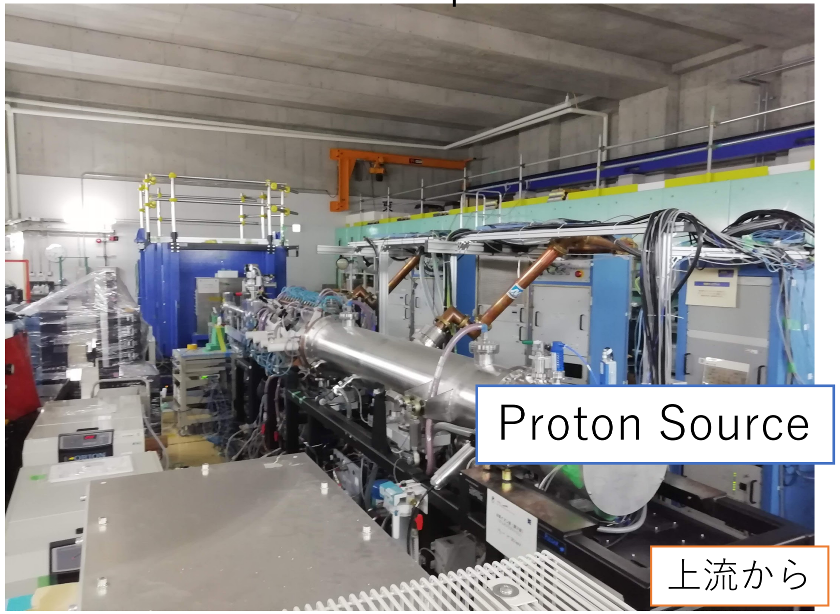


In general, fluoropolymer is known to to be weak against the radiation

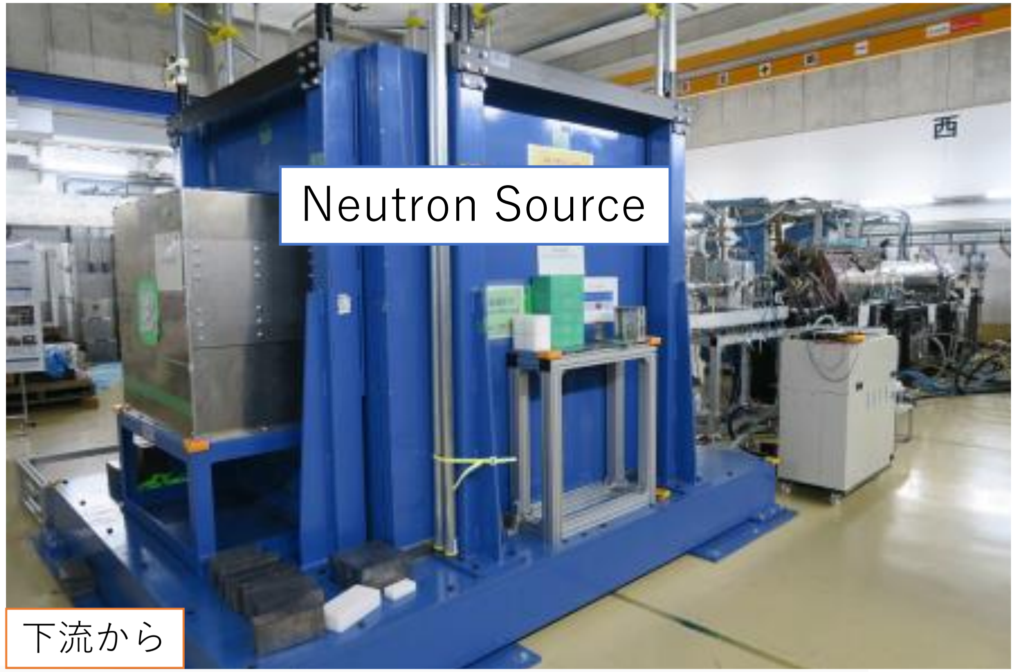
Radiation Test of μ-Coax

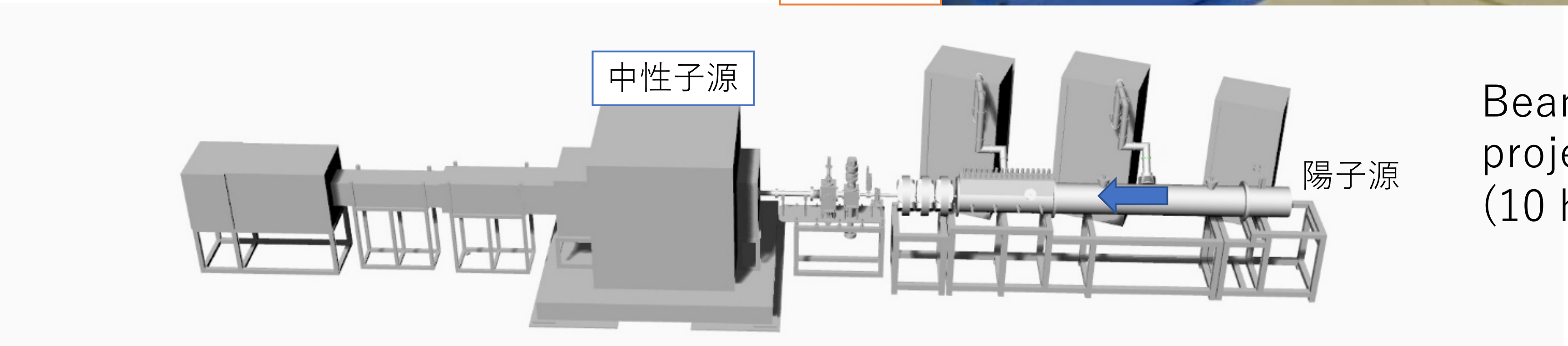
RIKEN Accelerator-driven compact Neutron Source: RANS

View from Upstream



View from Downstream

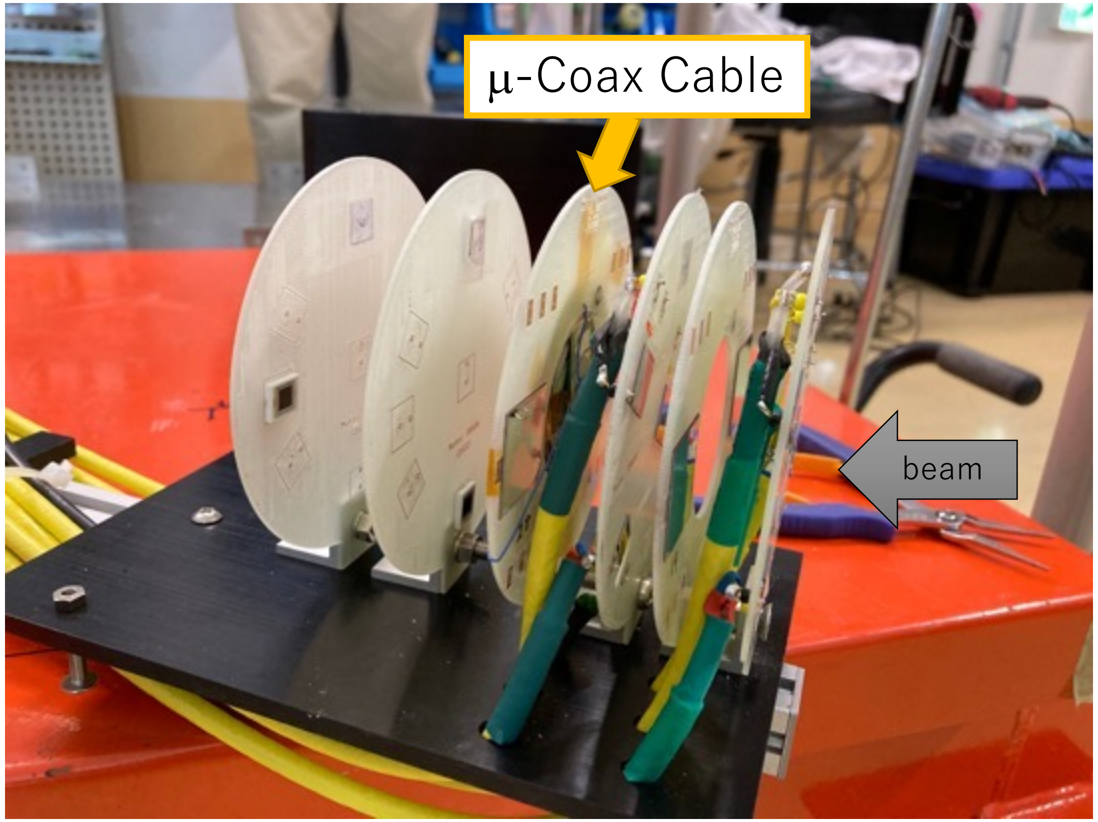


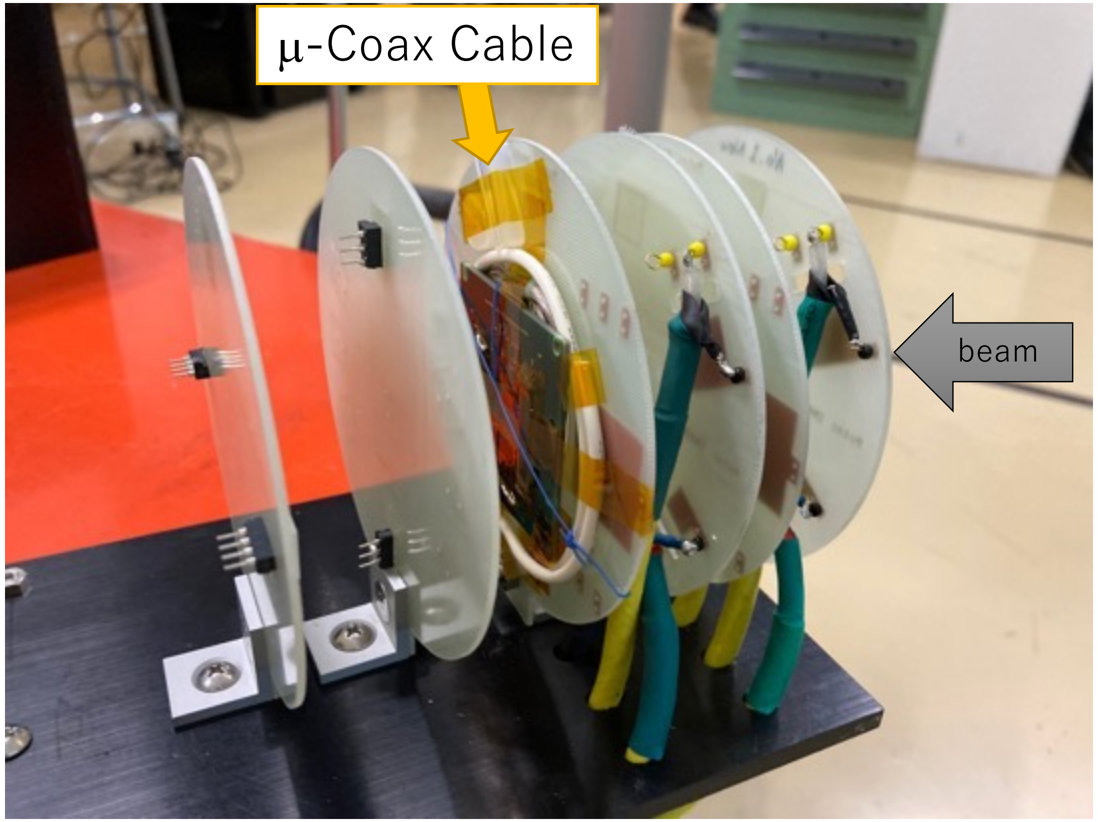


Beam Time for FoCAL@ALICE project in March 3-4, 2022. (10 hours)

2

Disk Mount Setup with FoCAL Sensors





Irradiated 9 hours total.
Total Neutron Flux = 1.7×10^{13} neutrons

To be checked its performance afterword

INTT Production Schedule

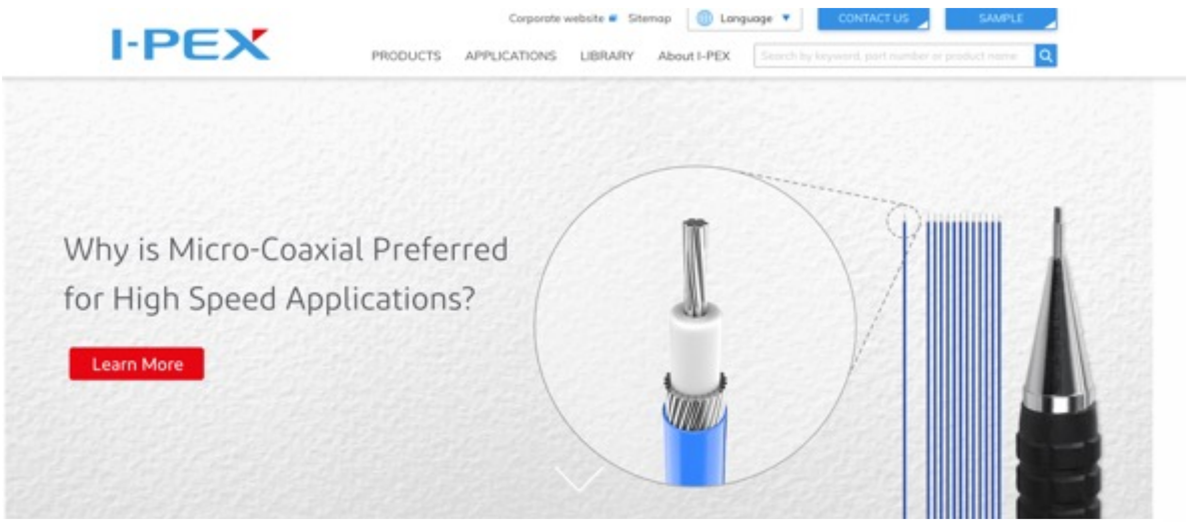
Today

* Beyond 112 are spares

2022	1	2	3	4	5	6	7	8	Qty*	Status
Silicon									135	Done
HDI									176	Done
Stave									204	Done
Bus Extender		Batch-1(20)	Contract		Batch-2(40)		Batch-3(70)		130	Production
Conversion Cable		Prototype-1	Contract		Prototype-2		Production (130)		130	Prototype
Barrel Assembly									1008 INSTALL	

Due to the supply chain crisis these days, KEL's lead time is at least 6 months. This is not gonna fit with out INTT construction schedule.

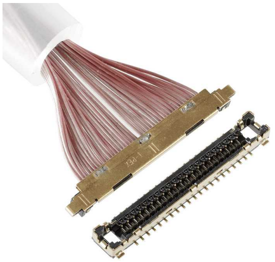
Alternative μ-Coax Model



Trade Name	I-PEX Inc.
Date of Incorporation	July 10th, 1963 (History)
President	Takaharu Tsuchiyama (Top Message, Board Members)
Head Office	12-4 Negoro, Momoyama-cho, Fushimi-ku, Kyoto, JAPAN 612-8024
Paid-in Capital	10.968 billion yen (as of December 31, 2021)
Consolidated Net Sales	66.8 billion yen (ended December 31, 2021)
Stock Exchange Listings	1st Sec., Tokyo Stock Exchange (Code: 6640) (Investor Relations)
Head Count	Consolidated: 5,667 (as of December 31, 2021) Non-Consolidated: 1,972 (as of December 31, 2021)
Group Companies	Japan: 4 (Including I-PEX Inc.) Overseas: 17 (Network)
Business Operation	Connectors & Electronics Components Business Automotive Electronics & Associated Components Business Semiconductor Mfg. Equipment and Other Business

CABLINE®-UX II

Slim design suitable for throgh-hole solution, narrow pitch (0.25 mm), Right angle vertical mating type micro-coaxial connector



- ✓ Suitable for small connector spaces.
- ✓ Slim plug design, suitable for through-hinge assemblies.
- ✓ EMI shielding and multi-point ground design.

Pin counts:

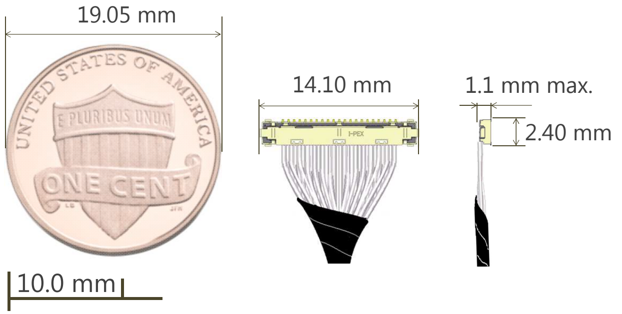
Range	Up to 50
Available	30, 34, 40, 50

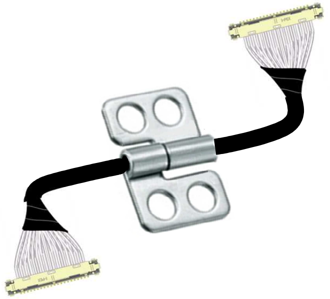
*Please inquire for pin counts not listed or outside of the pin count range.

Mating type			Right angle vertical
Wire (FPC) pitch (mm)			0.25
Board pitch (mm)			0.5
Mated size (mm)	Height		1.0 +/- 0.1
	Width Formula		4.1 + (0.25*?p)
	Depth		2.40
Wiping length (mm)			0.20
Applicable wire (AWG#)	Micro-coax for signals		45ohm : #44 or smaller
			50ohm : #46 or smaller
	Twincoax		-
	Discrete		#39 or smaller
Contact point			-
Performance (Reference only)			USB 3.1 Gen 1 (5 Gbps) V-By-One HS 1.4 (4 Gbps) HDMI 1.3 (3.4 Gbps)

Suitable for Small Connector Spaces

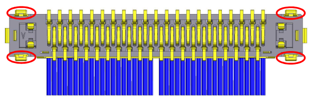
CABLINE-UX II 40p size is smaller than a one-cent coin.



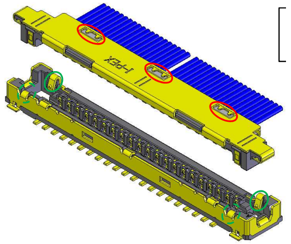


Flexible micro-coaxial cable harness is suitable for small applications with a hinge design.

EMI Shielding and Multi-point Ground Design

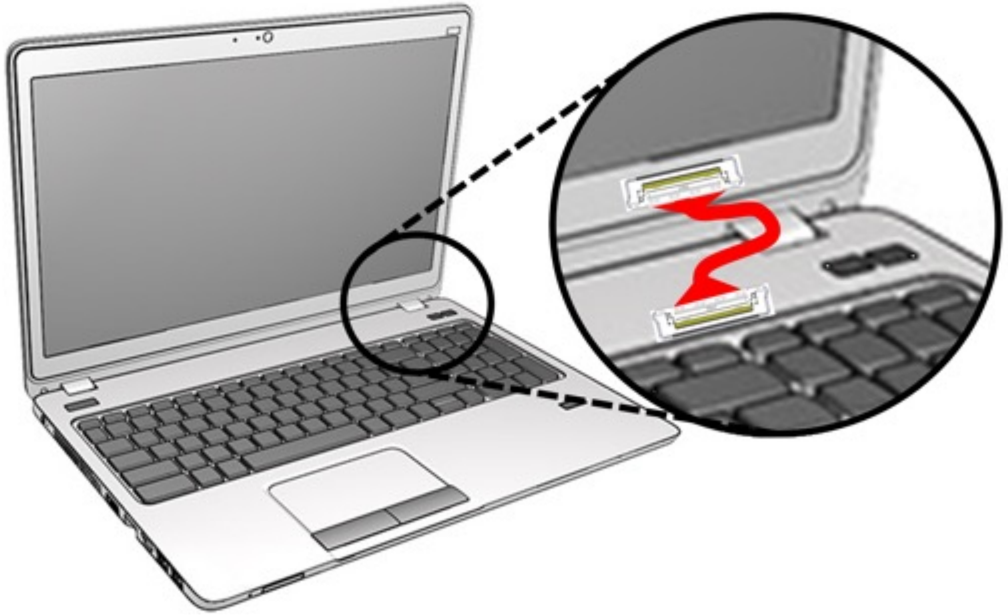


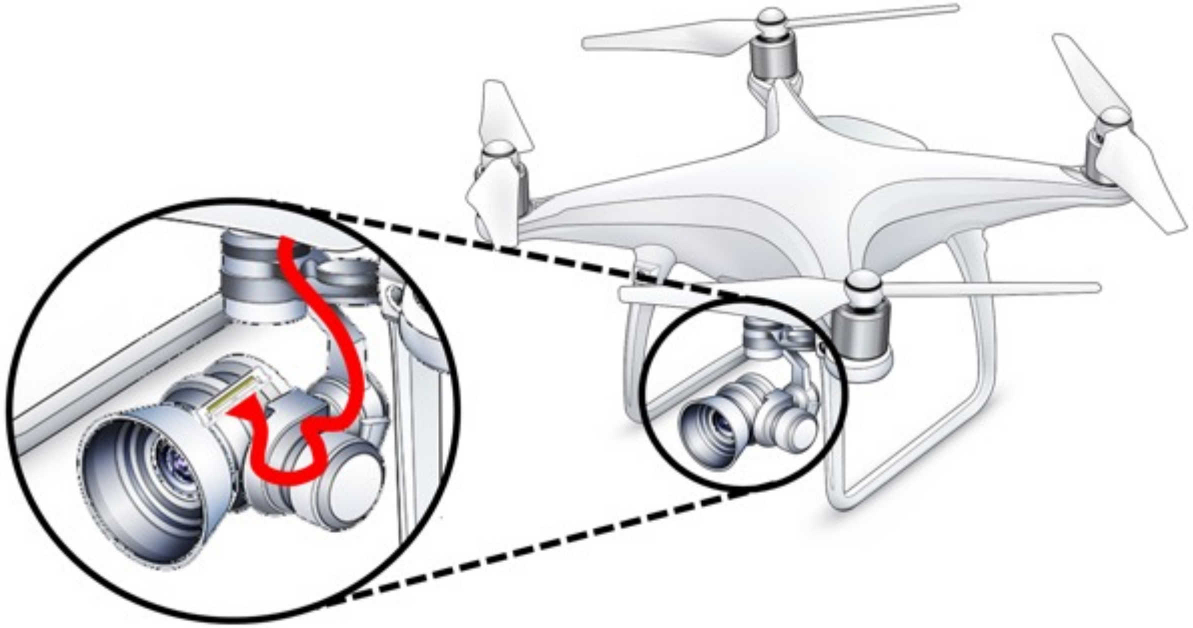
View From Underside



Lead time is 1 month

Market Share of I-PEX μ-Coax Product

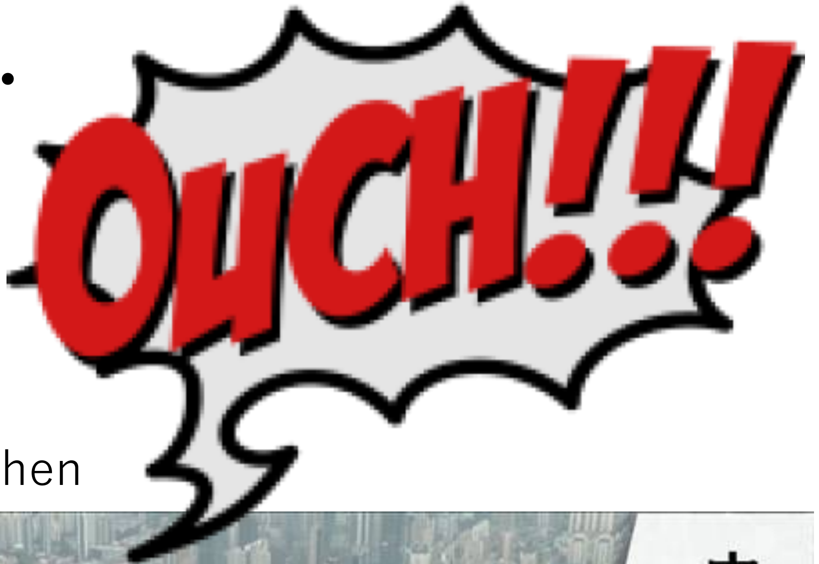




I-PEX Dominates world's market

Catching Up Schedule, but …

Still unclear if we can be in time …



Factory is in Shenzhen

March 2022

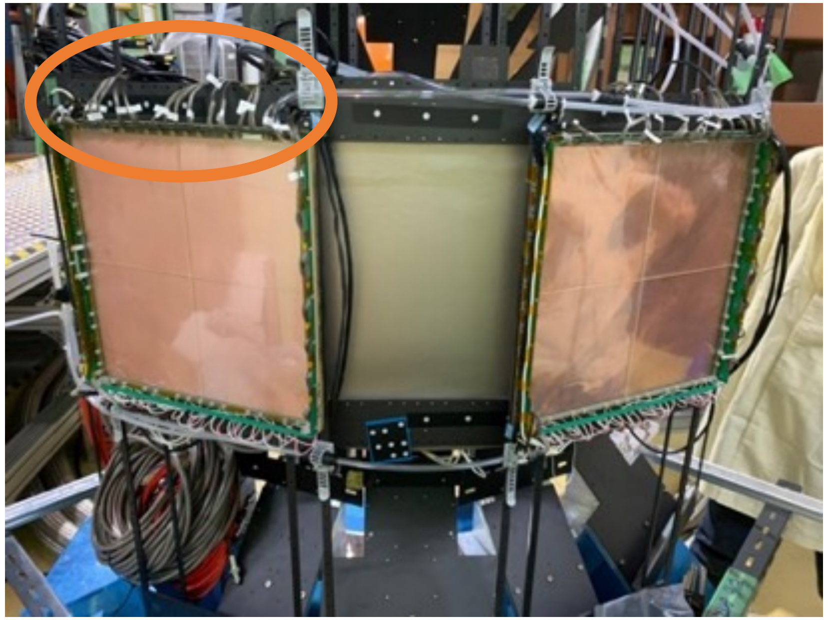
Summary

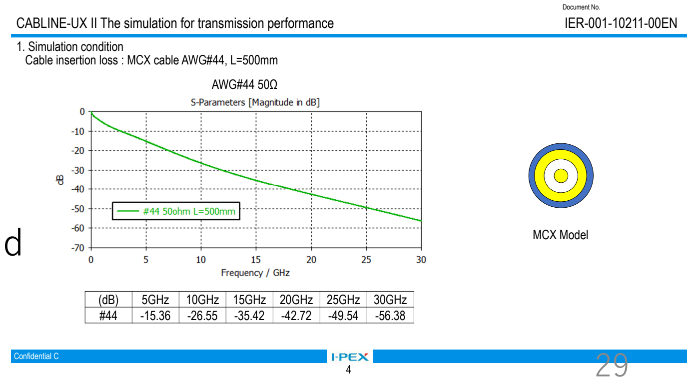
- The conversion cable was re-designed with μ-coax cable technology from FPC.
- The prototype-I demonstrated reasonable performance compared to FPC.
- Radiation test is ongoing.
- Switched the model from KEL’s XSL to IPEX’s UX-II to avoid severe delay of the mass production.

backup

The reason of XSL(KEL) as the first choise

1. It was used in E16 experiment at J-Parc and survives radiation (7.2Gray)
2. Fabrication experience of connector boards in Hayashi Repic.
3. Free samples were available.
4. KEL was willing to provide detailed signal transmission performance data.




Document No.
CABLINE-UX II The simulation for transmission performance
IER-001-10211-00EN

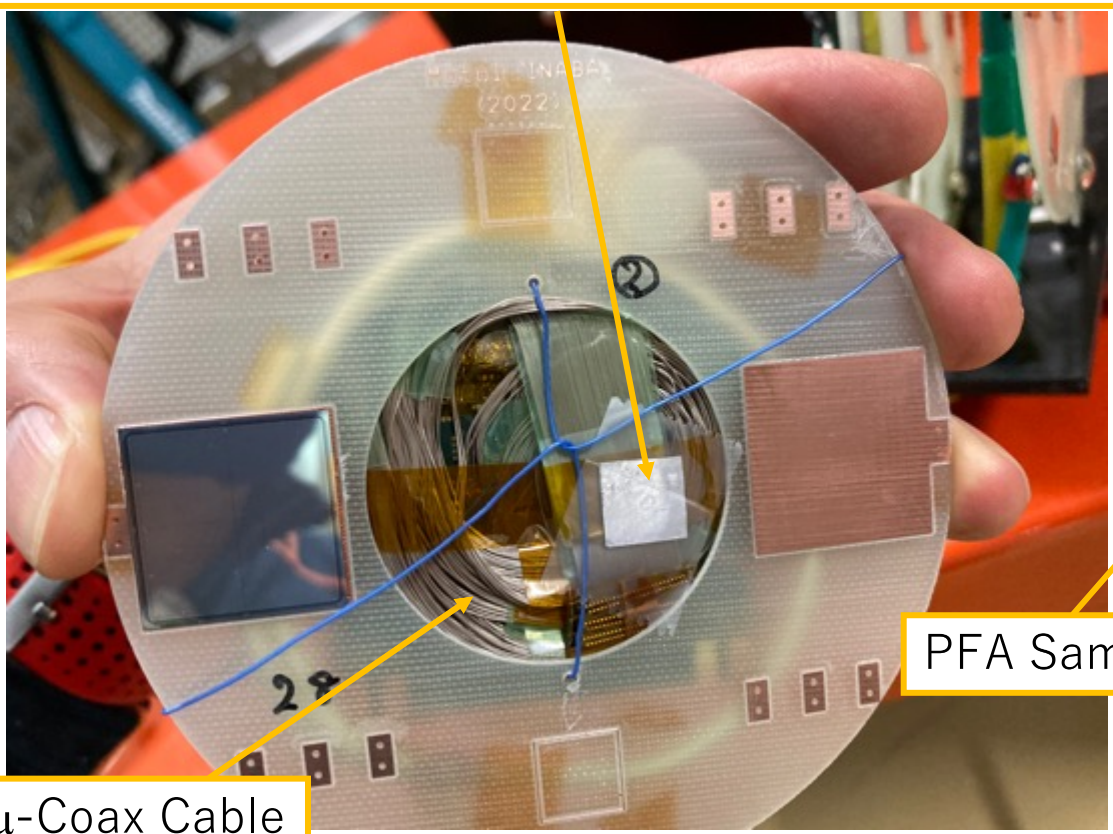
1. Simulation condition
Cable insertion loss : MCX cable AWG#44, L=500mm

(dB)	5GHz	10GHz	15GHz	20GHz	25GHz	30GHz
#44	-15.36	-26.55	-35.42	-42.72	-49.54	-56.38

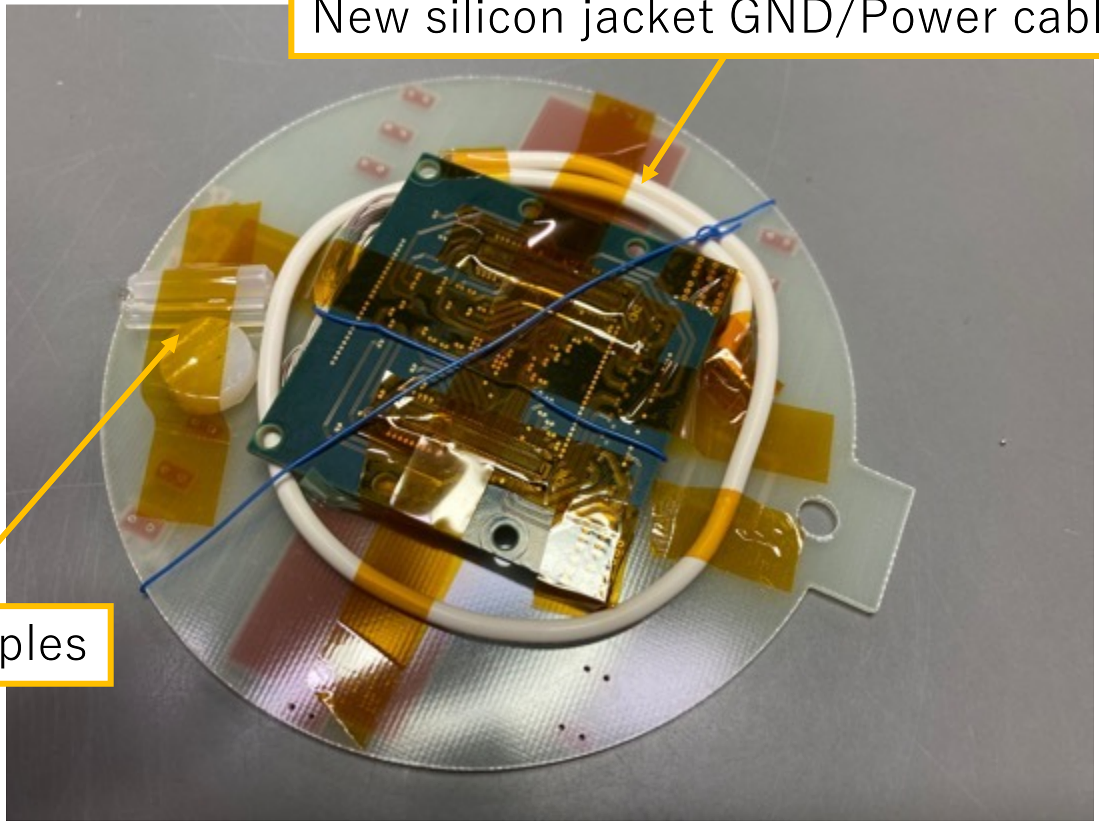
Confidential C
I-PEX
4

The performance data provided by I-PEX was too coarse

Prototype-I Cable Setup



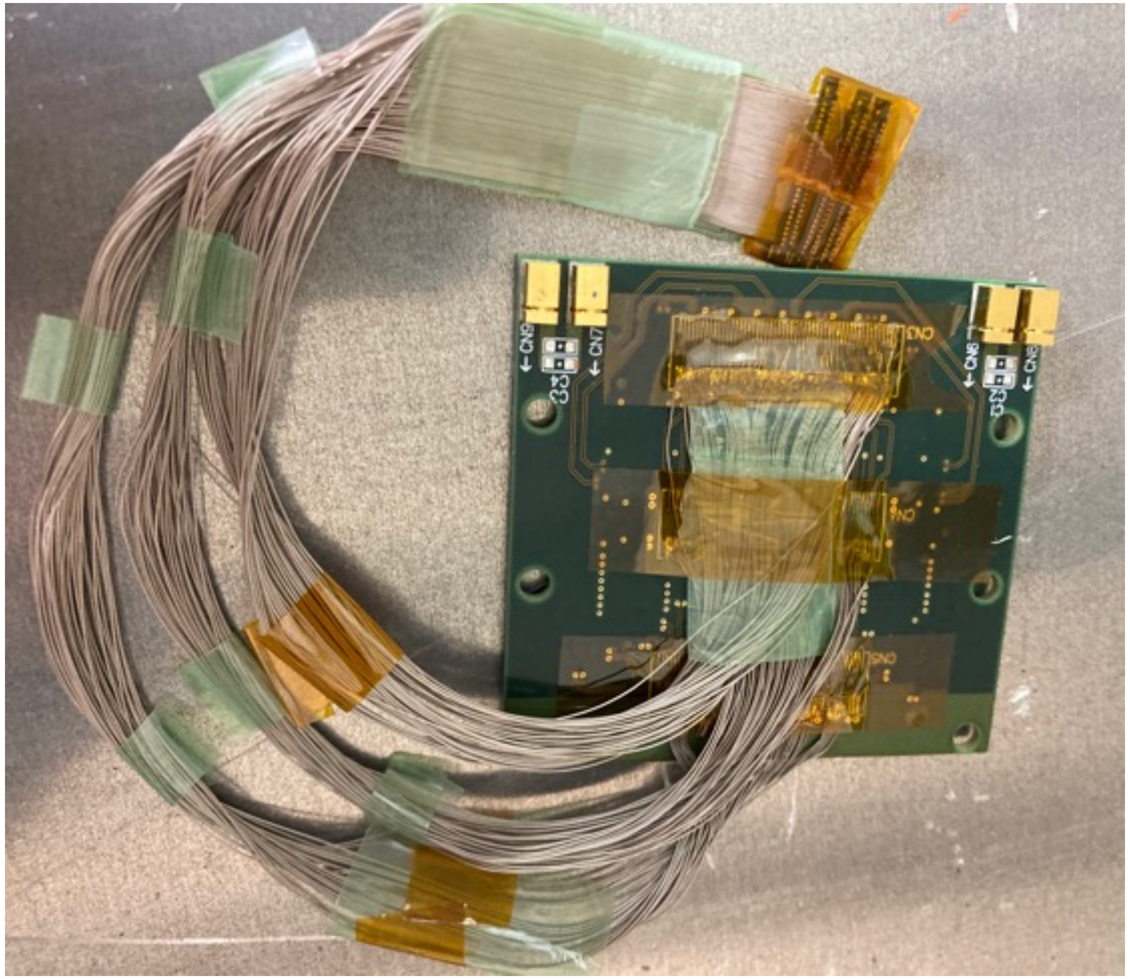
Attached to the disk (Front View)



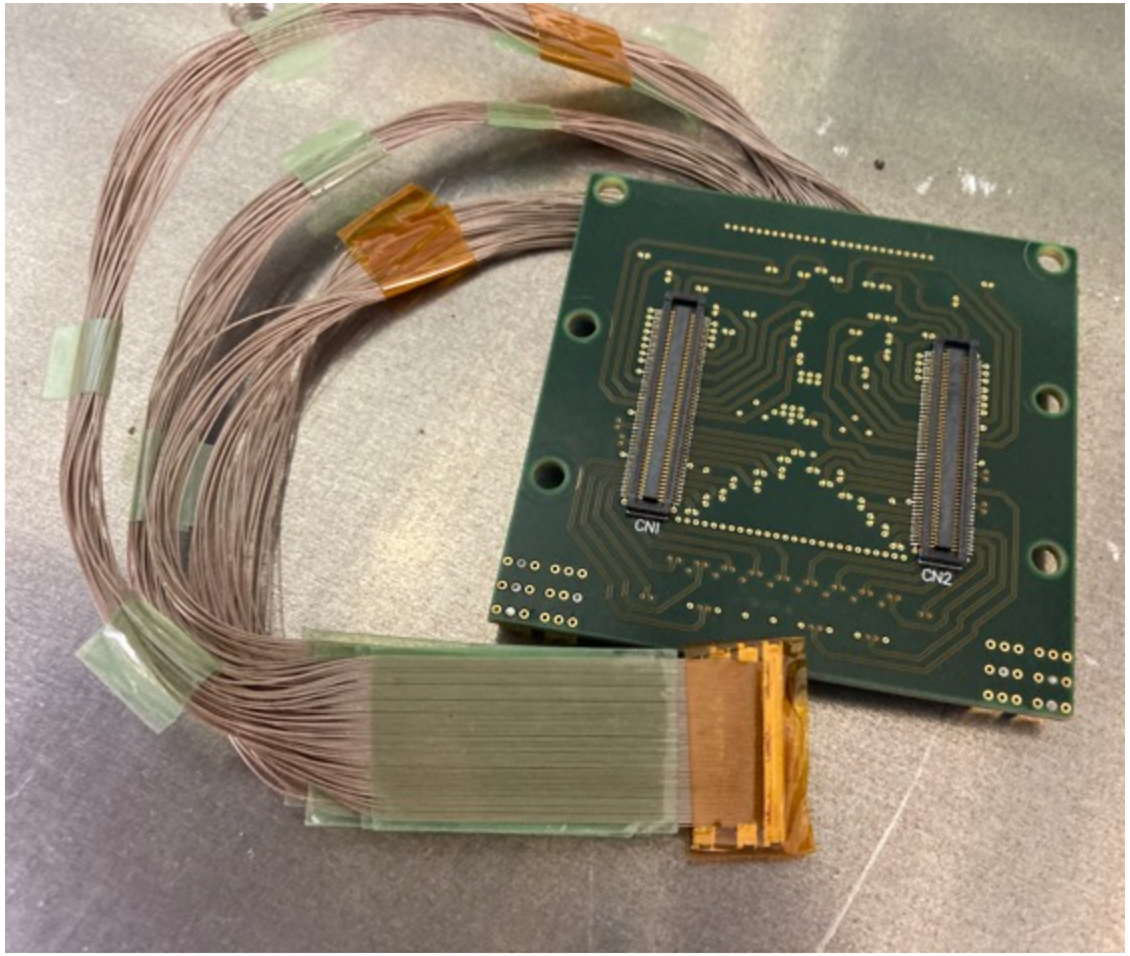
Attached to the disk (Back View)

Radiation Damage

After



After



No visible damage is observed after the irradiation.

Summary

- Prototype-I μ-coax conversion cable was irradiated for 1.7×10^{13} neutrons.
- No obvious damage has been observed after the irradiation at least visibly.
- The prototype-I cable is planned to be taken out from the radiation area and be tested again its performances.
  - sParameter and TDR in TIRI (April)
  - Stability data acquisition test with 1.1m BEX + μ-Coax at RIKEN (March ~ April)

Radioactivity Measurements

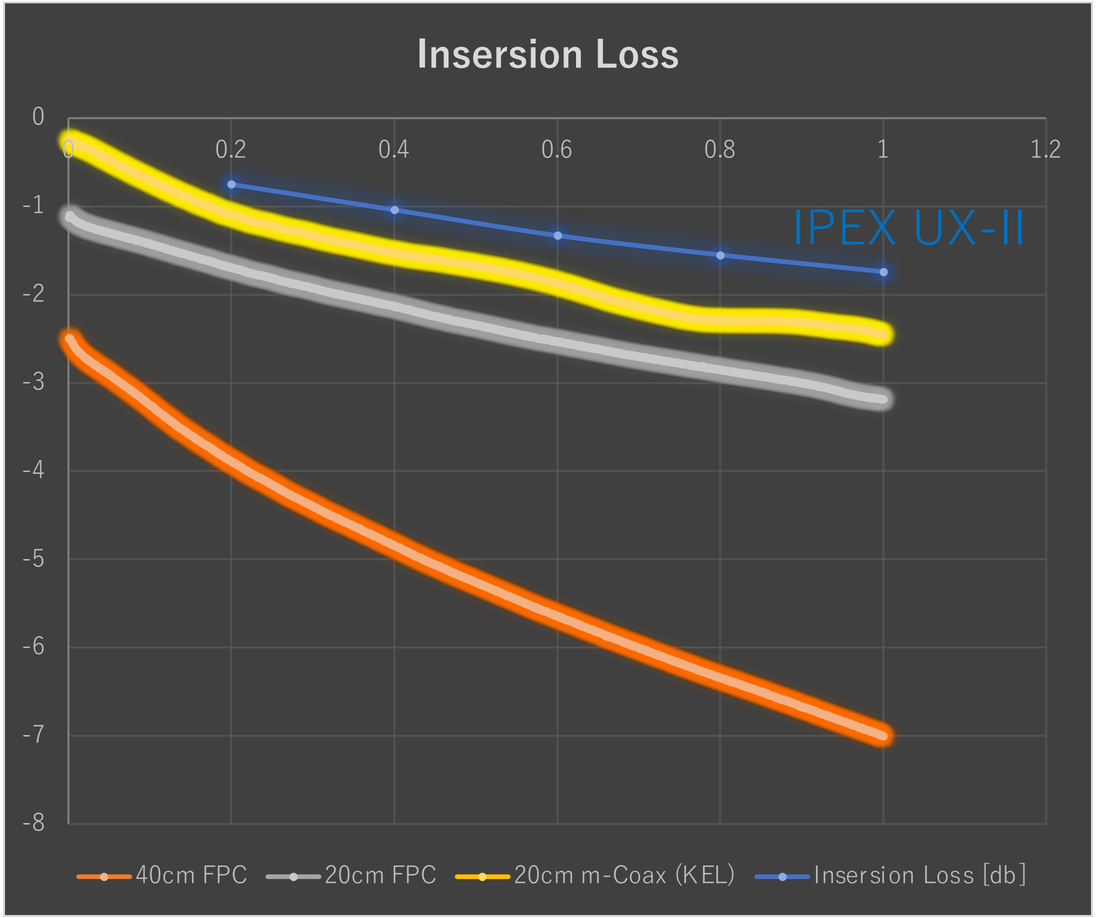
- March 4th : End of Neutron Exposure
- March 14th : 2.6 kcpm
- April 8th : 370 cpm

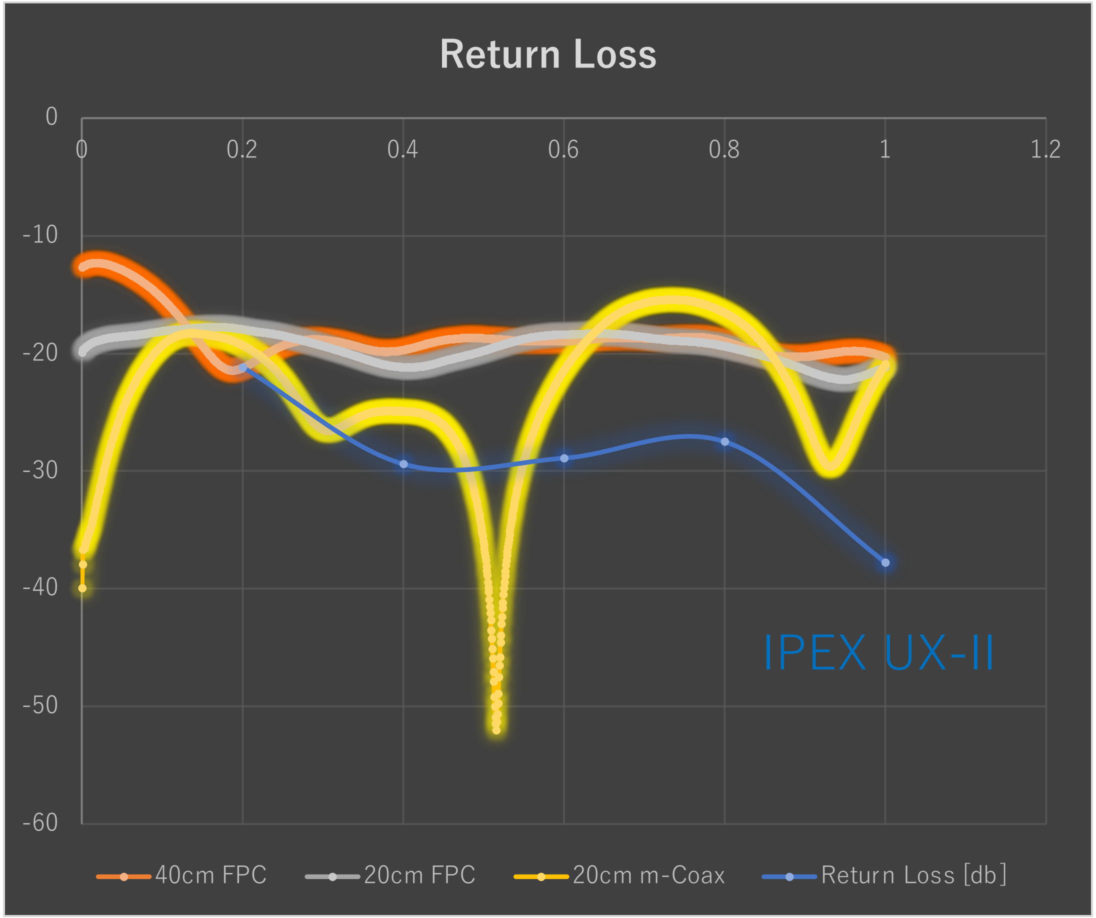
Requirement < 100 cpm

Another 1 ~ 2 weeks before we can take the prototype-I out of RANS experimental site.

いつまでも管理区域内に安置できない。ケーブルの材質の材質毎に放射化については調べてくださいとの要請が来ています。

sParameter Comparison





Specification Comparison (Executive Summary)

High Frequency Signal Transmission Performance @400MHz

	FPC		KEL XSL				IPEX UX-II
Length [cm]	**20**	40	10	10	20	30	50
AWG	**N/A**	N/A	46		44		44
Impedance [Ω]	**50**	50	50		45 ± 3		50
Diff Impedance [Ω]	**110**	110	93		83		
Insertion Loss [%]	**80**	56	84	90	84	80	88
Return Loss [%]	**10**	20	25		18		3
Cross Talk [%]	**<12***		1				
Eye Diagram	**similar**		similar				

*20cm conversion cable with bus extender

Conclusion

There is no data available for the exactly same condition between FPC and μCoax cables.
Presumably 20cm FPC can be compared to XSL-AWG46-10cm and XSL-AWG44-20cm.
Resulting performances look similar within 20cm. To be executed actual measurement once prototype is made. Hard to extrapolate the performance to 1.41m, need to wait for the actual measurement.

Slide from 2021/8/9 INTT meeting