Front-end electronics for the FoCal Pad detector and mini-FoCal production

8 March, 2019.

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for the ALICE FoCal collaboration

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Topics

1. Requirements for the FoCal-E Si-pad.
2. Preparation for Mini-FoCal.
3. The mini-FoCal production in 2018.
4. New studies for the (full-size) FoCal.

Requirements

(1) Good energy resolution - Good S/N.

(2A) The gain calibration ➡ MIPS data of the cosmic rays ?

(2B) The wide dynamic range ➡ > 17 bits at the least.

(3) A large number of channels - 3,840 channels / module.

(61,440 channels in the full-size FoCal.)

(4) Thin components - Thinner layers (5.5mm / layer in Mini-FoCal.)

(5) The small space for front-end electronics and cables.

(6) Radiation durability ➡ > 1 M Gray (?)

(7) Magnetic field hardness - No cooling fan, no transformer.

(8) Low power consumption - An issue of cooling.

(9) A lot of ADCs / Analog memory units.

(10) A high-sampling-rate ADC - The waveform measurement.

(11) A high DAQ rate.

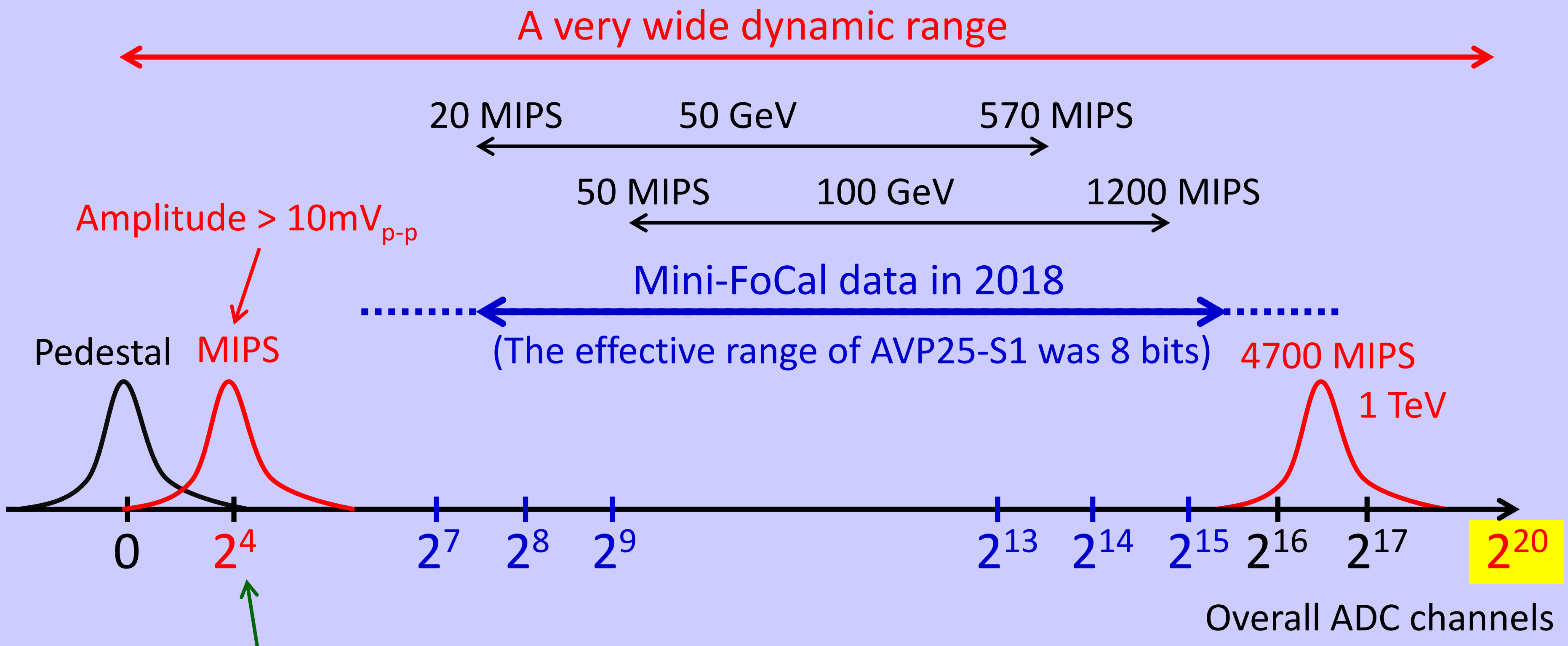
(12) A fast trigger.

(13) Rejection of piled-up events.

(14) Low production costs. - Si-pad and ASIC, and so on.

The dynamic range

It needs the dynamic range of 20 bits or higher for covering the range from MIPS to 1 TeV shower max data, but it is hard to realize it using a single device so far. We used CERN RD51 APV25-S1 for Mini-FoCal.



A very wide dynamic range

20 MIPS 50 GeV 570 MIPS

50 MIPS 100 GeV 1200 MIPS

Amplitude > $10mV_{p\text{-}p}$

Mini-FoCal data in 2018

(The effective range of AVP25-S1 was 8 bits)

Pedestal

MIPS

4700 MIPS

1 TeV

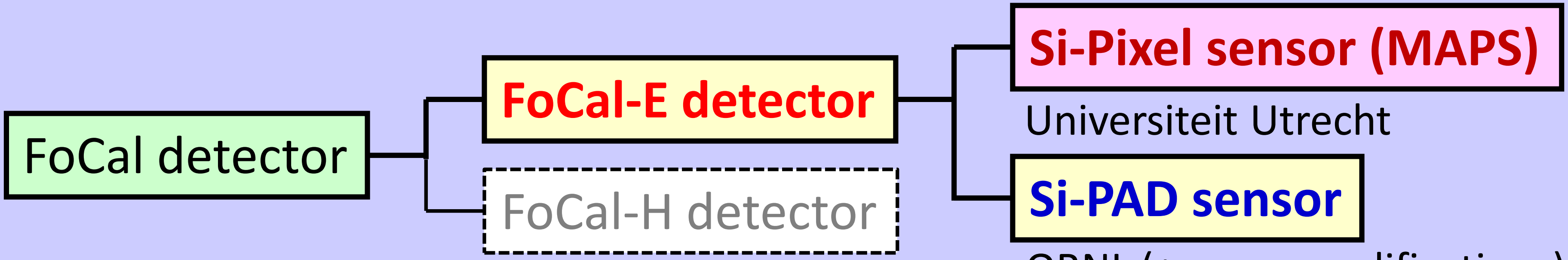
0 2^4 2^7 2^8 2^9 2^{13} 2^{14} 2^{15} 2^{16} 2^{17} 2^{20}

Overall ADC channels

In the case of APV25-S1, it was approximately 2^8 at the ELPH beam test in 2017.

Preparation for Mini-FoCal

FoCal-E prototype in 2014 and 2015



FoCal detector

FoCal-E detector

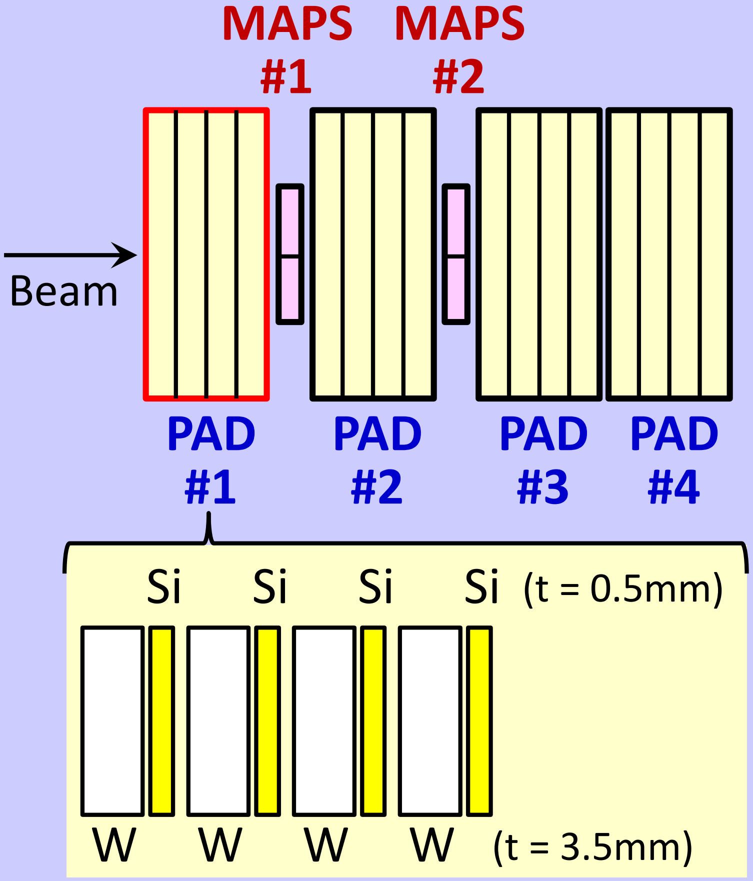
FoCal-H detector

Si-Pixel sensor (MAPS)

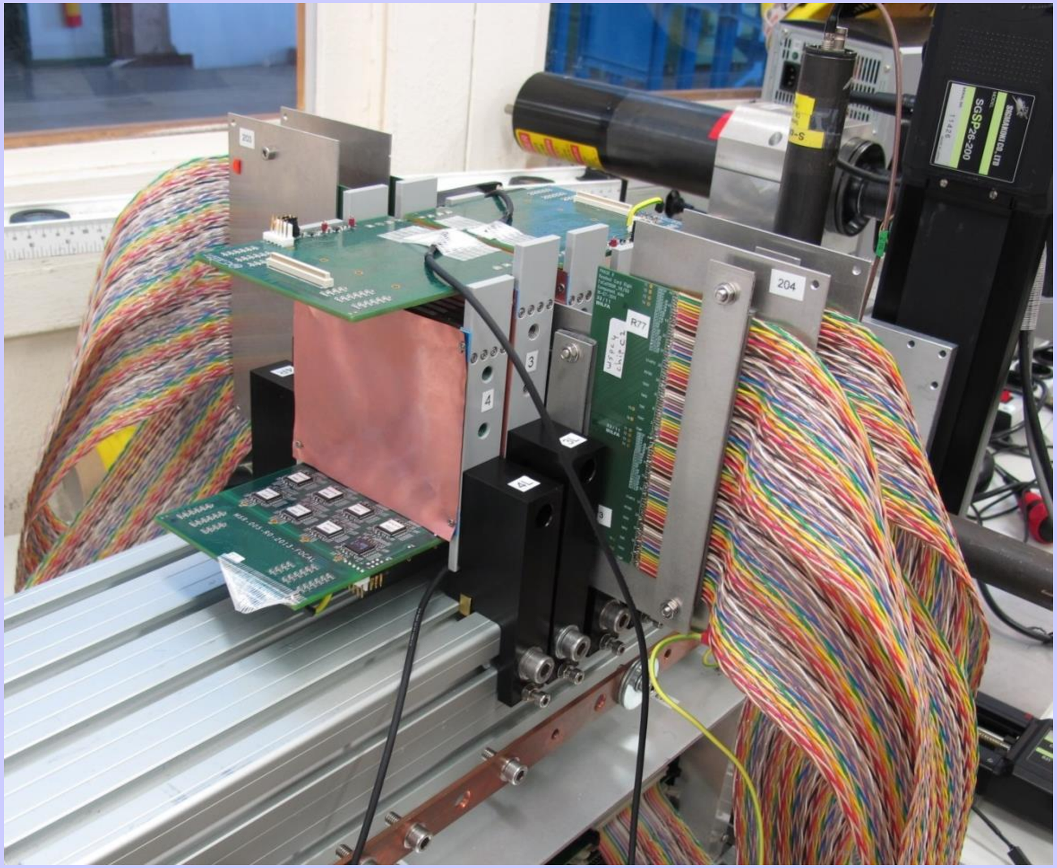
Universiteit Utrecht

Si-PAD sensor

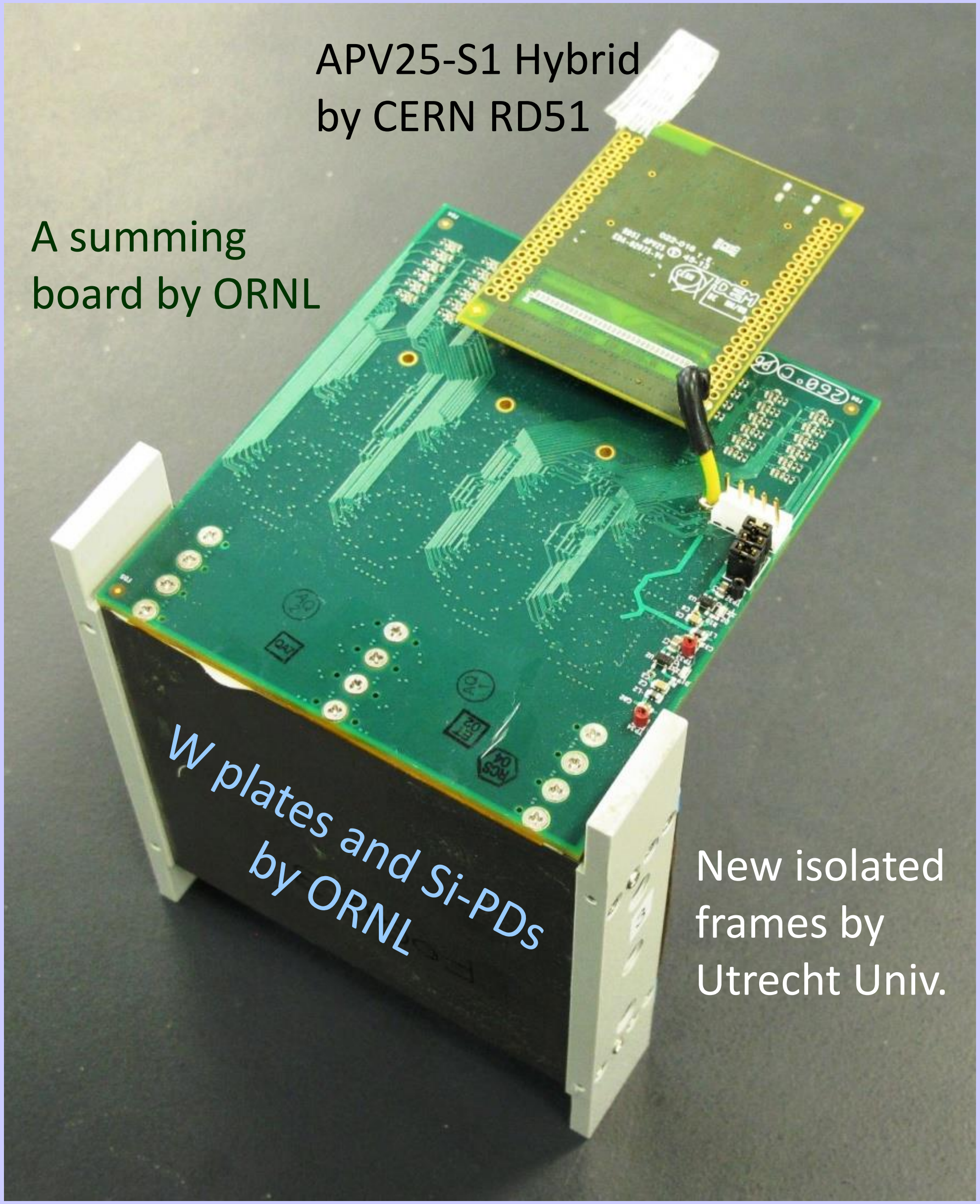
ORNL (+ some modifications)



(Si-W calorimeter)



FoCal-E PAD detector prototype

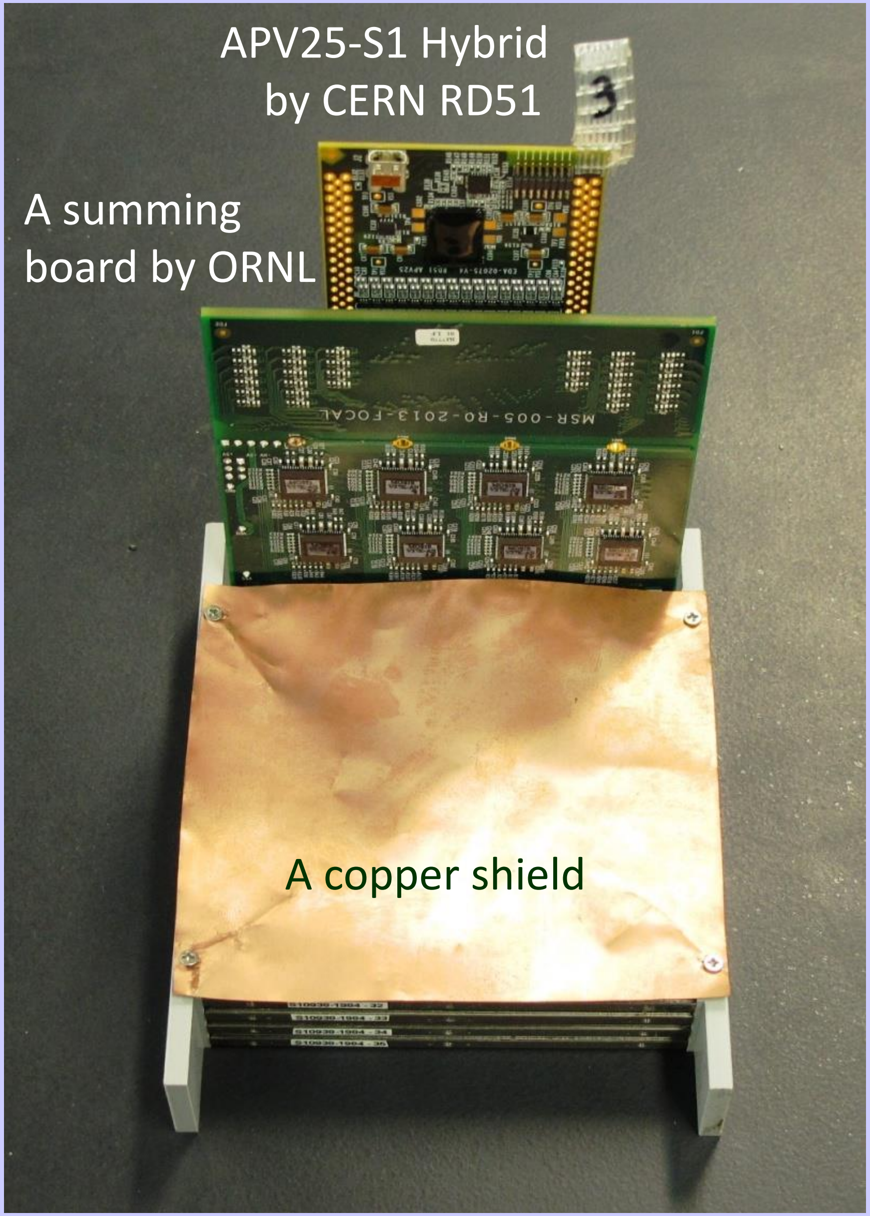


APV25-S1 Hybrid
by CERN RD51

A summing
board by ORNL

W plates and Si-PDs
by ORNL

New isolated
frames by
Utrecht Univ.

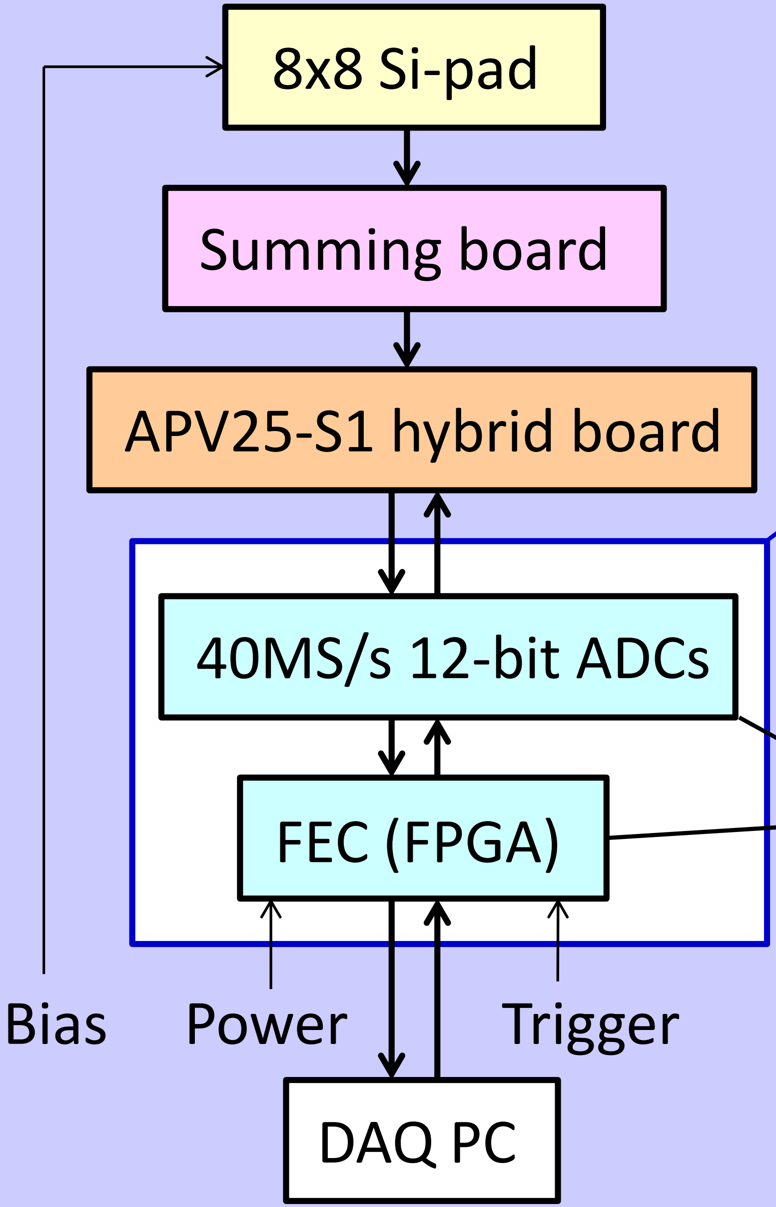


APV25-S1 Hybrid
by CERN RD51

A summing
board by ORNL

A copper shield

SRS readout system with APV25-S1



8x8 Si-pad

Summing board

APV25-S1 hybrid board

40MS/s 12-bit ADCs

FEC (FPGA)

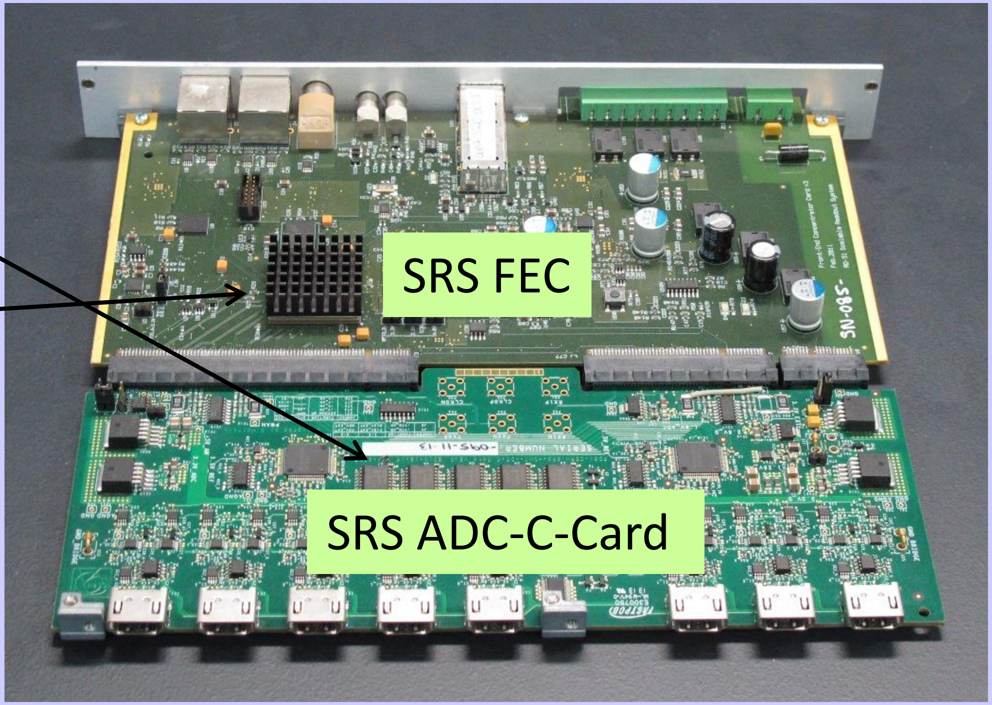
Bias

Power

Trigger

DAQ PC

New mini-Crate

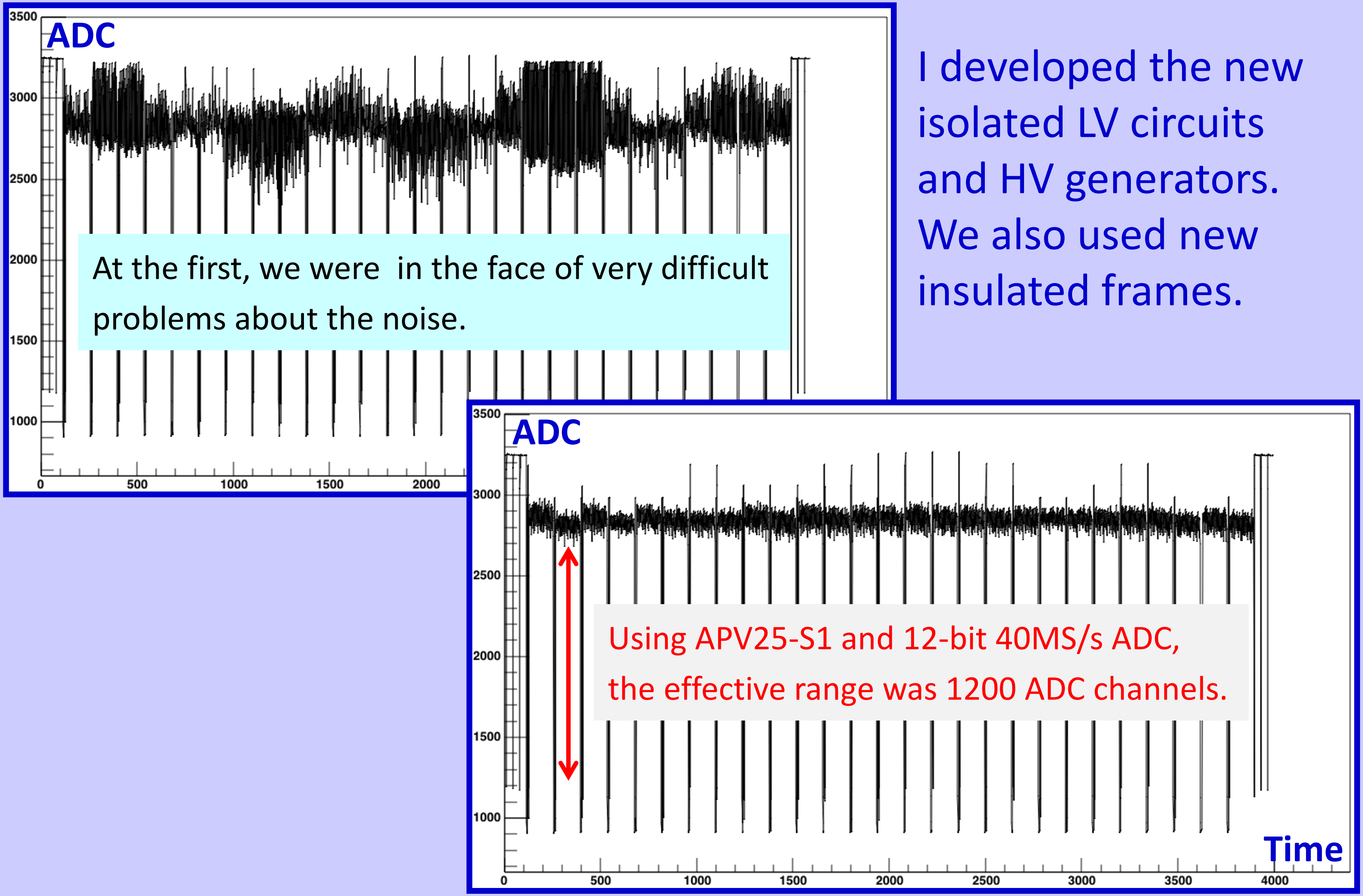


SRS FEC

SRS ADC-C-Card

Some modifications against the noise

I developed the new isolated LV circuits and HV generators. We also used new insulated frames.



At the first, we were in the face of very difficult problems about the noise.

Using APV25-S1 and 12-bit 40MS/s ADC, the effective range was 1200 ADC channels.

New summing boards in 2016

CERN PS/SPS in 2014 and 2015

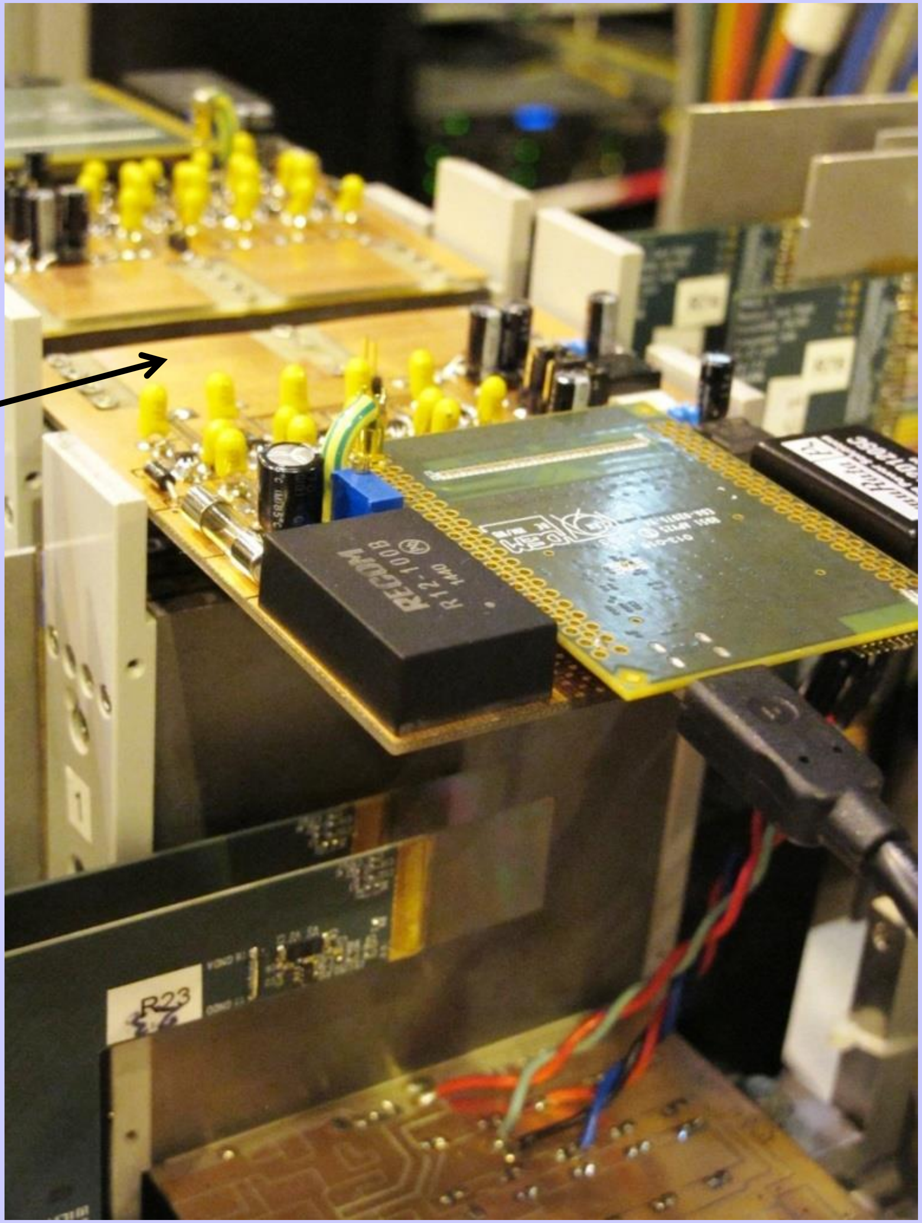
ORNL summing boards
+ APV25-S1 hybrid boards

CERN SPS in 2016

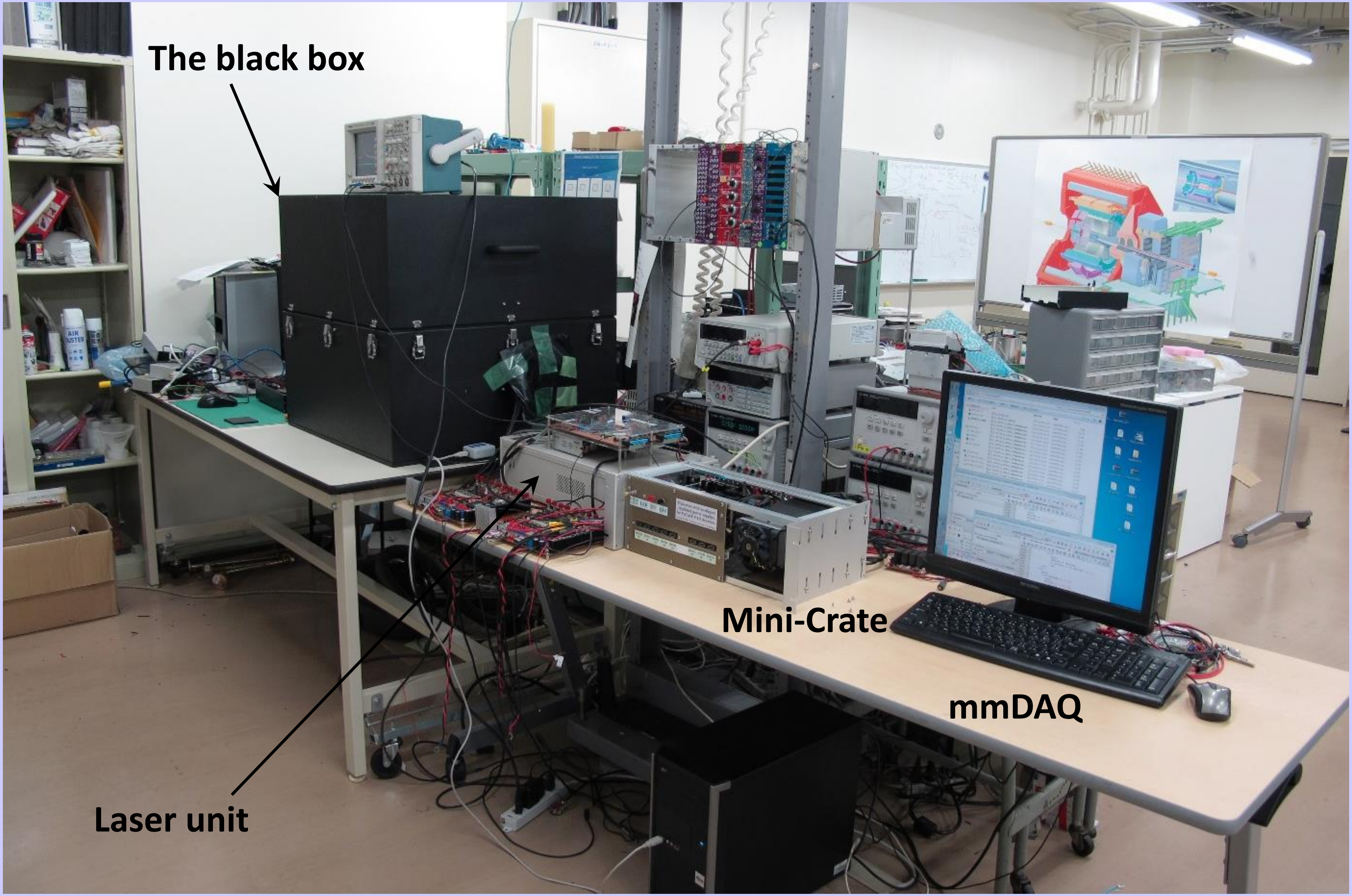
New summing boards
+ APV25-S1 hybrid boards

➡ The improvement of S/N.
➡ Dynamic range extension.
➡ Simultaneous data taking between MAPS and PAD.

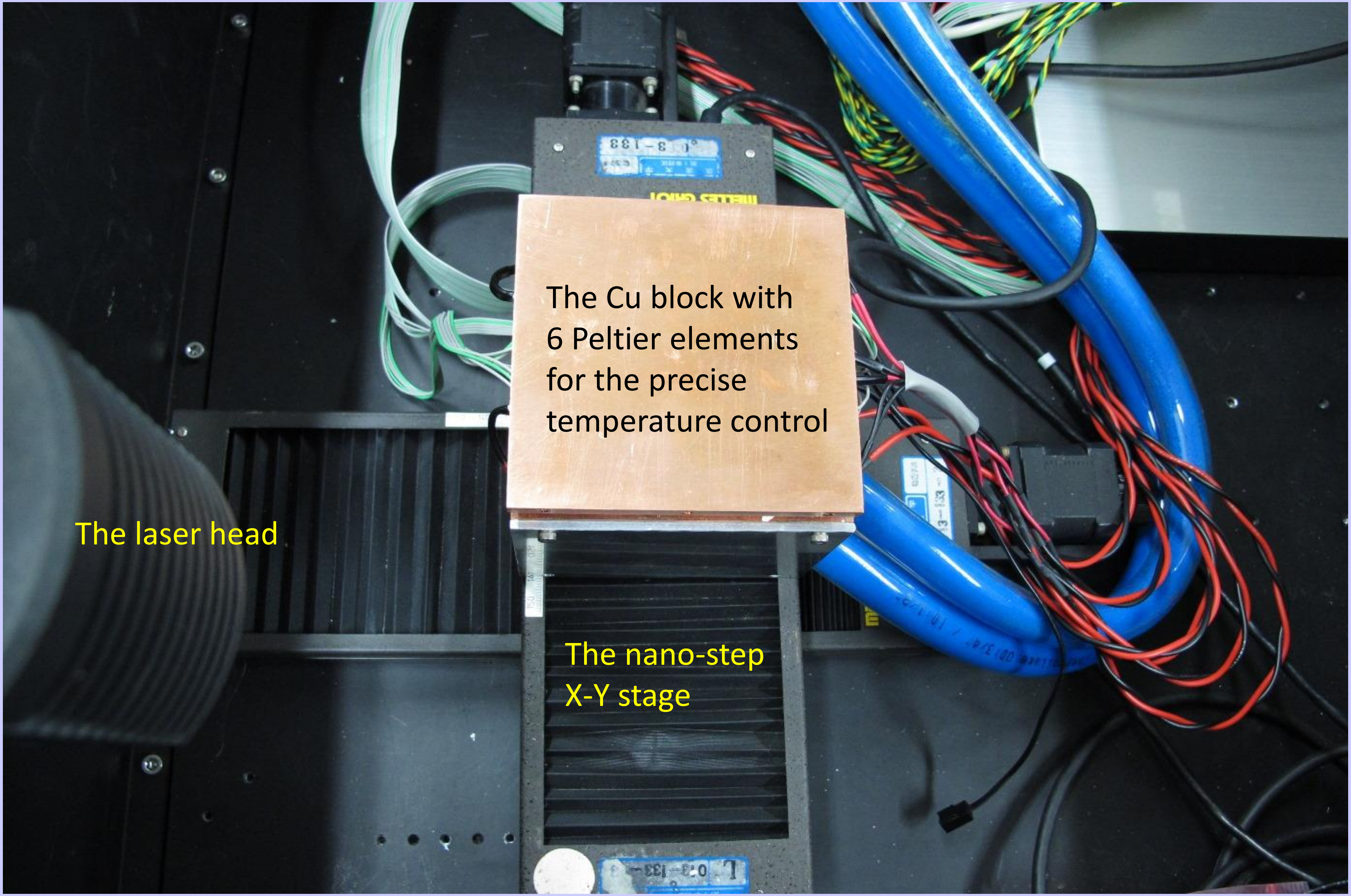
We have studied a lot of things about Si-pad sensors and APV25-S1. The next step was the test of new Si-pads for Mini-FoCal.



The Si-pad test bench in Tsukuba



In the black box



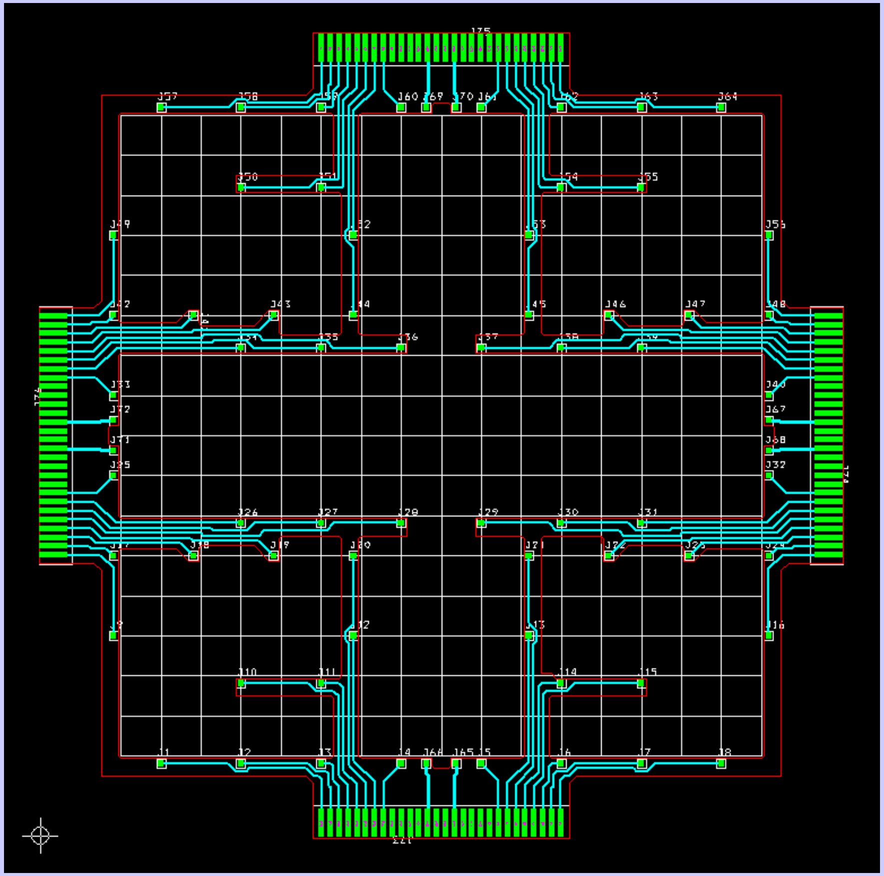
The Cu block with
6 Peltier elements
for the precise
temperature control

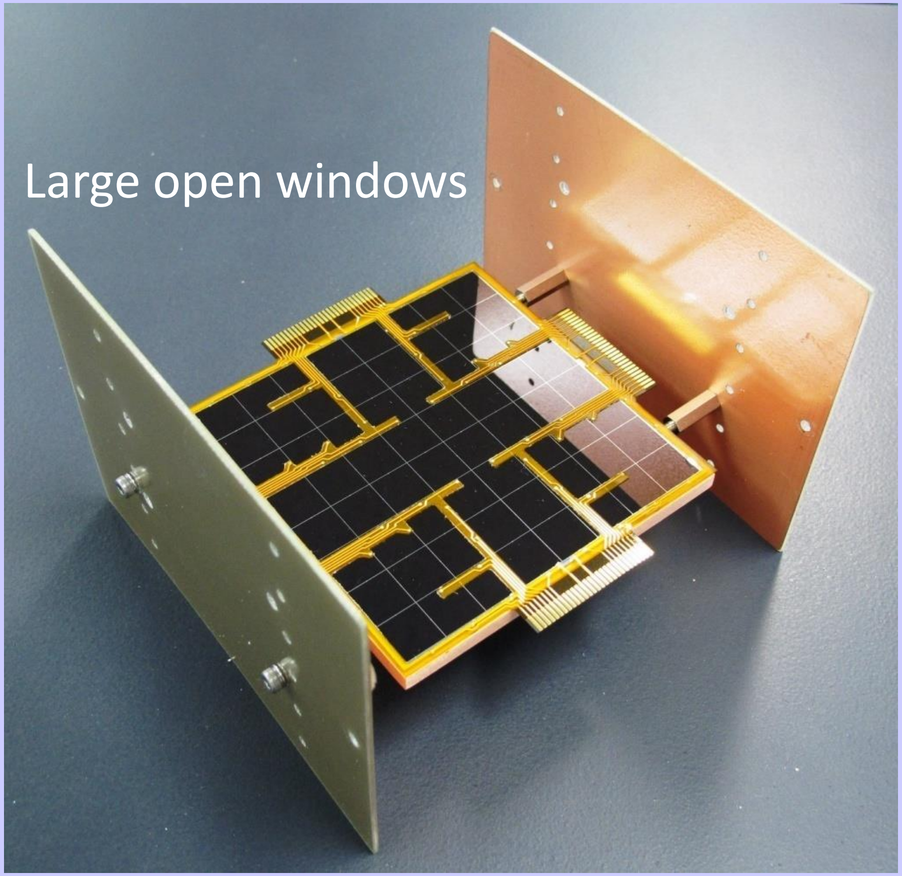
The laser head

The nano-step
X-Y stage

New Si-pad sensors for testing

- ✓ V-I characteristics measurement.
- ✓ V-C characteristics measurement.
- ✓ The temperature dependence study (including a break-down point).
- ✓ The position dependence study using a laser source.

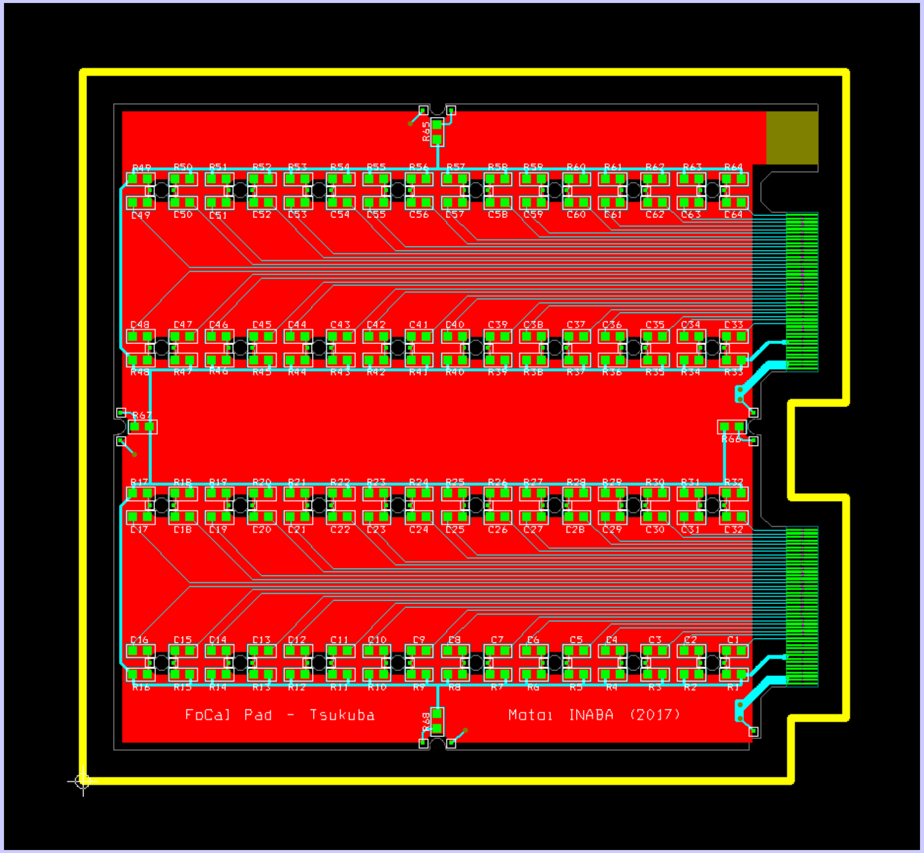


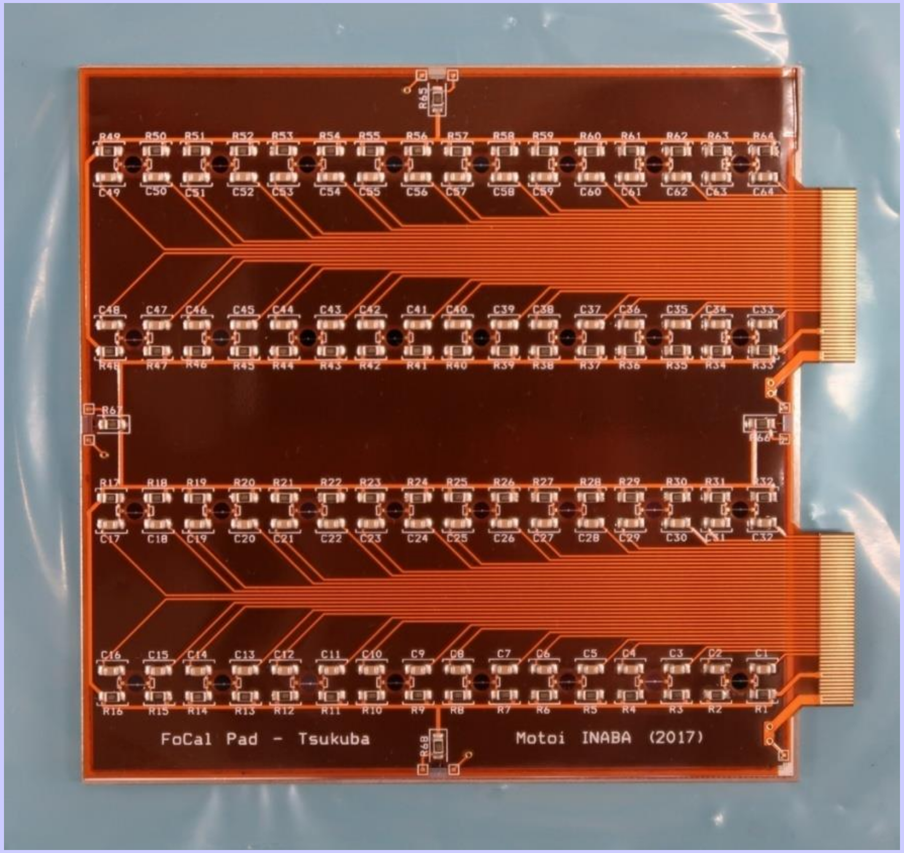


Large open windows

New Si-pad sensors for testing

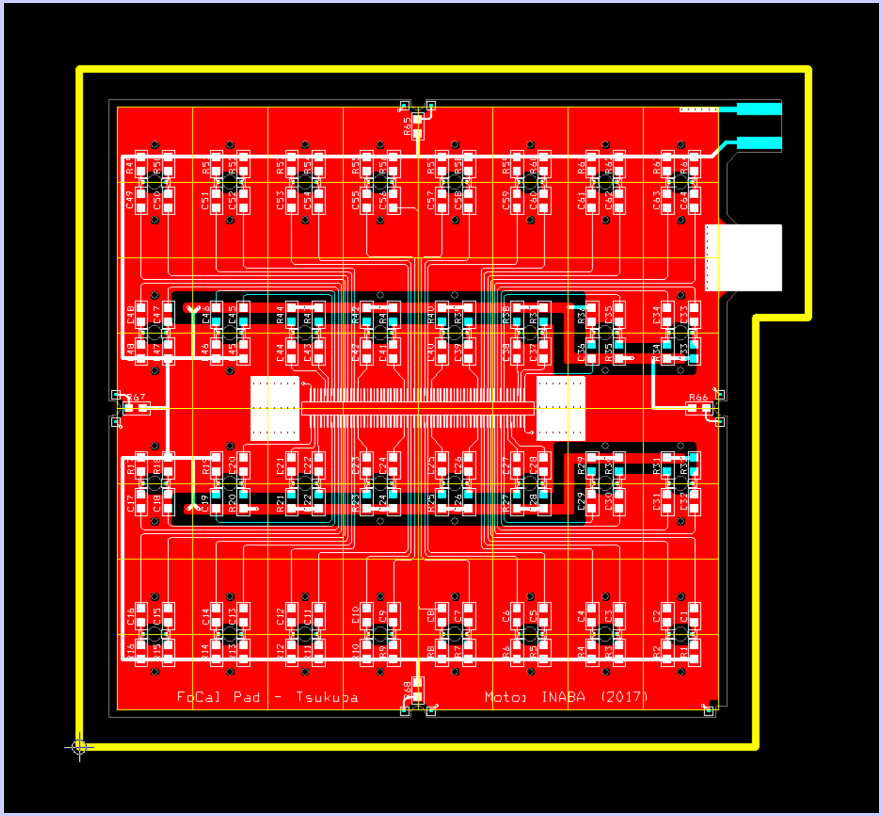
- ✓ For the new front-end electronics development.
- ✓ The improvement of S/N (The optimization of GND).
- ✓ The signal-line-length dependence study.
- ✓ The crosstalk study.

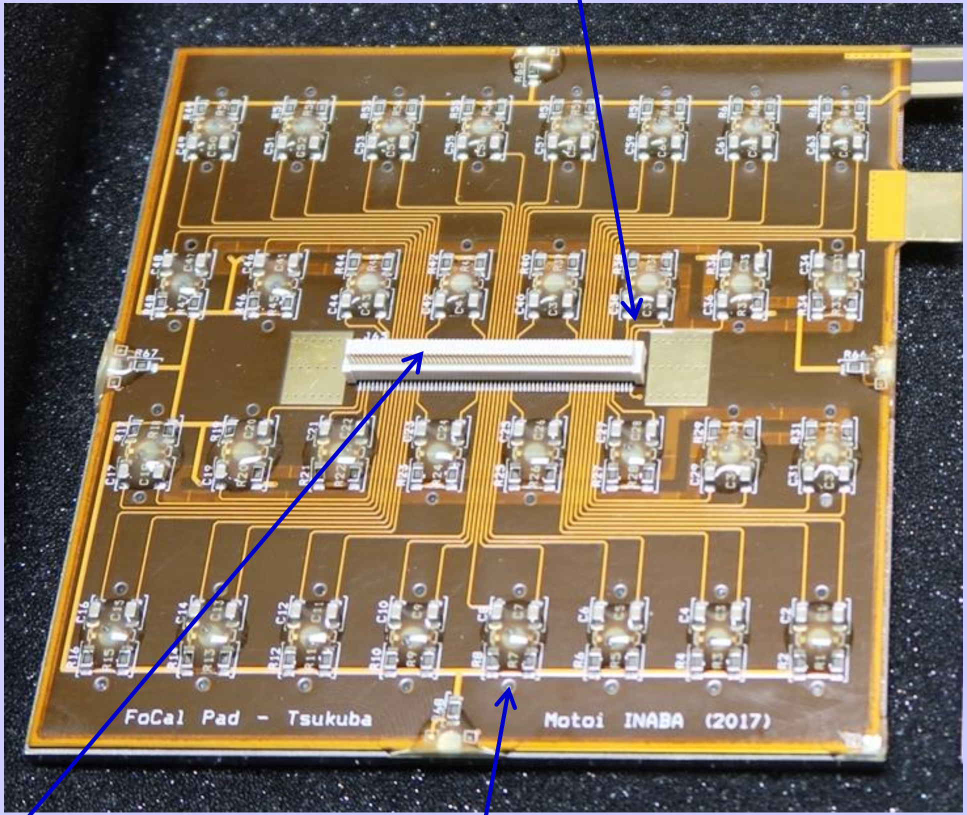




New Si-pad sensors for testing

- ✓The improvement of S/N (The optimization of GND).
- ✓ The signal-line-length dependence study.
- ✓ The crosstalk study.
- ✓ The MIPS data measurement.



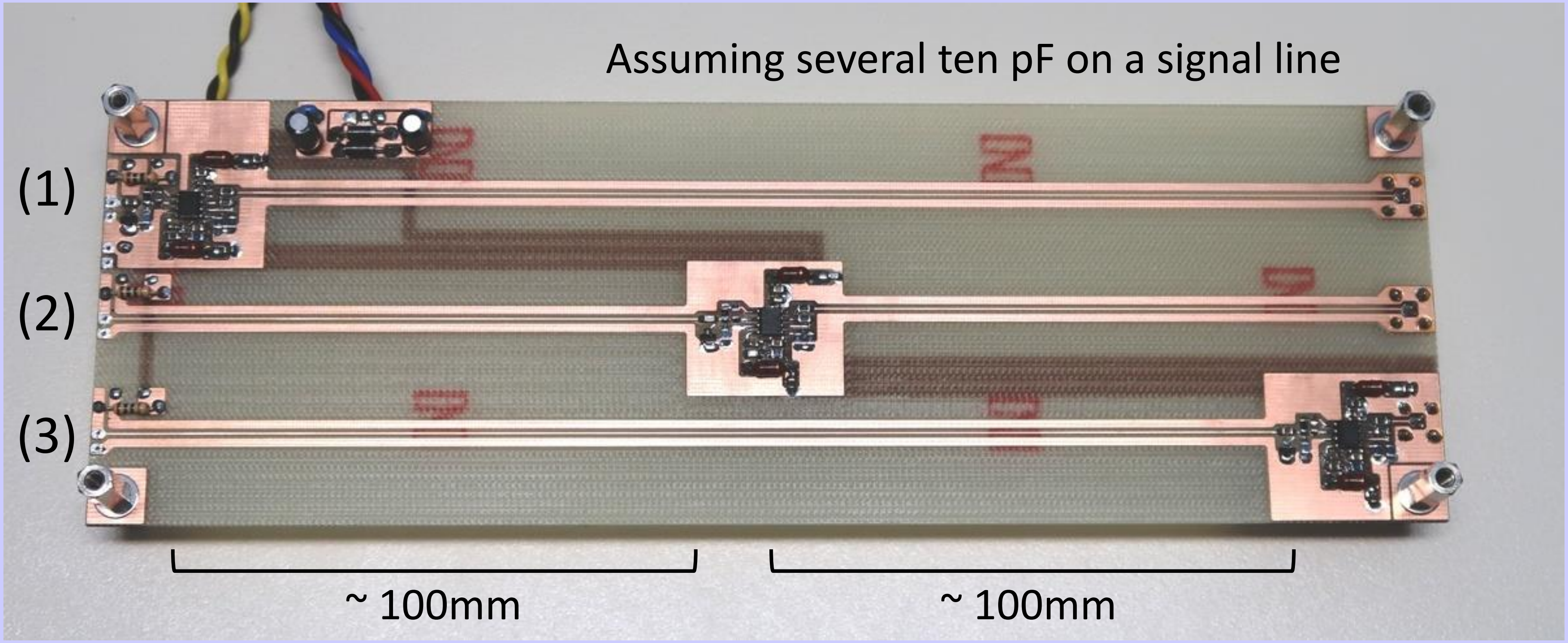


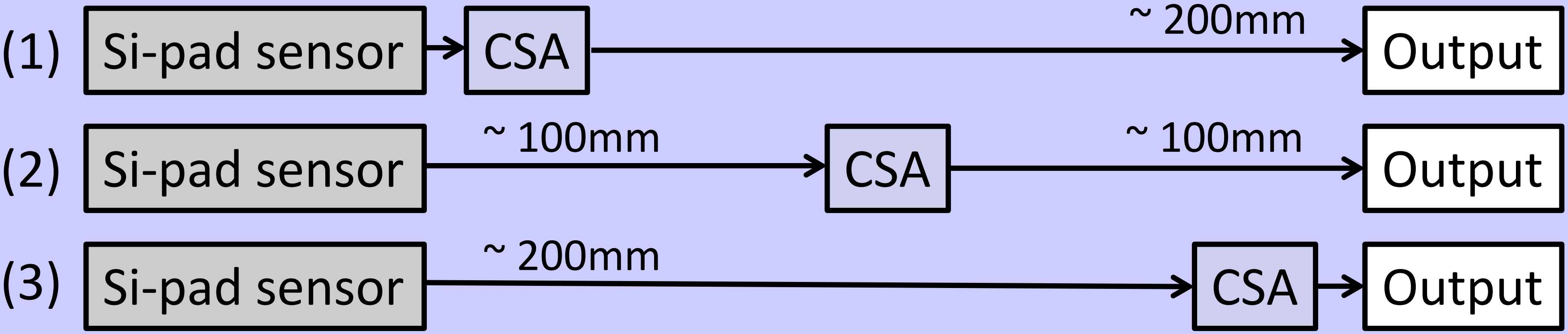
The shortest case of a signal line.

The 130-pin connector for the APV25-S1 hybrid board

Holes for the Laser light

Sensitivity tests of a signal line


Assuming several ten pF on a signal line

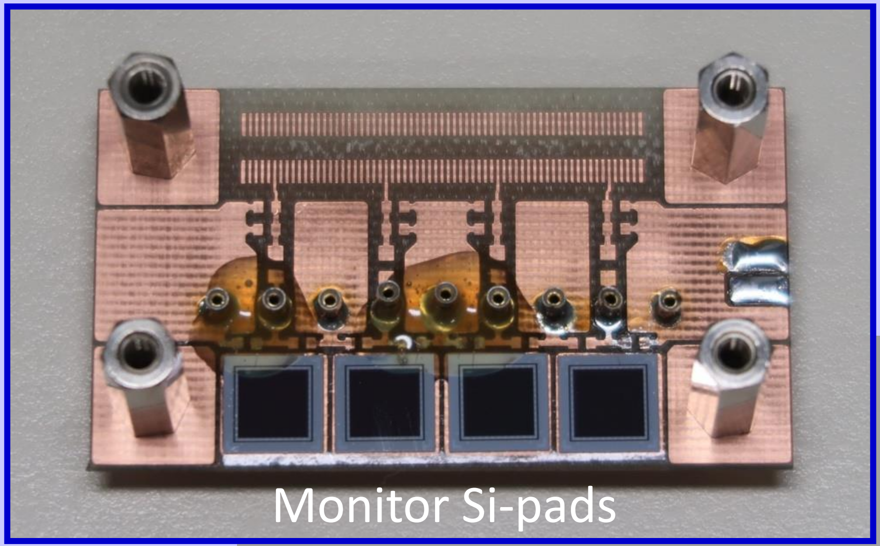

(1) Si-pad sensor → CSA → ~ 200mm → Output

(2) Si-pad sensor → ~ 100mm → CSA → ~ 100mm → Output

(3) Si-pad sensor → ~ 200mm → CSA → Output

CSA includes the pole-zero cancellation circuit.

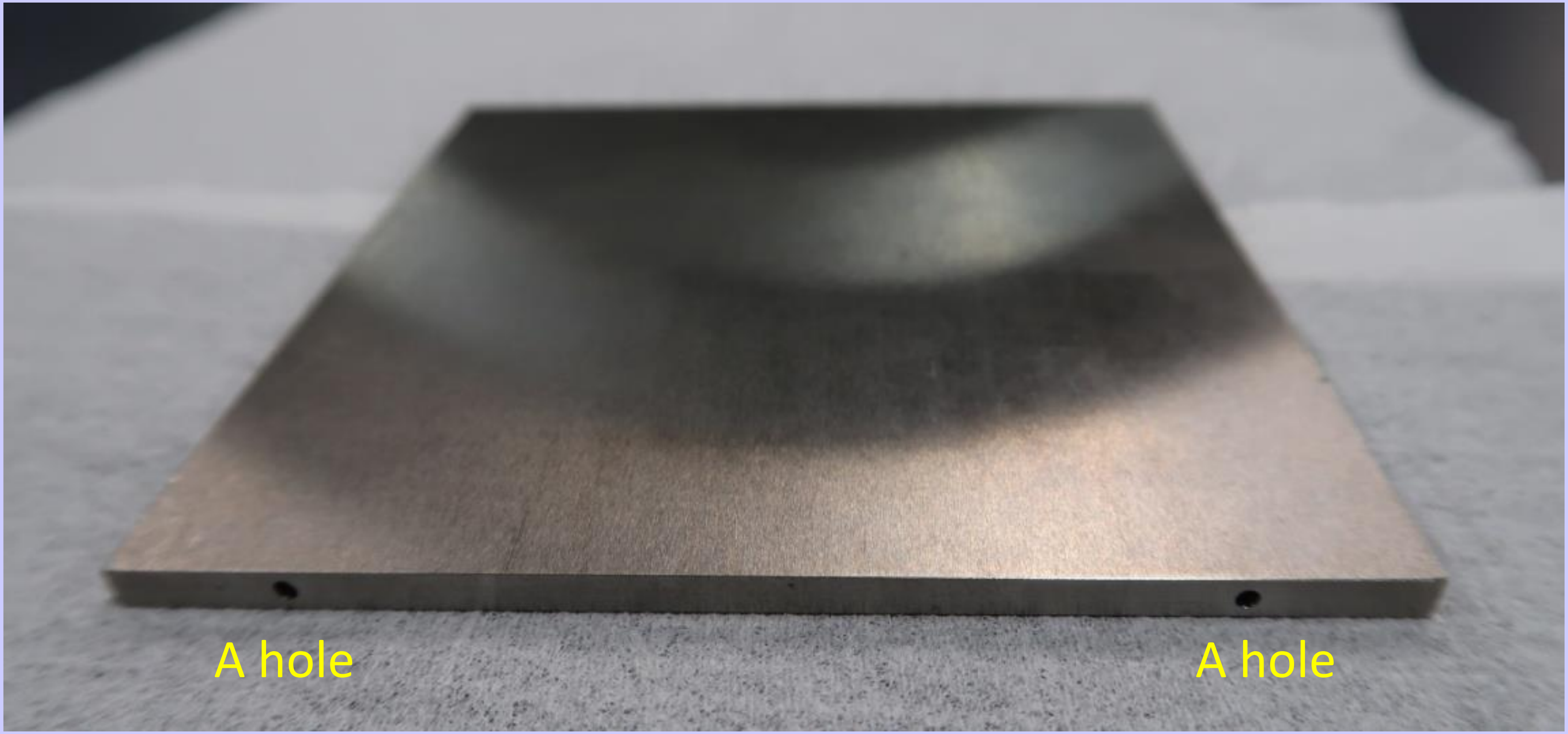
Protection for bonding wires



- ✓ Stability (and safety).
- ✓ Temperature variation.
- ✓ How to apply the agents.
- ✓ How to reject bubbles.

Metalworking (Tungsten alloy plates)

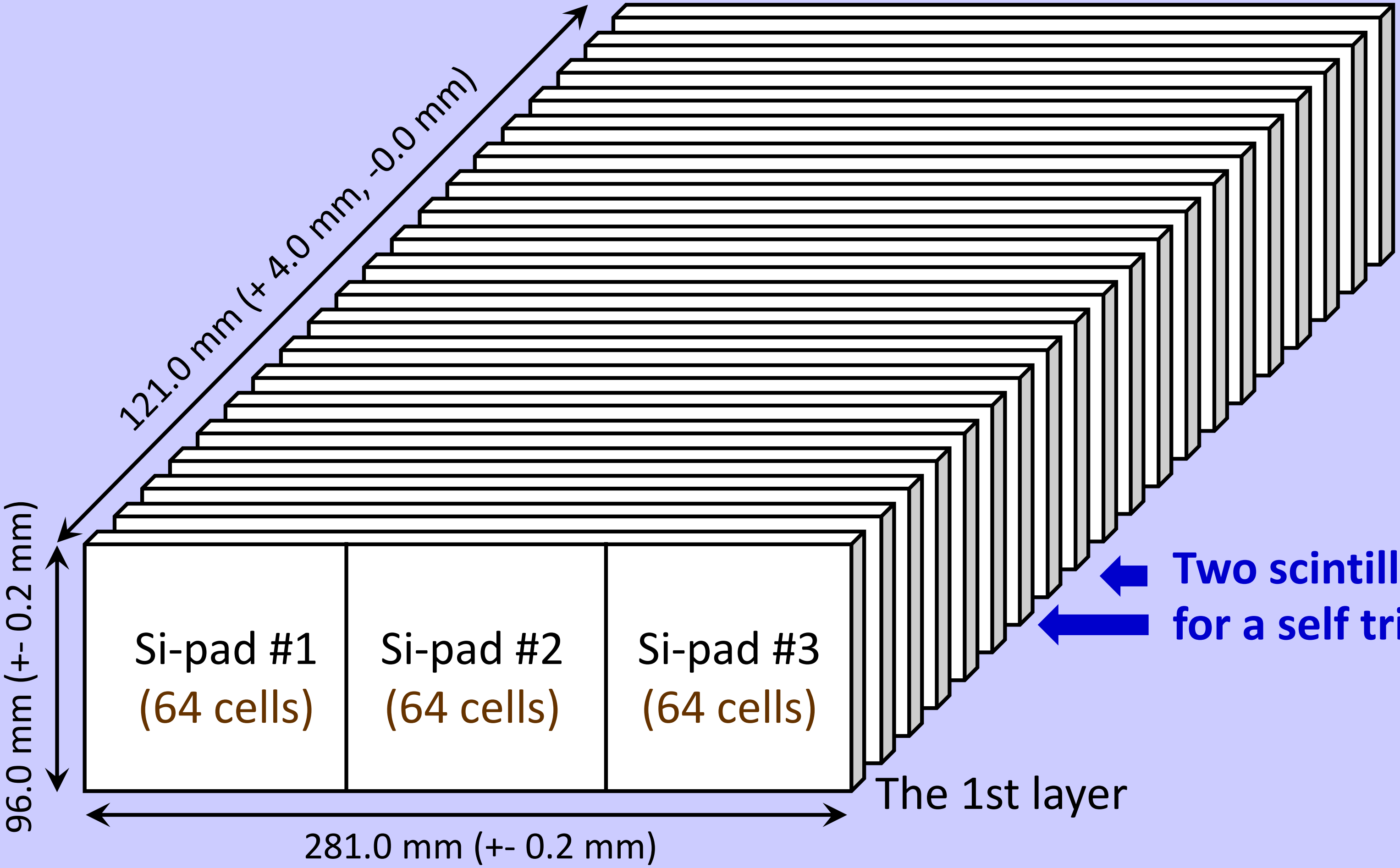
Tungsten is a heavy and hard material. I tried to make hole on the side of the Tungsten alloy plate. Finally, I found out the better way to make holes for fixing.



Mini-FoCal production

The ALICE mini-FoCal design

We decided to make the **1x3** tower with **20** Si-pad layers as mini-FoCal. The number of cells is equal to **3,840** in total. We could get the CERN RD51 **APV25-S1** only as the front-end electronics in 2017.

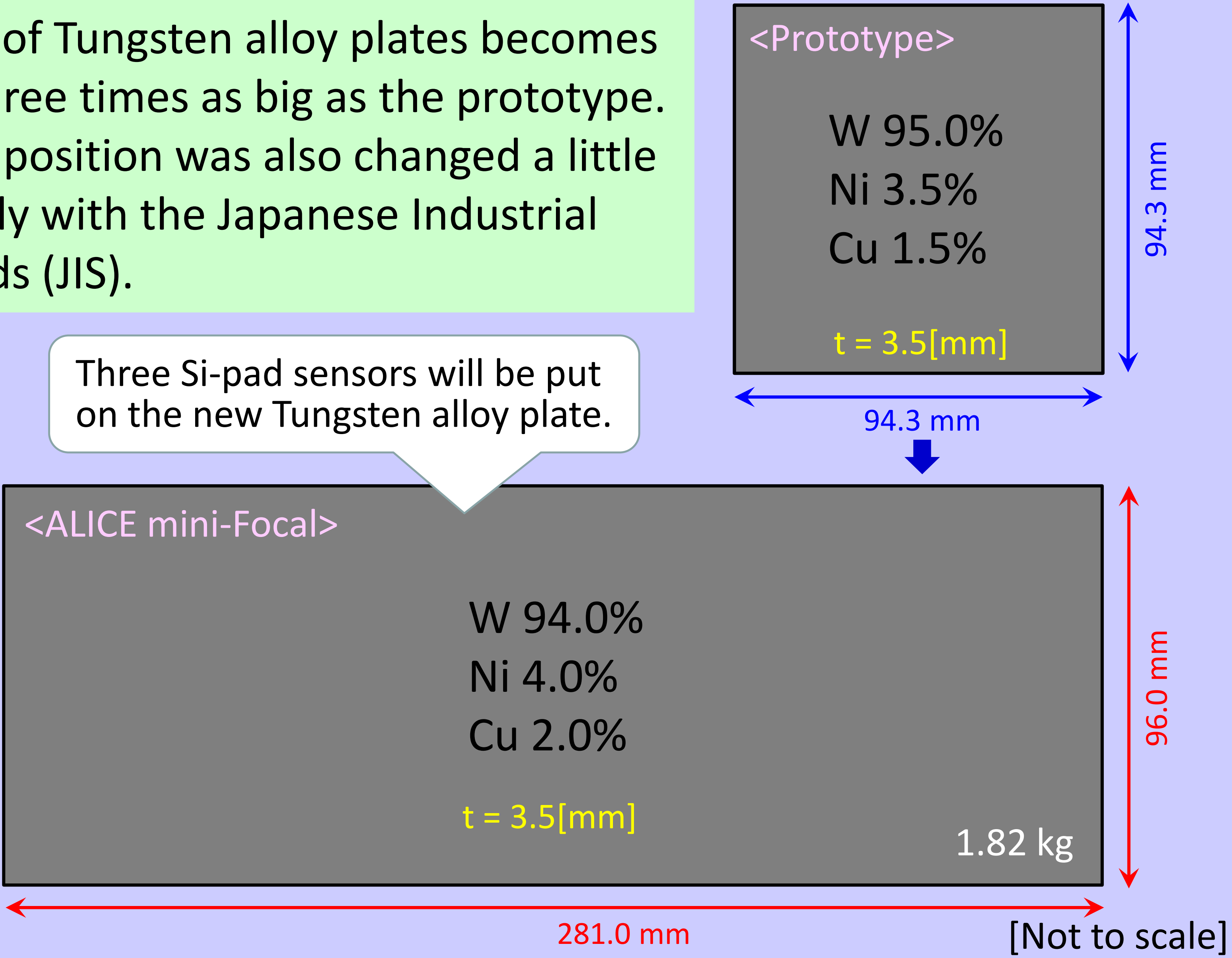


Two scintillation counters for a self trigger signal.

[Not to scale]

New Tungsten alloy plates

The size of Tungsten alloy plates becomes about three times as big as the prototype. The composition was also changed a little to comply with the Japanese Industrial Standards (JIS).



Three Si-pad sensors will be put on the new Tungsten alloy plate.

[Not to scale]

New Si-pad sensors

Modified items

Si thickness ➡ 320 um

Si-pad surface ➡ Aluminum
(No window on the surface.)

Wire bonding pads
➡ Bigger in a new position

No change

Si-pad sensor size: 93.0 mm^2

The number of cells: 64

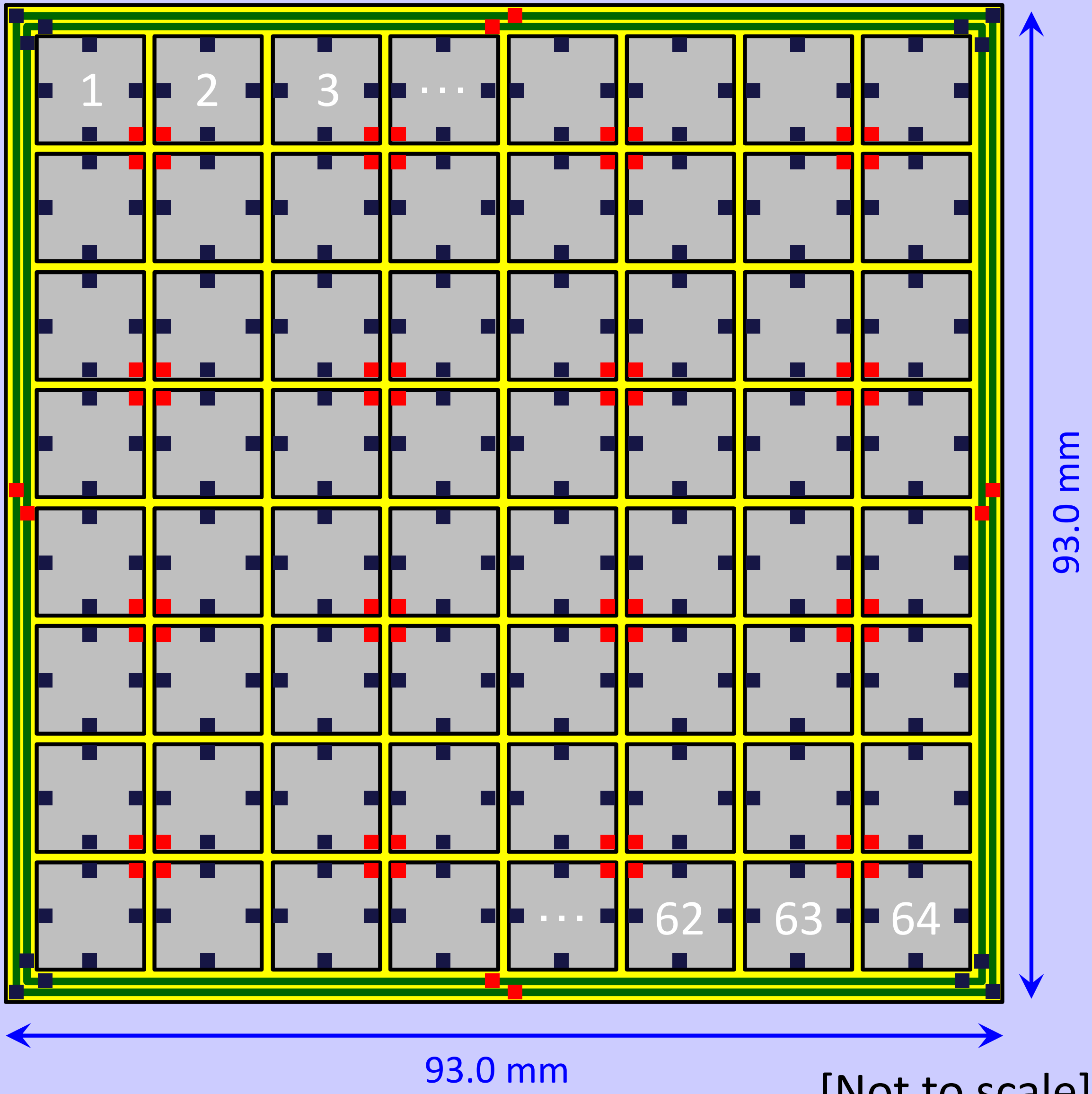
The cell size: 11.25 mm^2

The cell pitch: 11.30 mm

The guard ring: Yes

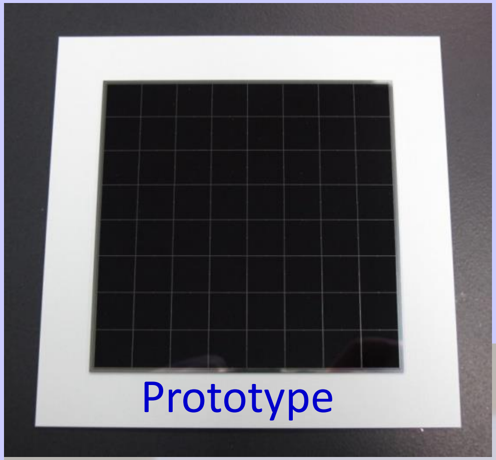
The back side plating: Au

72 wire-bonding-pads in red were used.



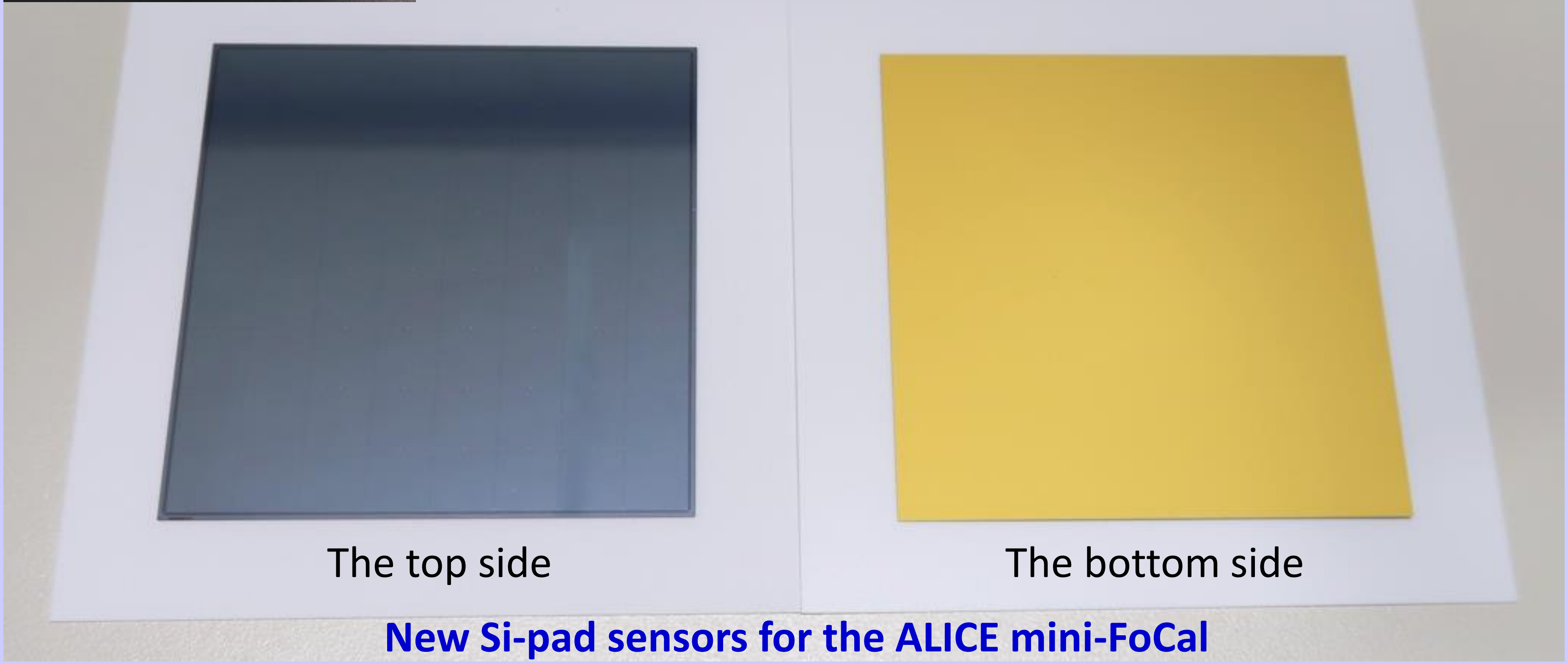
[Not to scale]

New Si-pad sensors in 2018



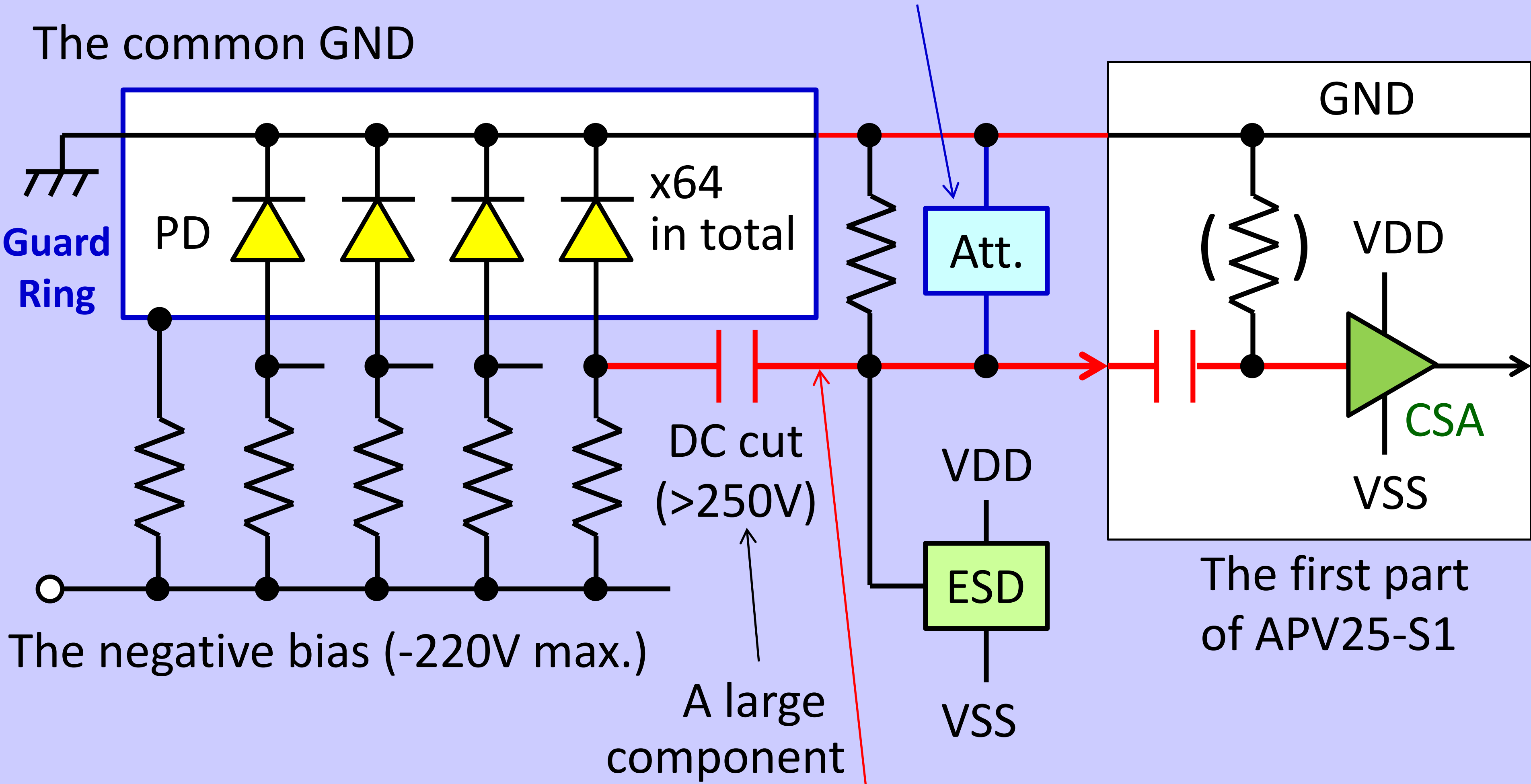
- ✓ The light-tighter design.
- ✓ New wire bonding pads.
- ✓ For the improvement of the radiation durability.

New



New Si-pad sensors for the ALICE mini-FoCal

Attenuation of signals



Passive components as an attenuator.

These lines are very sensitive to the noise / crosstalk.
It is important to keep a length of these lines the shortest.

The attenuation ratio

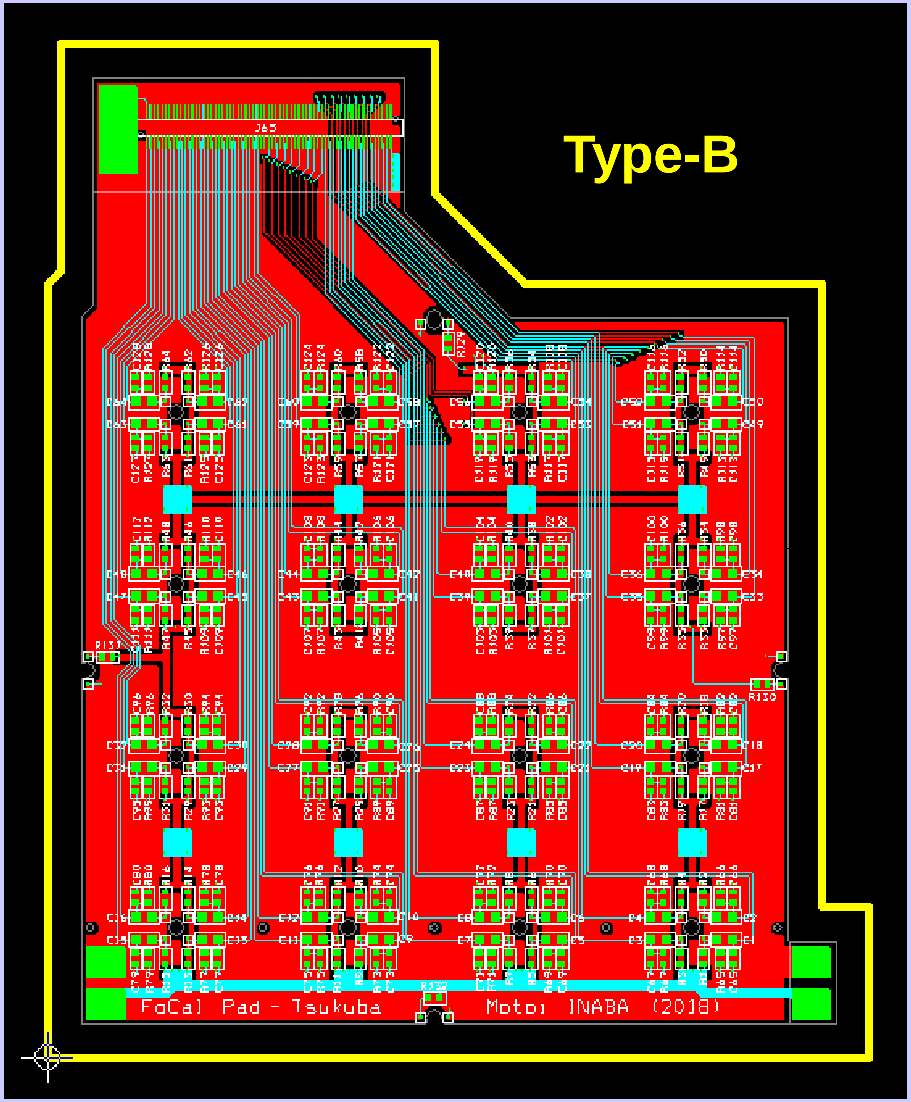
Layer	Detector & attenuation		FPC
1	Scintillation counter		
2	Si-pad	**1/18**	Type-B
3	Si-pad	**1/18**	Type-A
4	Si-pad	**1/180**	Type-B
5	Si-pad	**1/180**	Type-A
6	Si-pad	**1/180**	Type-B
7	Si-pad	**1/180**	Type-A
8	Si-pad	**1/180**	Type-B
9	Si-pad	**1/180**	Type-A
10	Si-pad	**1/180**	Type-B
11	Si-pad	**1/180**	Type-A

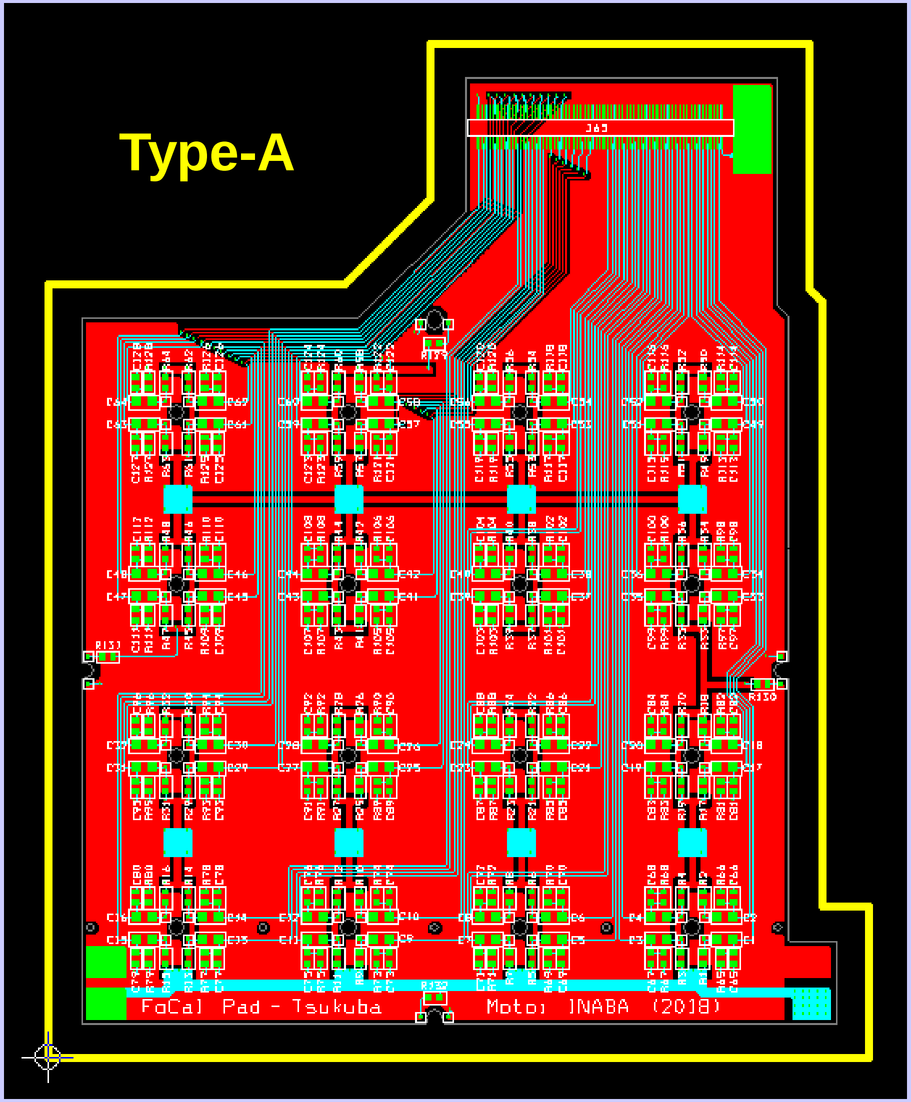
Layer	Detector & attenuation		FPC
12	Si-pad	**1/180**	Type-B
13	Si-pad	**1/180**	Type-A
14	Si-pad	**1/180**	Type-B
15	Si-pad	**1/180**	Type-A
16	Si-pad	**1/180**	Type-B
17	Si-pad	**1/180**	Type-A
18	Si-pad	**1/180**	Type-B
19	Si-pad	**1/180**	Type-A
20	Si-pad	**1/180**	Type-B
21	Si-pad	**1/180**	Type-A
22	Scintillation counter		

Notes: It is possible to adjust a gain of APV25-S1 within +/- 20% through a slow control.

New FPCs

I designed two types of FPC with two layers for the mini-FoCal.





Channel maps

In order to reduce a crosstalk between signals, I tried to separate the channels with the next number from each other as much as possible.

⊗ **Seen from the collision point**

87	30	103	14	110	45	8	100
27	94	11	78	3	13	40	68
91	19	66	6	73	41	72	36
31	83	2	70	105	9	104	4
111	79	74	71	69	37	12	96
23	47	10	39	101	5	44	64
107	75	99	67	65	33	76	32
15	43	7	35	97	1	108	0

Type-B

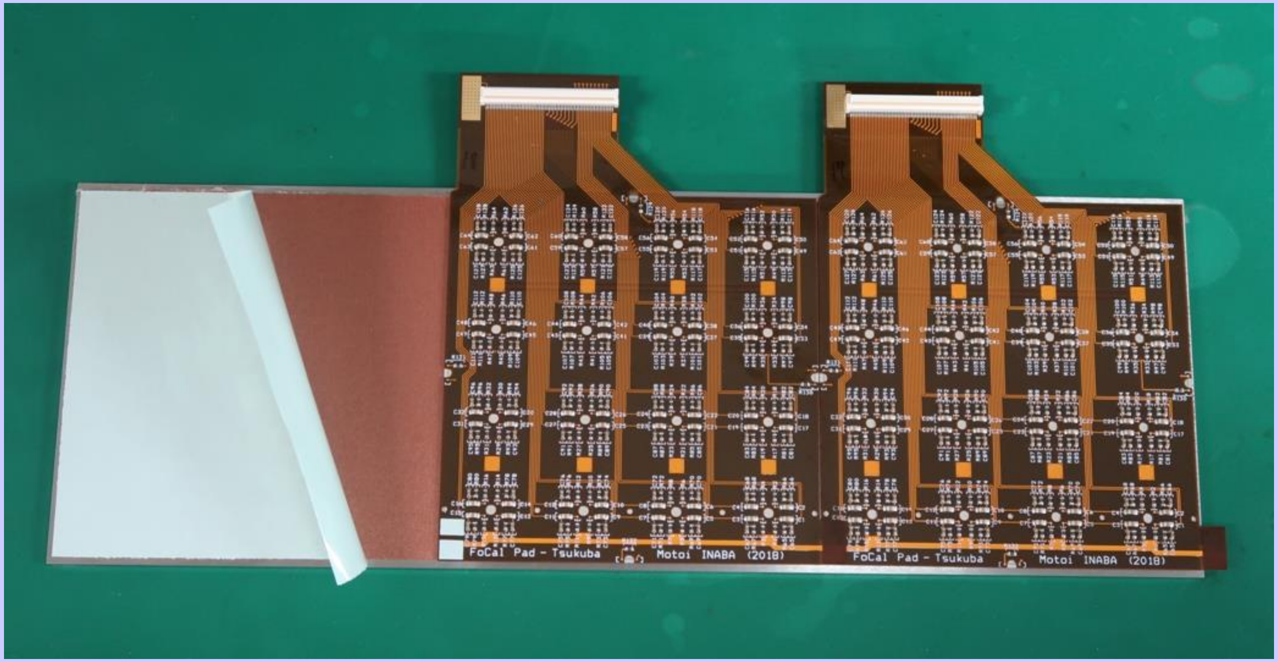
⊗ **Seen from the collision point**

11	103	66	33	37	40	53	56
43	71	98	1	97	8	113	116
75	39	70	38	45	100	49	52
107	7	102	6	105	68	124	112
15	99	74	42	41	36	64	32
47	67	106	10	101	4	96	0
79	35	78	46	76	44	72	120
111	3	110	14	108	12	104	60

Type-A

Gluing

We used two kinds of adhesive sheets to glue FPC onto Si-pad and Si-pad onto the Tungsten alloy plate after some tests.



Insulated adhesive sheets

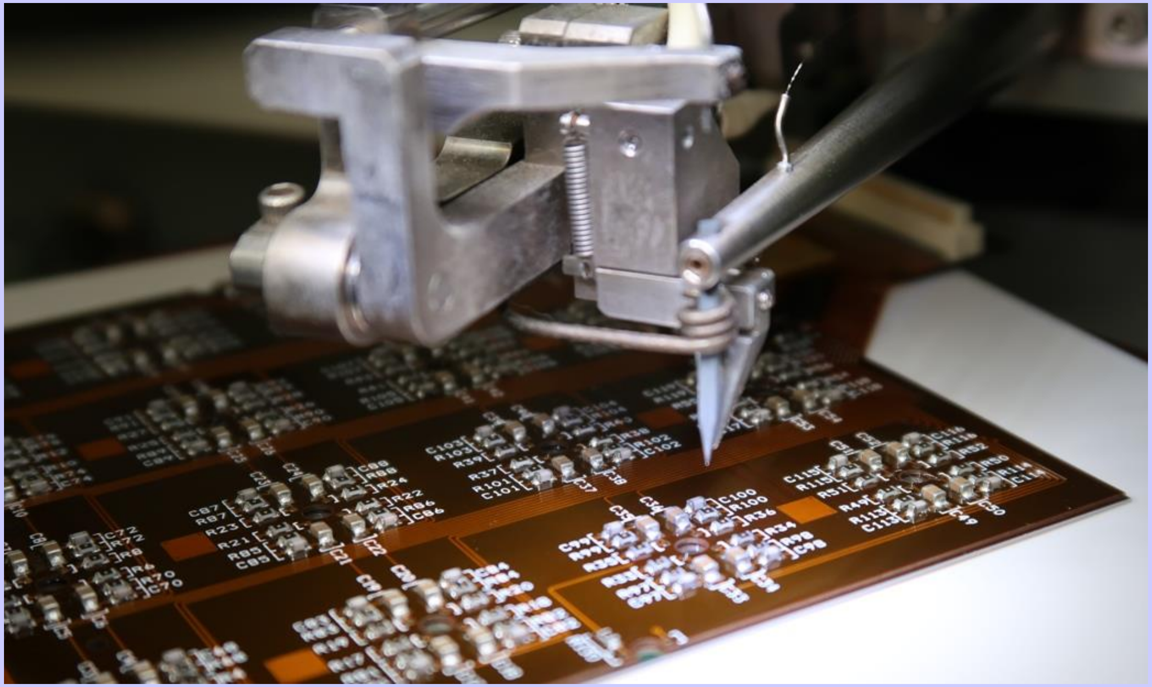
Product Number	Carrier	Thickness	High Temp. Range	Dielectric Properties
9495MP	**Clear PET**	**0.013mm**	**121℃**	**54kV/mm**
9495LE	Clear Polyester	0.013mm	93℃	43kV/mm
9490LE	Clear PET	0.013mm	93℃	40kV/mm

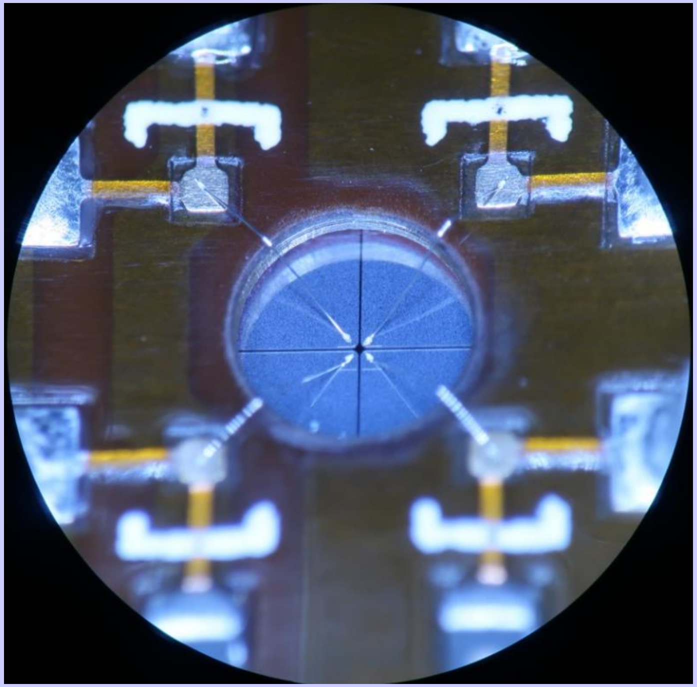
Conductive adhesive sheets

Product Number	Carrier	Thickness	Adhesive Force	Resistance
X7001	**Cu-planting**	**0.110mm**	**6.6 N/cm**	**0.015Ω ／25mm^2**
CN-4490	Cu/Ni plated	0.050mm	3.9 N/cm	0.050Ω ／mm^2
AL-25DC	Al-base	0.085mm	3.6 N/cm	0.035Ω ／25mm^2

Wire bonding

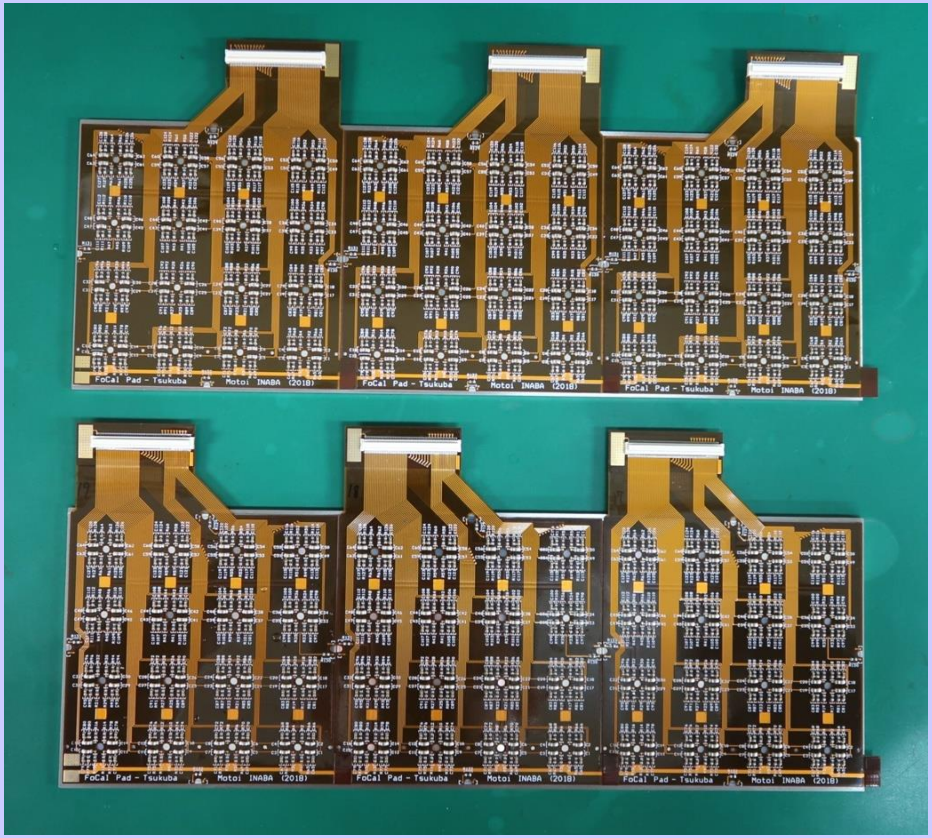
After FPC was glued onto Si-pad, I bonded aluminum wires from the Si-pad sensor to FPC. One sensor needed 64 signal wires, 4 bias wire and 4 GND wires. 4 signal wires came though the same hole on FPC. One company in Japan helped us for reducing a production schedule.



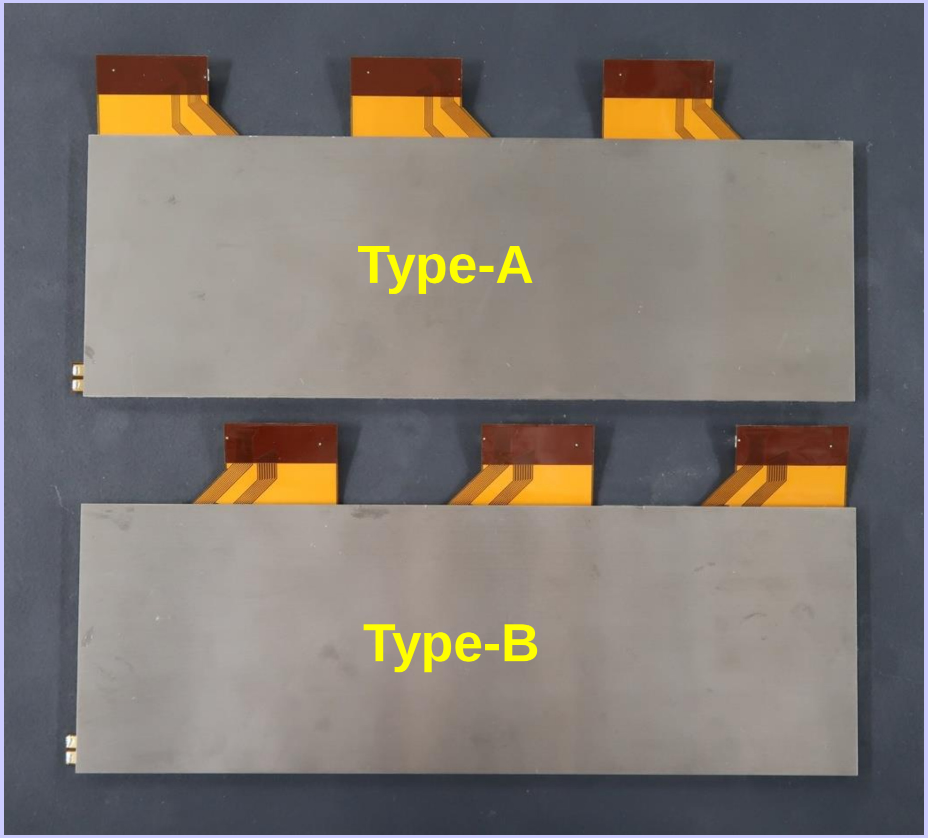


Two types of Si-pad layer

Finally, we have produced both of Type-A and Type-B layers. It has three 130-pin connectors for APV25-S1 hybrid boards on the top side and a bias connector at the bottom corner.

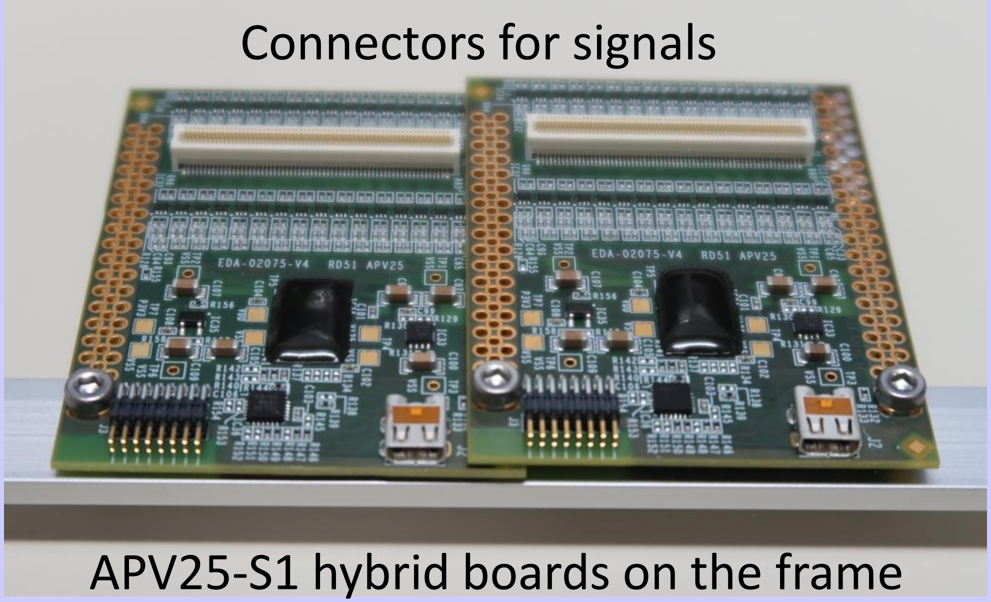


The FPC side

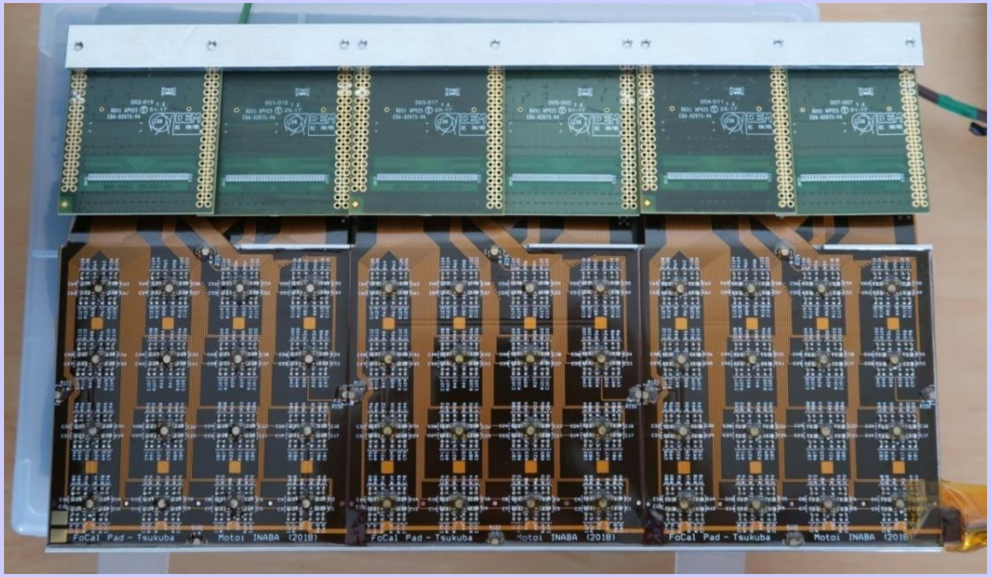


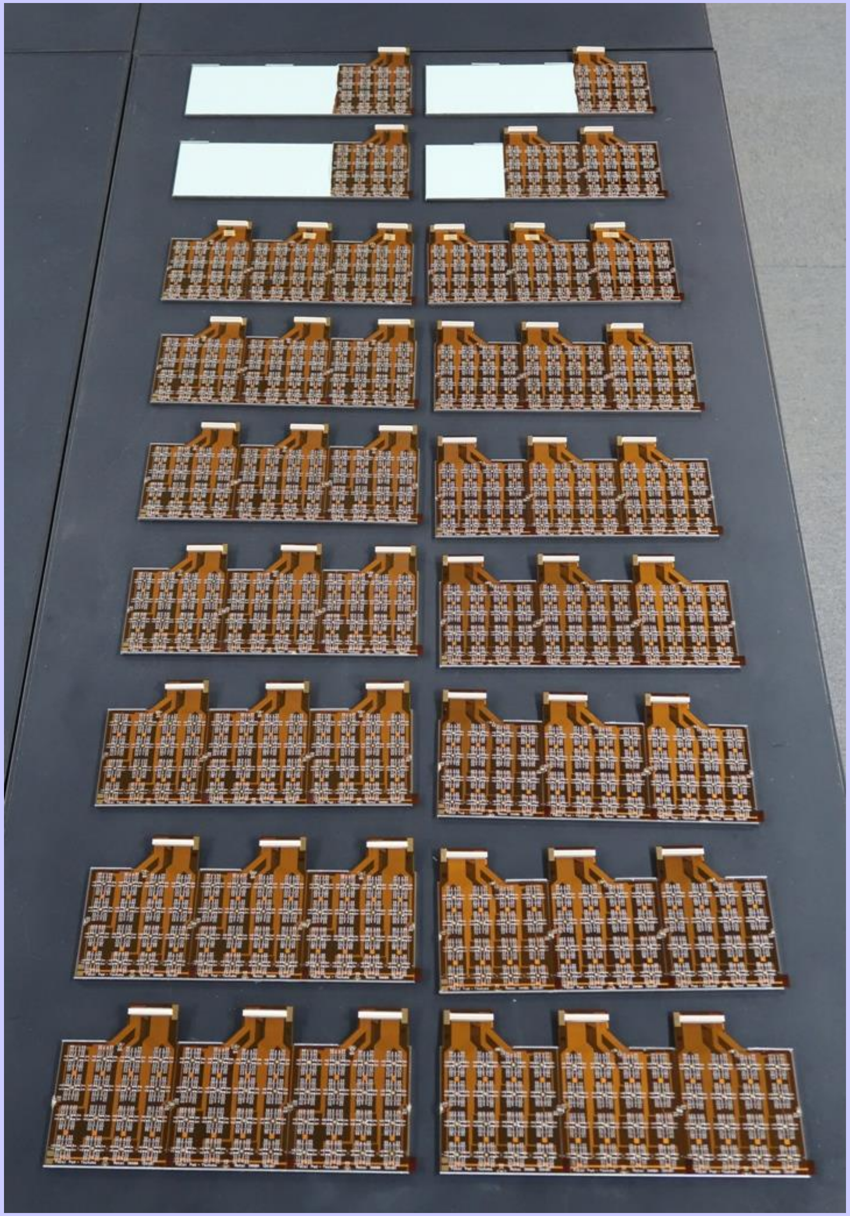
The Tungsten side

New Si-pad sensors in 2018


Connectors for signals

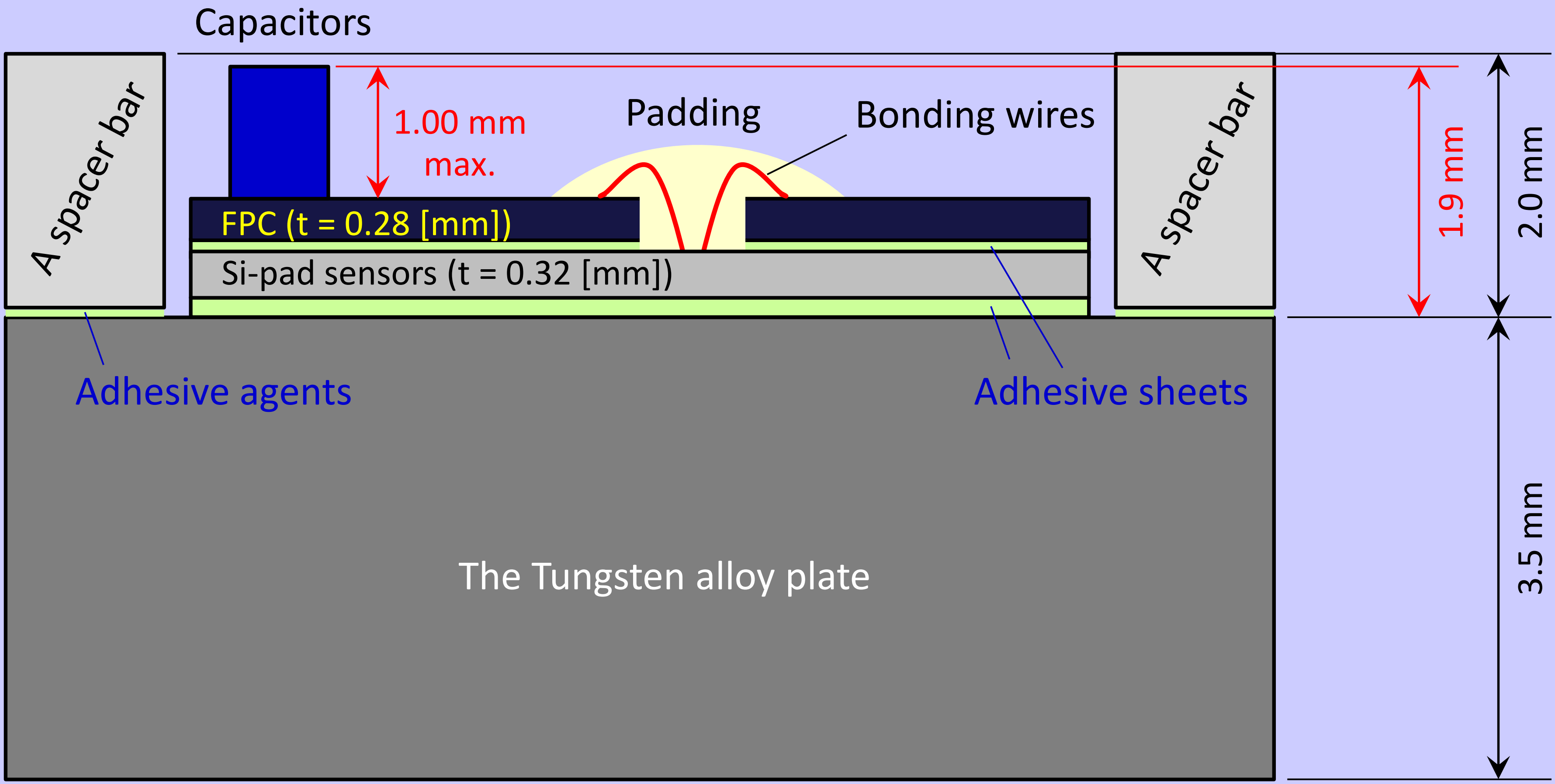
APV25-S1 hybrid boards on the frame





A thickness of one layer

A height of the 250V DC-cut capacitor was equal to 1.0 mm. In order to keep a gap between the capacitor and the next layer, we asked a company to make small aluminum bars called “Spacer bars”.



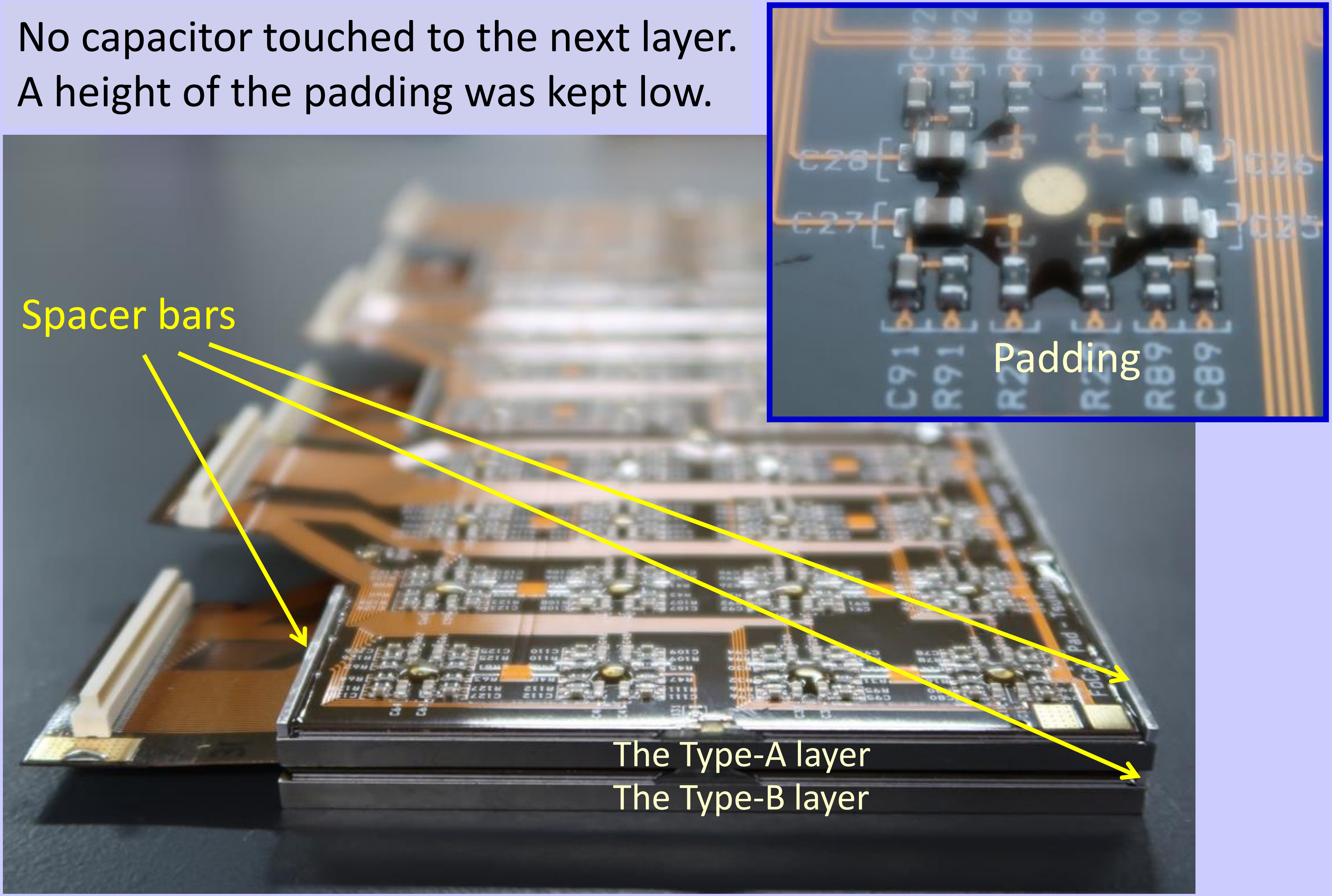
< A sectioned drawing >

[Not to scale]

Spacer bars

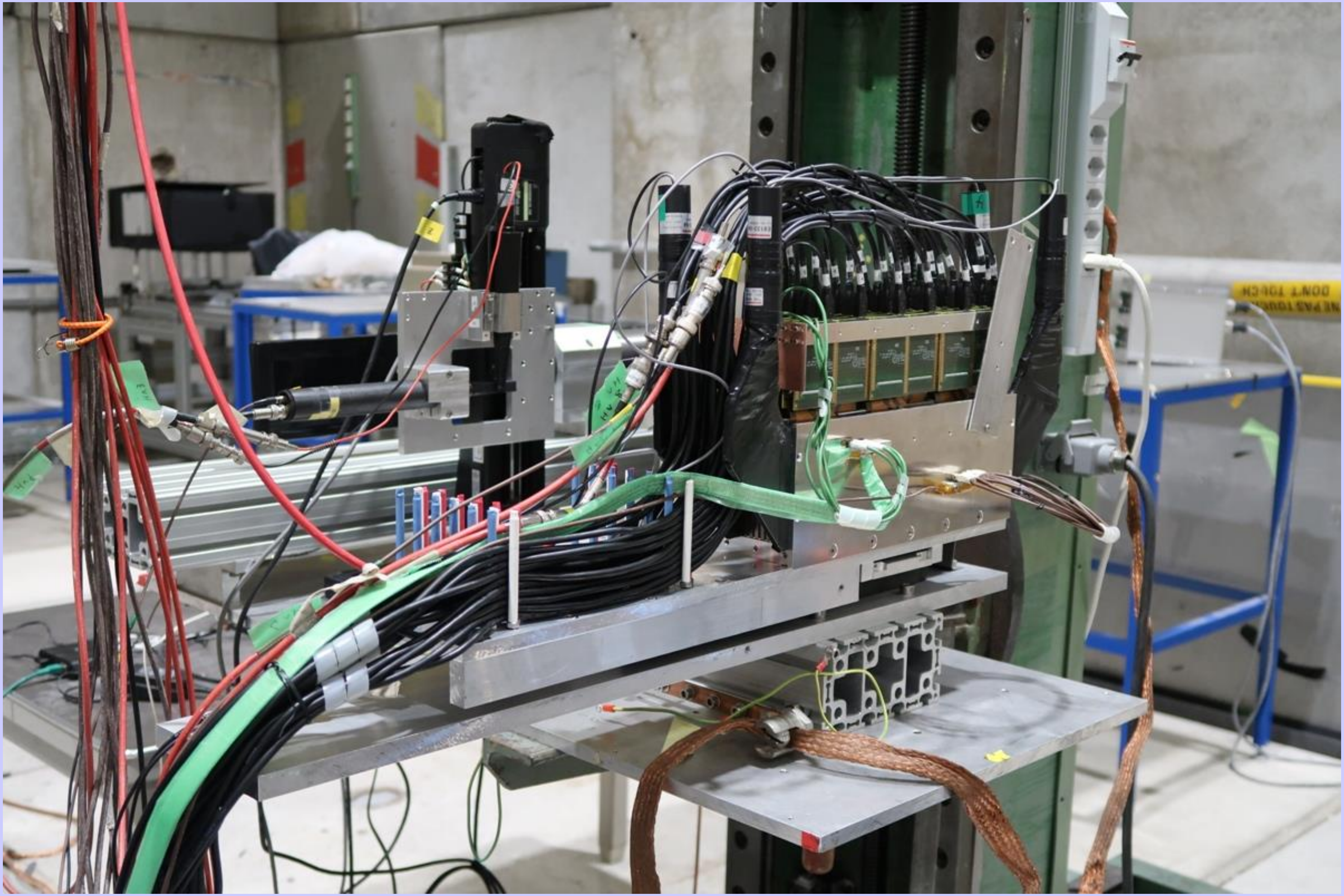
No capacitor touched to the next layer.

A height of the padding was kept low.

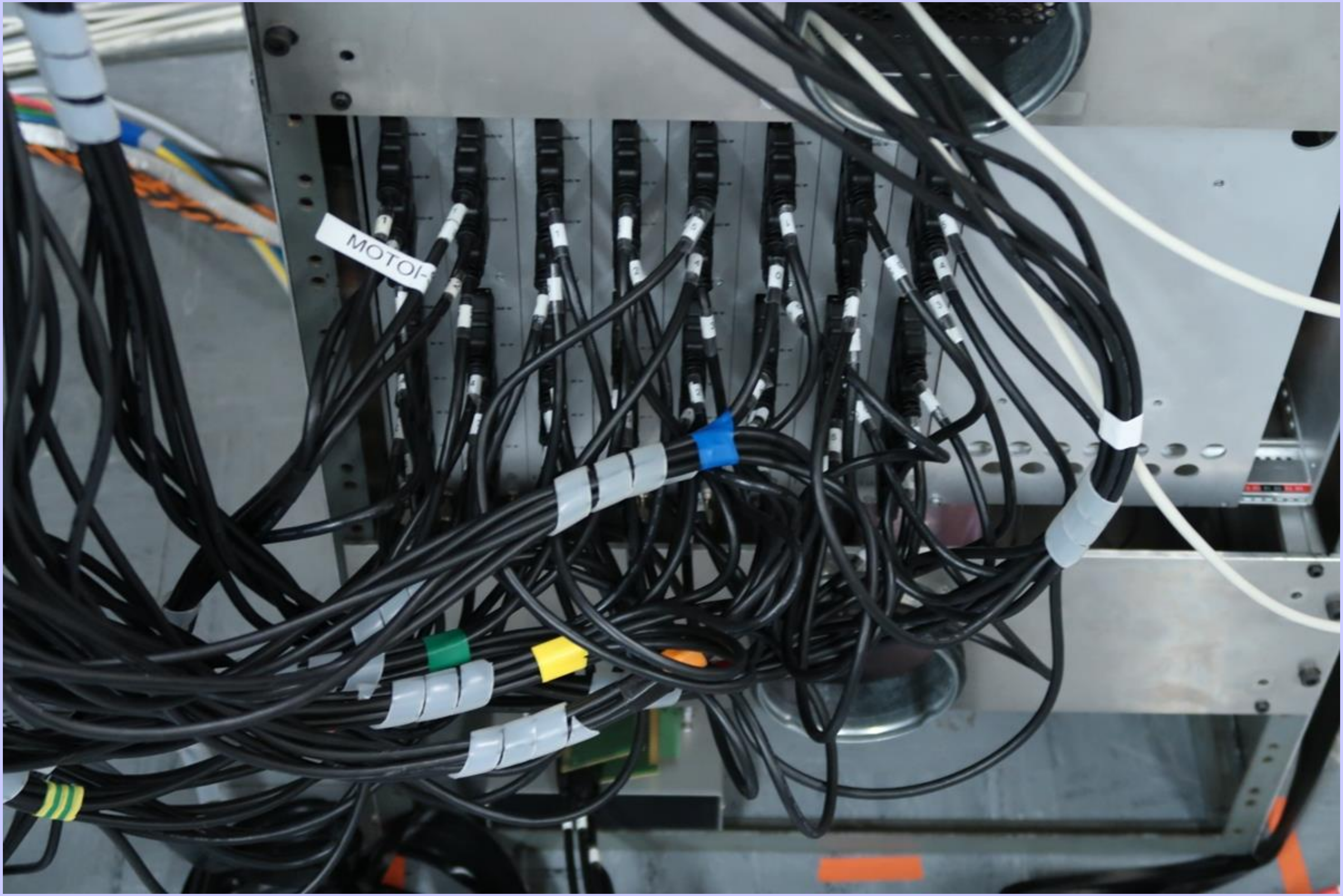


Beam tests at the CERN PS and SPS complexes

Mini-FoCal at the SPS complex in 2018



Cabling to the SRS readout system

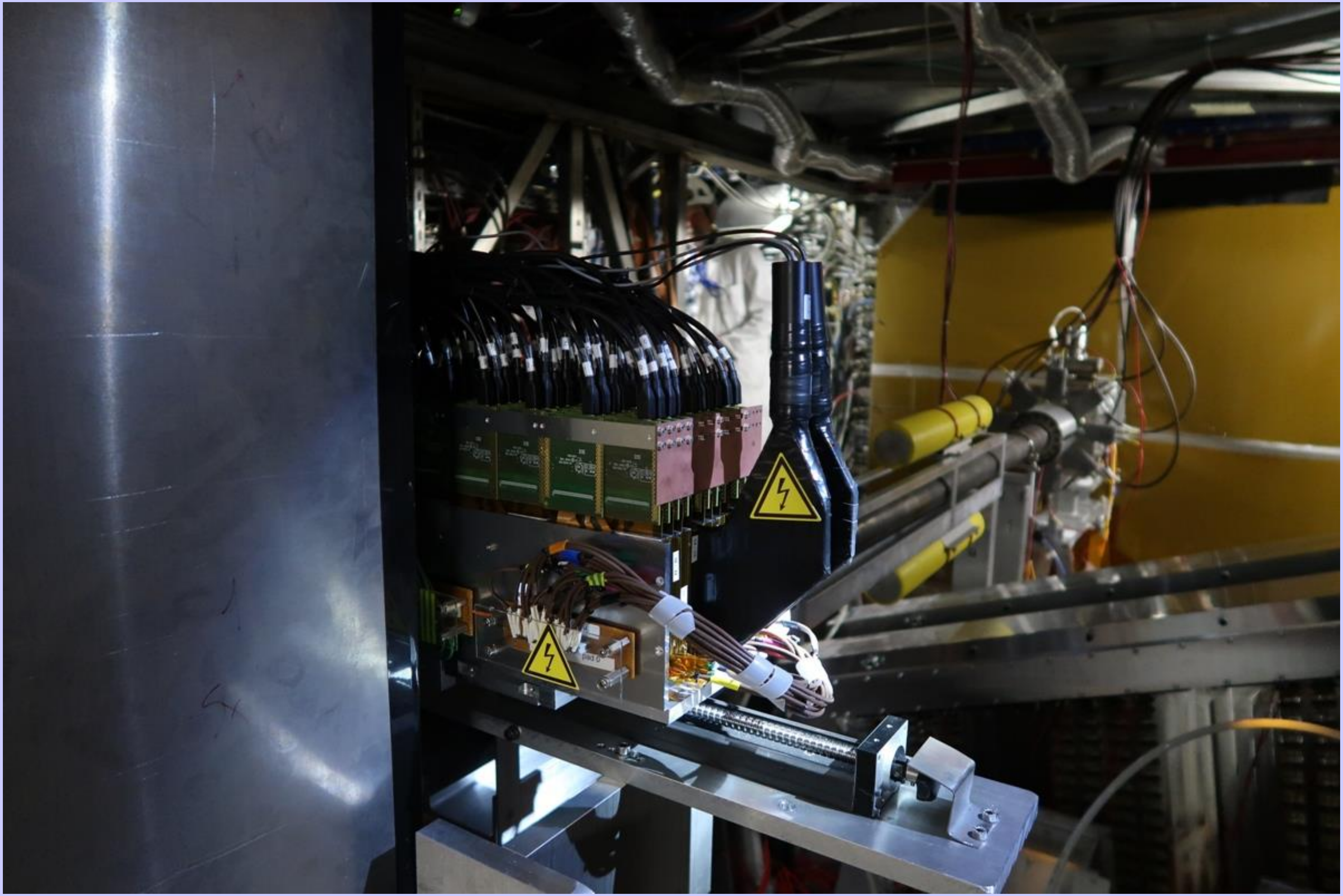


Crews at the SPS complex in 2018

Installation of Mini-FoCal at the ALICE cavern

Mini-FoCal at the ALICE cavern in 2018

Mini-FoCal at the ALICE cavern in 2018



Crews at the ALICE cavern in 2018

Results of beam tests and ALICE cavern

Results of the beam test at the CERN **PS** complex in 2018

→ By Takashi Hachiya in this afternoon.

→ By Yoko Minato in this afternoon.

Results of the beam test at the CERN **SPS** complex in 2018

→ By Saori Takasu in this afternoon.

Results of the mini-FoCal p-p run at the **ALICE** cavern in 2018

→ By Norbert Novitzky in this afternoon.

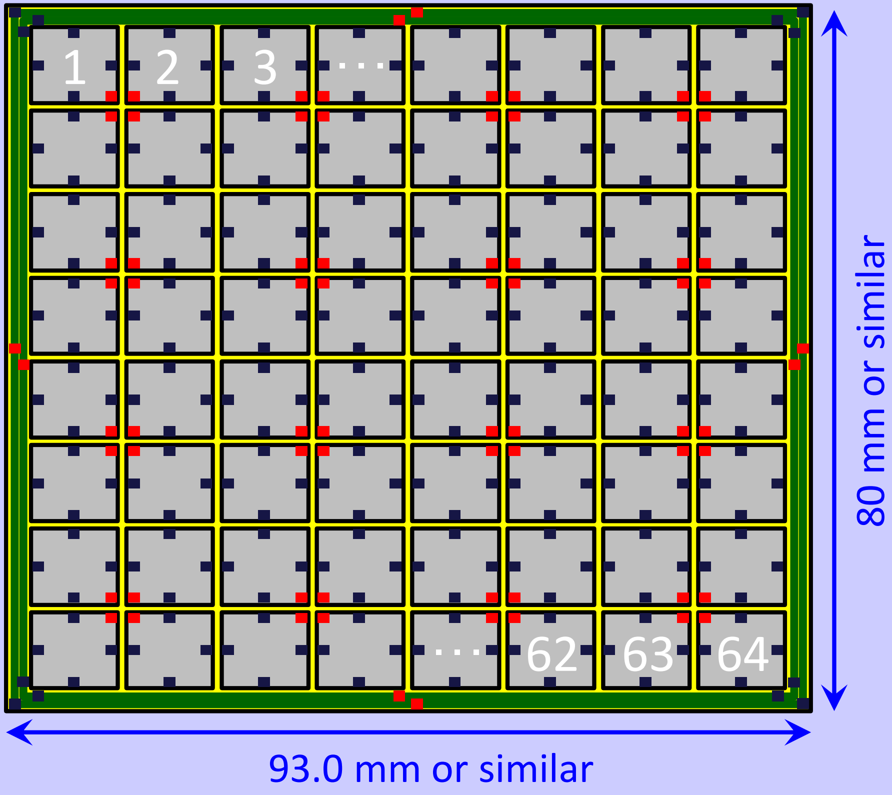
New studies for the (full-size) FoCal

1. A design of the new Si-pad sensor
2. For the thinner Si-pad layer
3. The SAMPA test board
4. Some other ideas

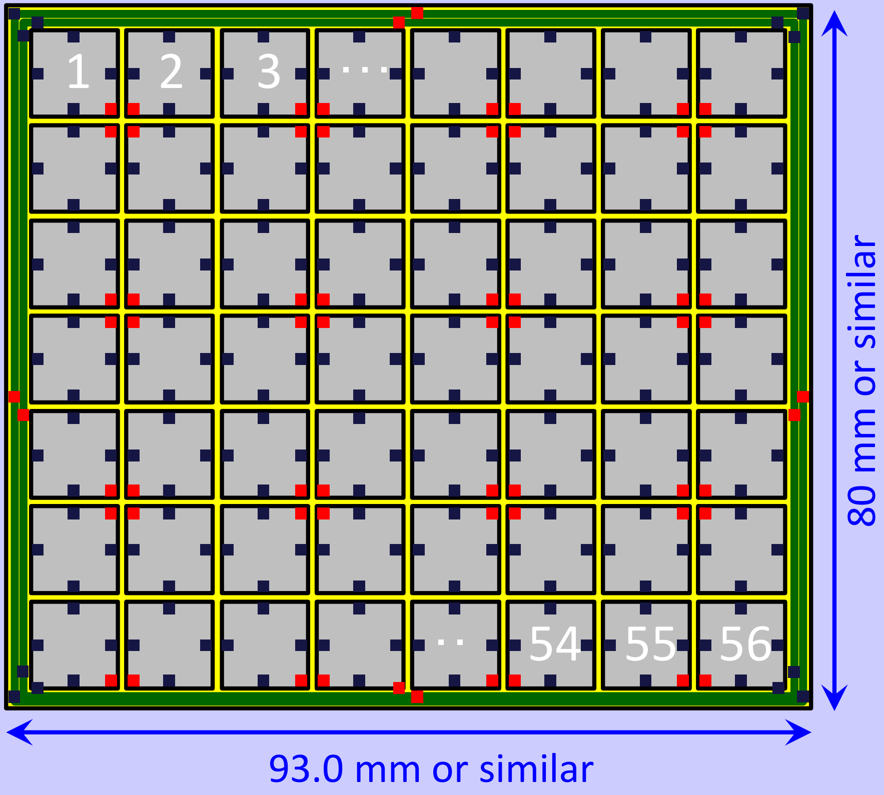
(1) A design of the new Si-pad sensor

I hope that we have no technical problem to change the size, a number of channels, a guard ring of new Si-pad sensors for the (full-size) FoCal in order to fit for the size of the MAPS module.

For examples: with rectangular cells



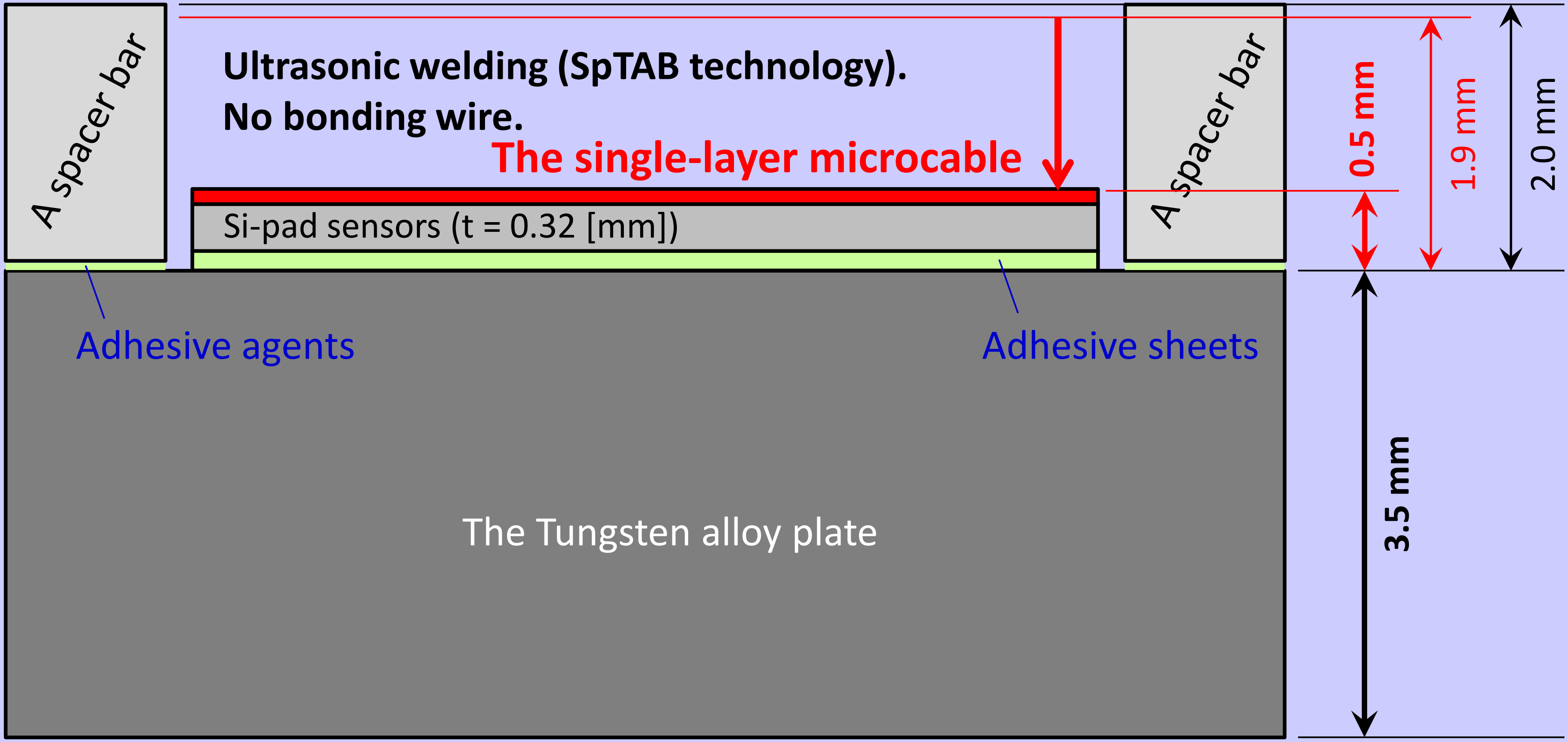
In the 8 x 7 layout



[Not to scale]

(2) For a thinner Si-pad layer

We should study if we can use a long cable (~300mm) from the Si-pad to the front-end electronics or not. If analog signals are not covered by the noise, all components can be removed from FPC or a cable. A thickness of one layer might become about 4.0 mm.

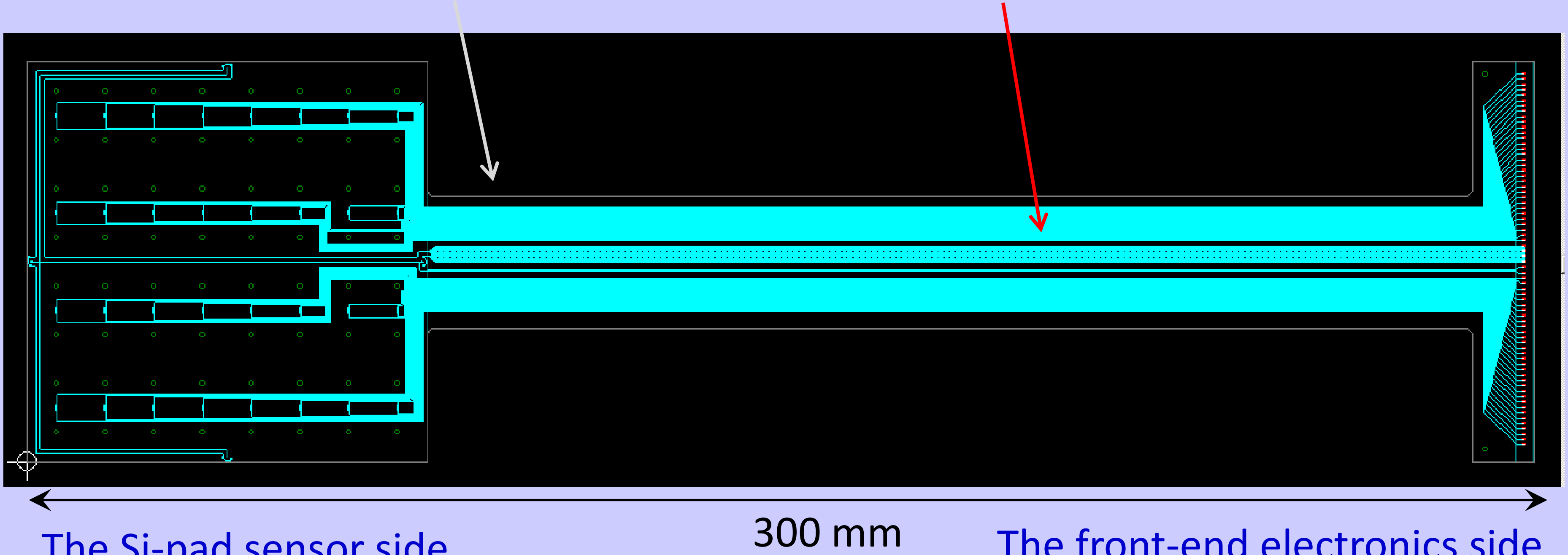


< A sectioned drawing >

[Not to scale]

A design of the microcable

I already submitted the data to a company in the Ukraine.
We are looking forward to the microcable for testing.



Outline of the microcable

64 signal lines, 1 bias line and 1 GND line.

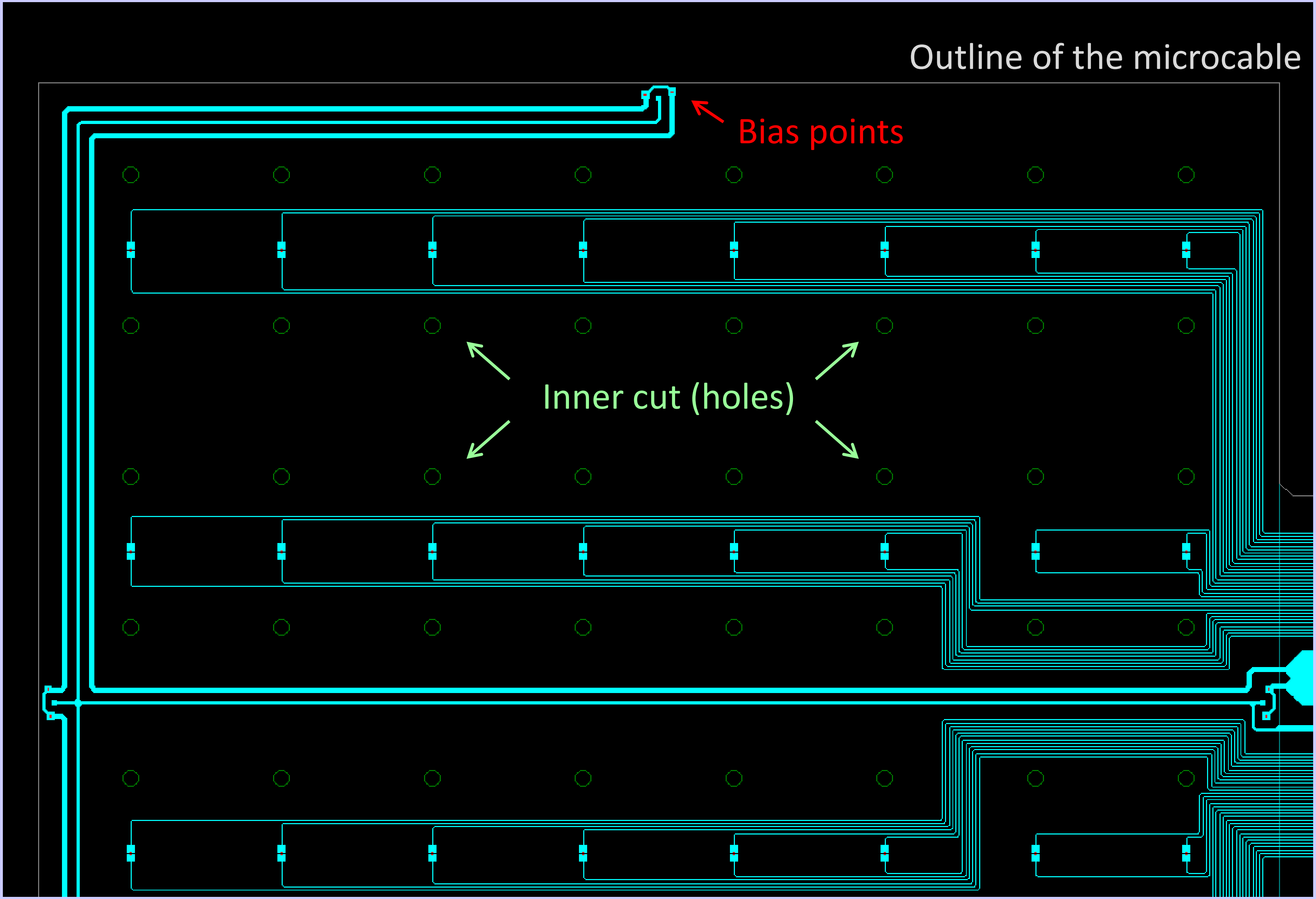
300 mm

The Si-pad sensor side
(93mm x 93mm)

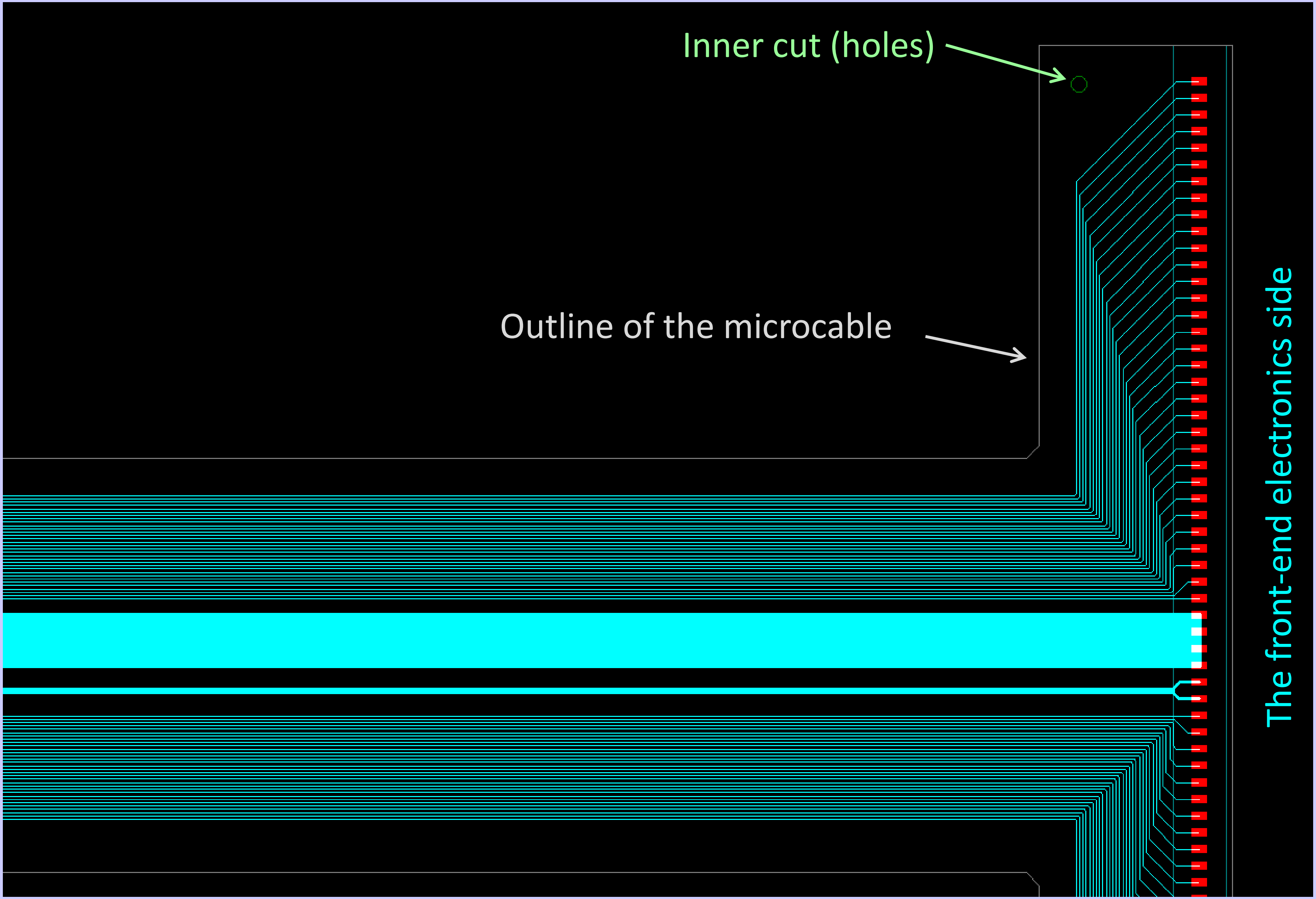
The front-end electronics side

If signal lines are contaminated with the large noise, we needs some active components near the Si-pad sensor.

A design of the microcable



A design of the microcable

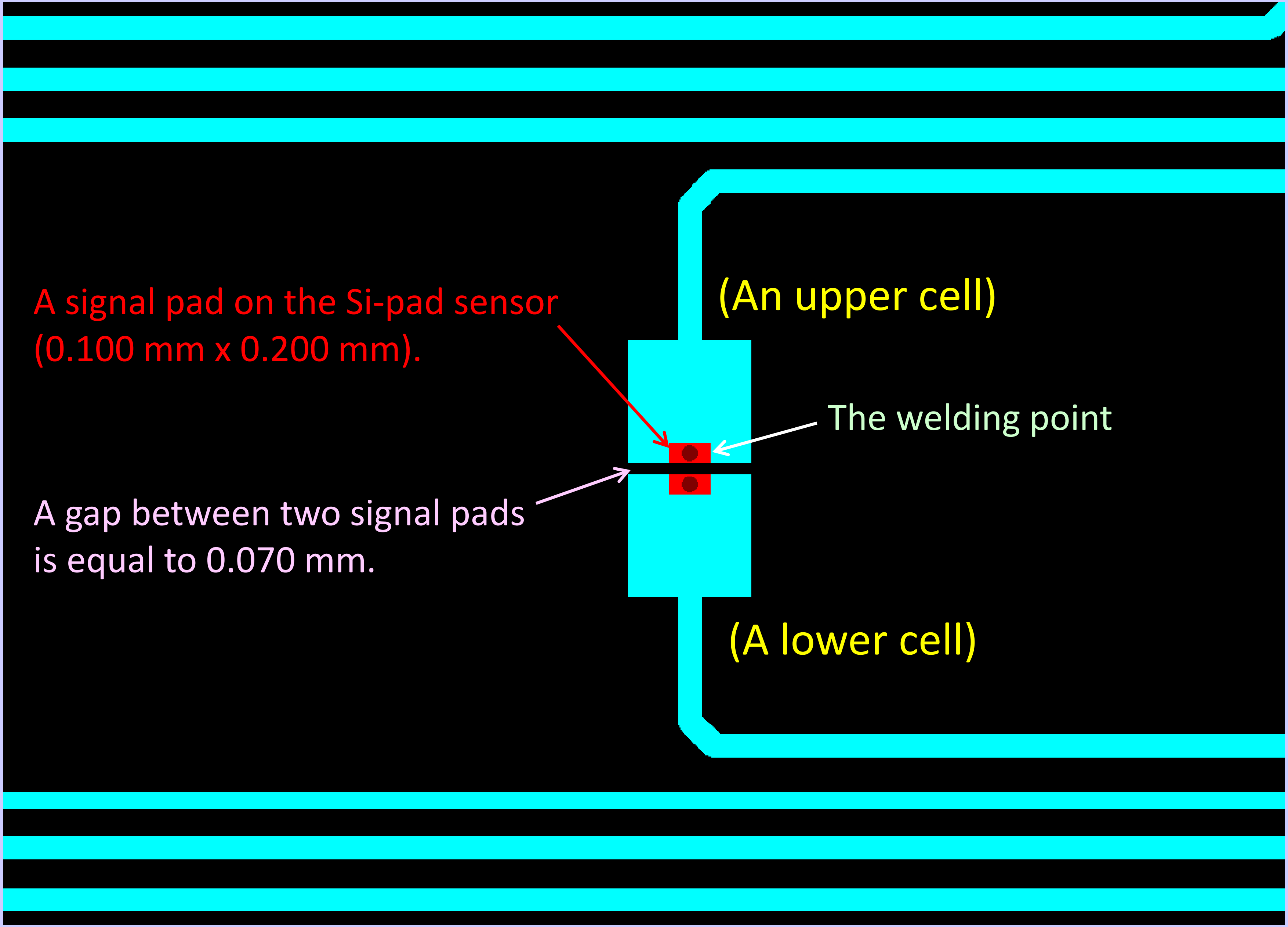


Inner cut (holes)

Outline of the microcable

The front-end electronics side

A design of the microcable

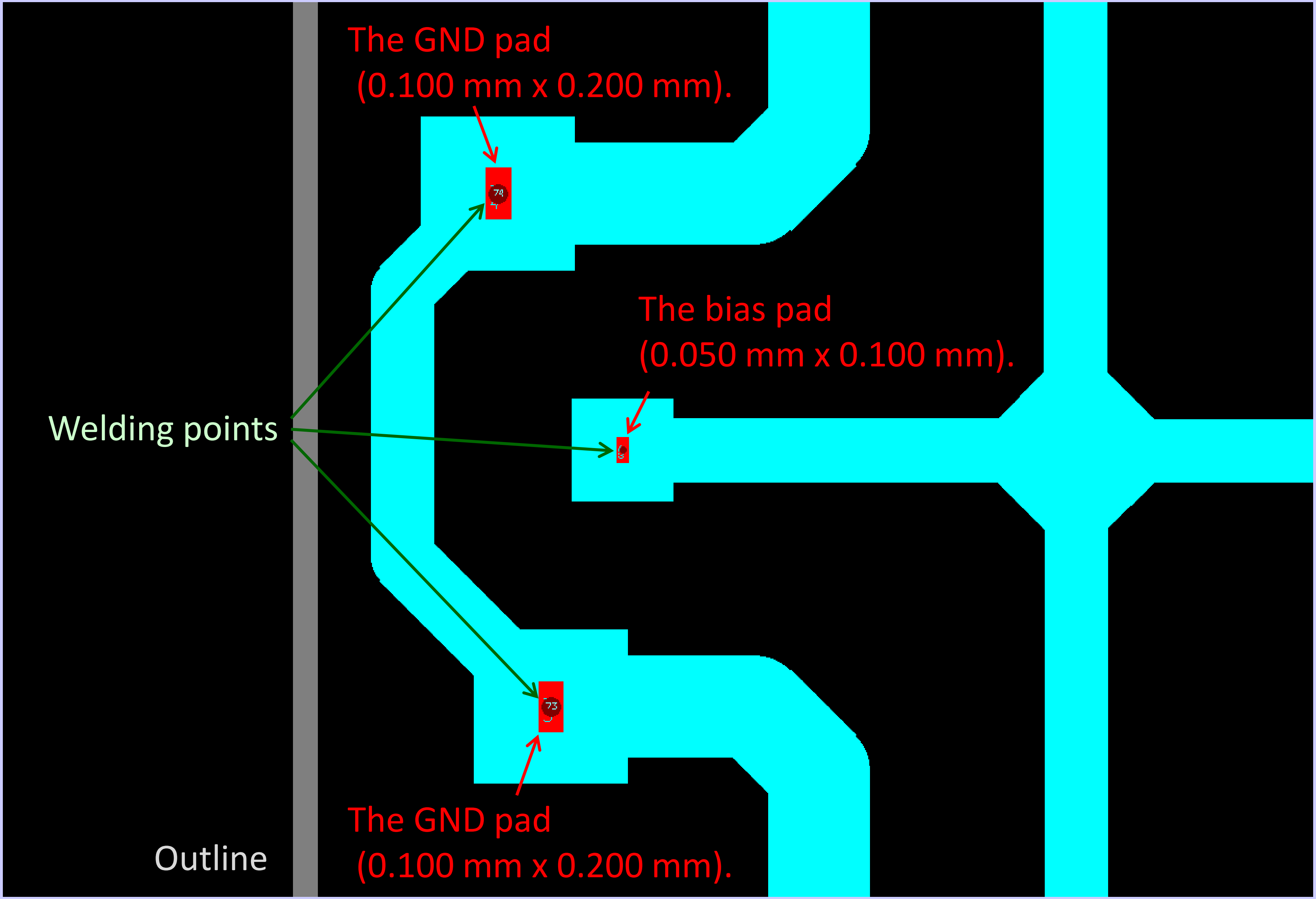


A signal pad on the Si-pad sensor (0.100 mm x 0.200 mm).

The welding point

A gap between two signal pads is equal to 0.070 mm.

A design of the microcable



The GND pad (0.100 mm x 0.200 mm).

The bias pad (0.050 mm x 0.100 mm).

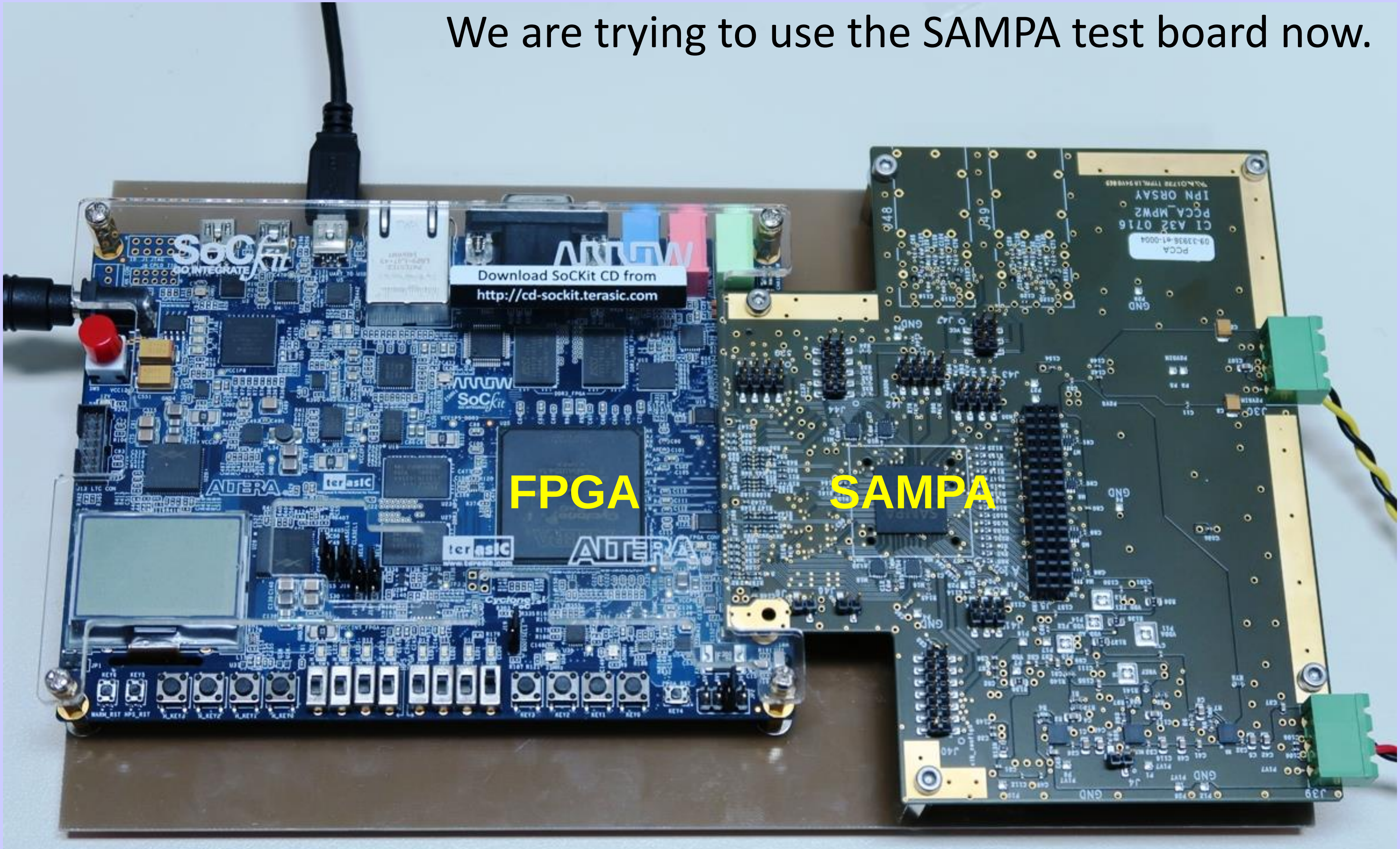
Welding points

The GND pad (0.100 mm x 0.200 mm).

Outline

(3) SAMPA test board

We are trying to use the SAMPA test board now.



New SAMPA ASIC ? Dual / triple gain ? Higher ADC sampling rate ?

(4) Some other ideas

We have three types of the front-end electronics.

Type A: **A current-to-amplitude converter** (A current-sensitive type)

It has a simple circuit construction and a wider dynamic range, it is easy to make the multiple gains, but it is unsuitable for a small signal such as the MIPS data.

Type B: **A charge-to-amplitude converter** (A charge-sensitive type)

It is suitable for the MIPS measurement, but it has a complex circuit diagram (it needs a large space) and it is difficult to realize the multiple gains.

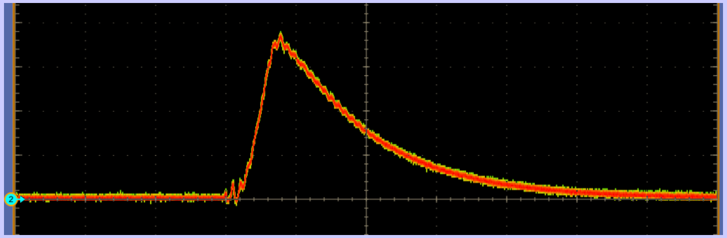
Type C: **An integration circuit** (A peak-hold type)

It has a simple circuit construction and it is possible to use for the MIPS measurement, but it has no information of timing.

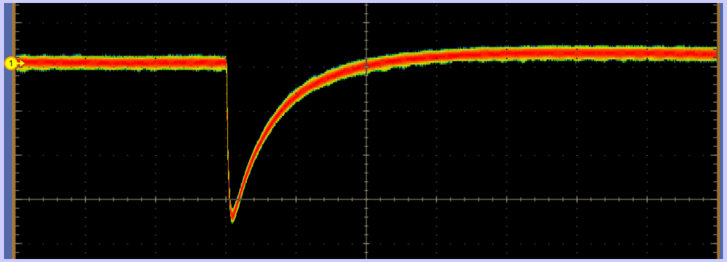
A possibly to adopt two types

We have three types of the front-end electronics.

Type A: **A current-to-amplitude converter** (A current-sensitive type)



Type B: **A charge-to-amplitude converter** (A charge-sensitive type)

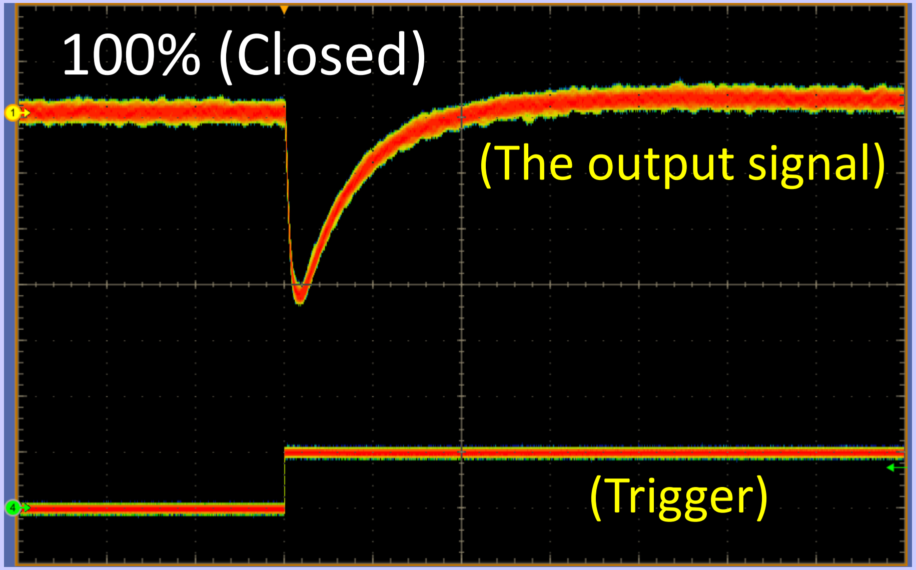


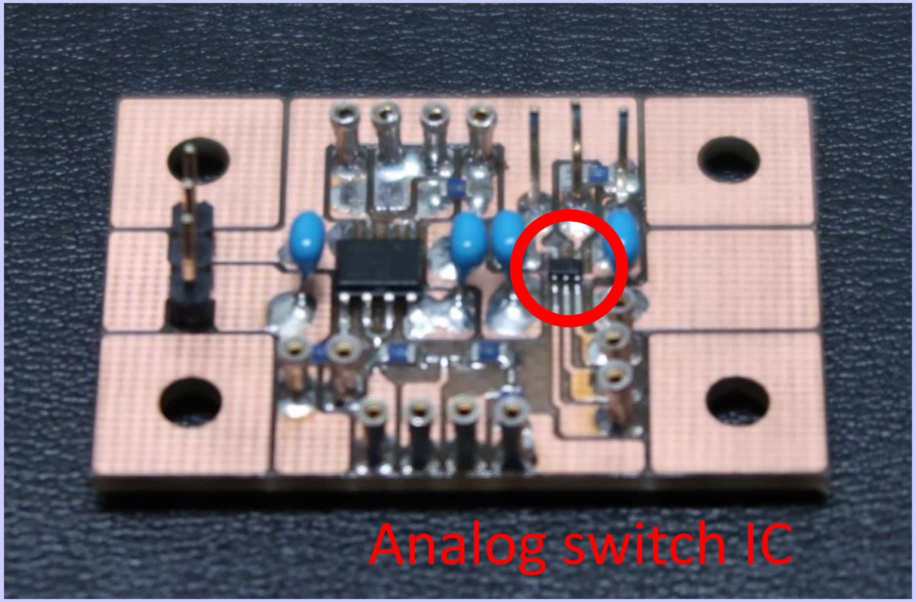
~~**Type C**: **An integration circuit** (A peak-hold type)~~

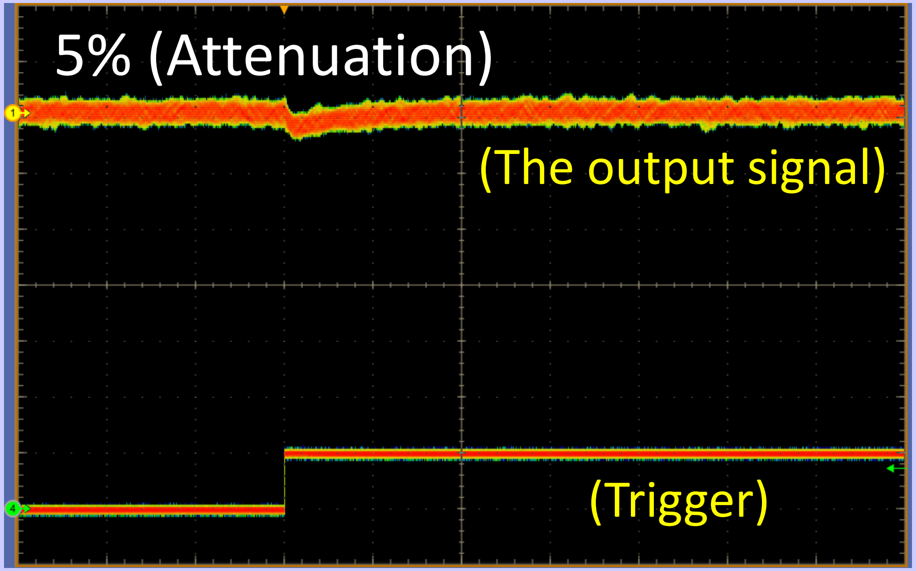
~~It has a simple circuit construction and it is possible to use for the MIPS measurement, but it has no information of timing.~~

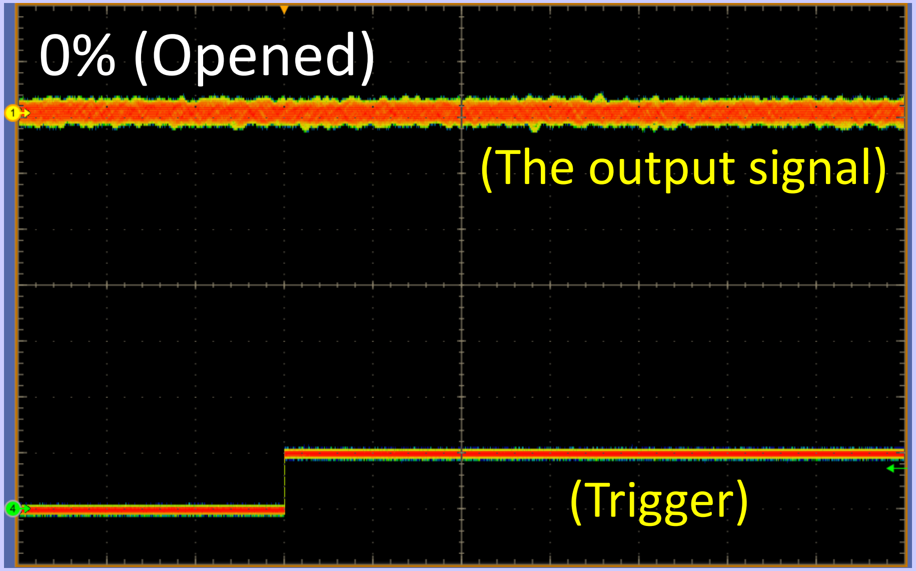
This type can not remove the pile-up events.

Analog switches / current mirrors


100% (Closed)




5% (Attenuation)


0% (Opened)

It has a possibility to merge the current- and the charge-sensitive types.

Summary