INTT Ladder NIM Figures

RIKEN/RBRC

Itaru Nakagawa

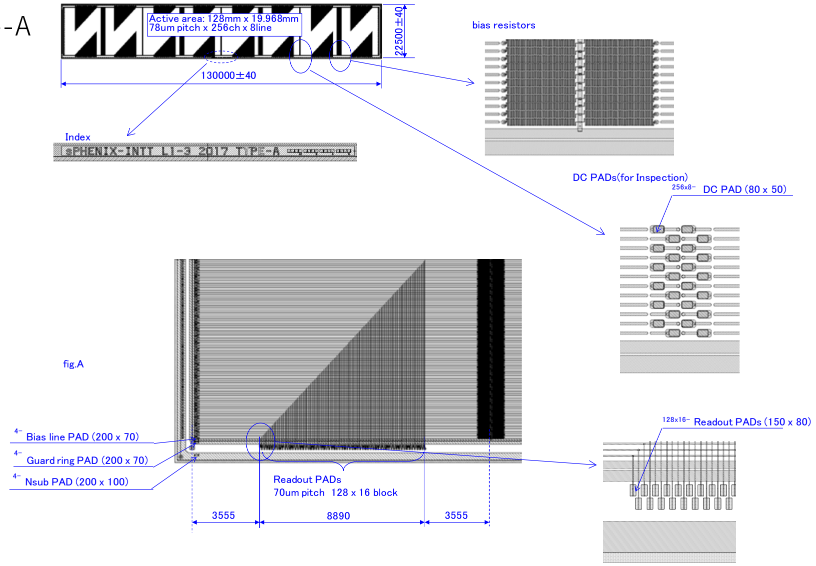
Some updates

Carefully checked through the materials and engineering drawings, there are minor updates in the following.

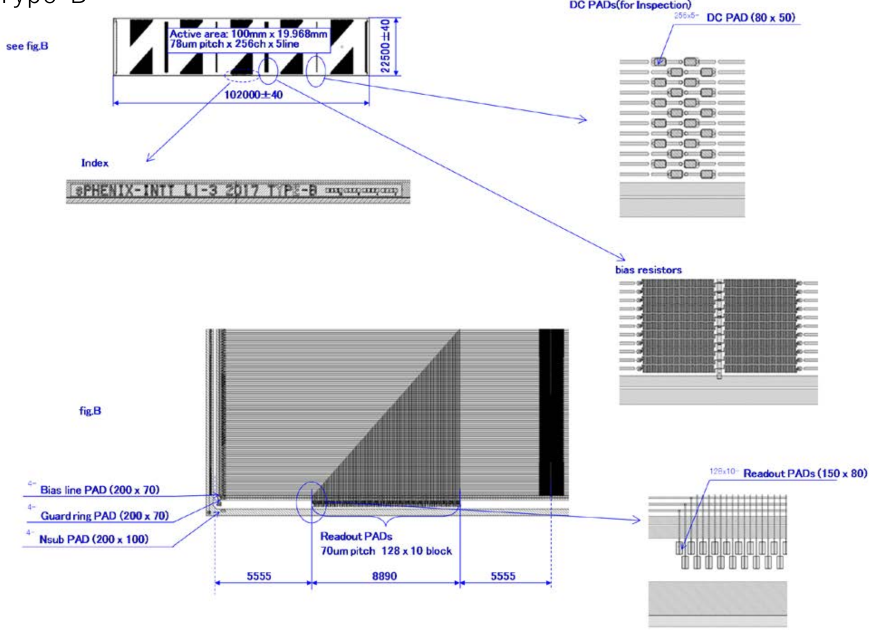
- Ladder material budget
- Dead space in the ladder

These are minor updates, but better be checked with the current INTT GEANT model hoping this is the last tuning.

Type-A

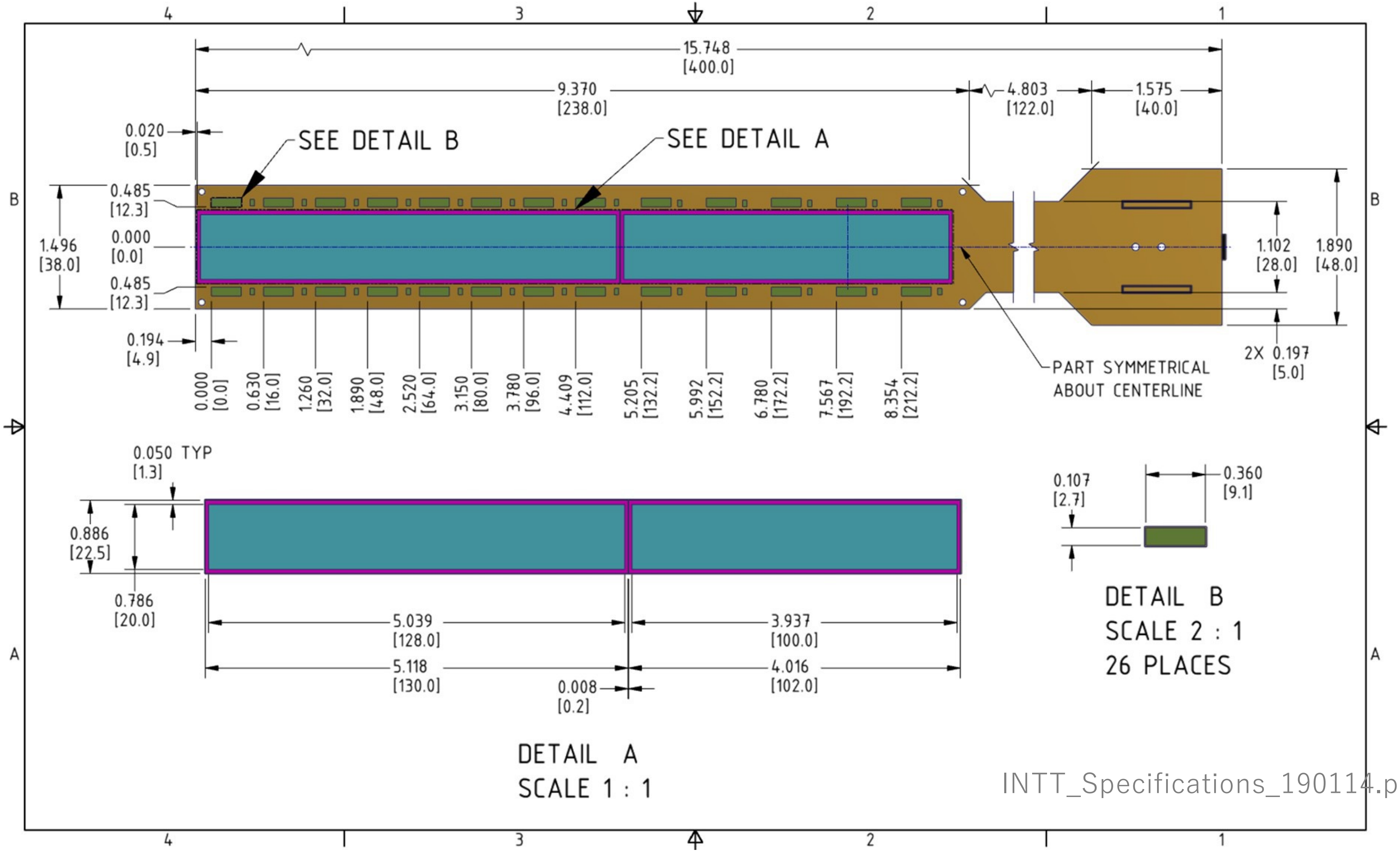


Type-B



Dimension	Type-A			Type-B		
	Horizontal [mm]	Vertical [mm]	Area [mm^2]	Horizontal [mm]	Vertical [mm]	Area [mm^2]
Physical	130	22.5	2925	102	22.5	2295
Active	128	19.968	2555.904	100	19.968	1996.8
Physical - Active	2.00	2.53	369.10	2.00	2.53	298.20
(Physical - Active)/2	1.00	1.27	184.55	1.00	1.27	149.10
Active/Physical	0.98	0.89	0.8738	0.98	0.89	0.8701

INTT_SiliconSensor.xlsx



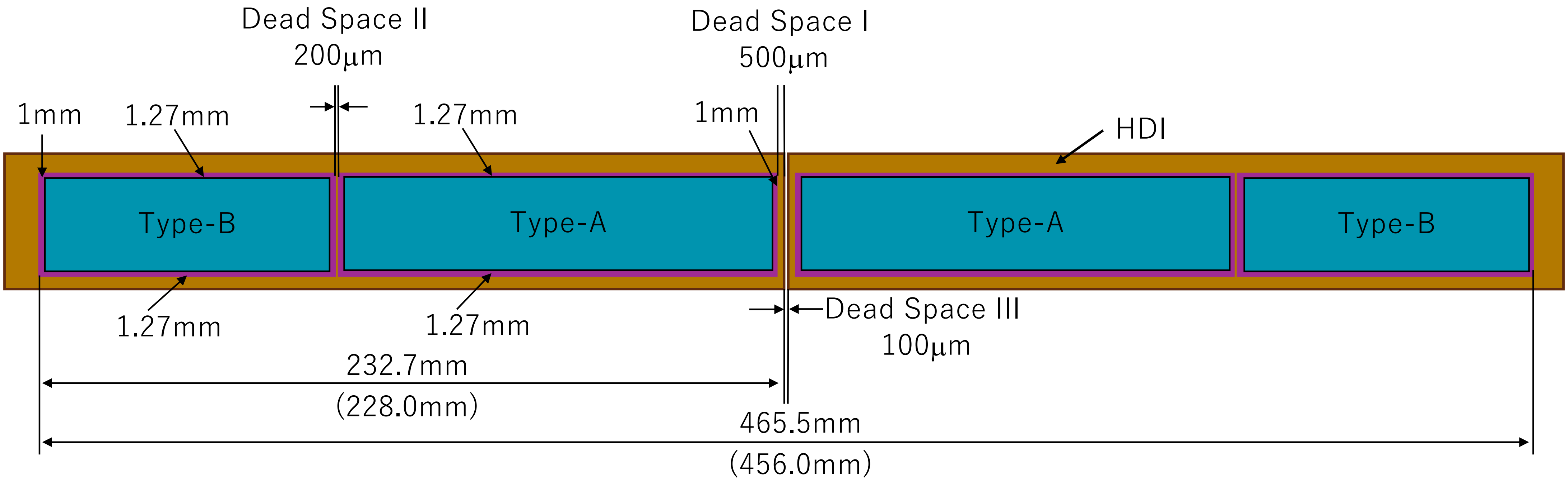
INTT_Specifications_190114.pptx

Active Area Summary for the Ladder

Hi Itaru,

Nominally, the gap between HDIs is 0.1mm

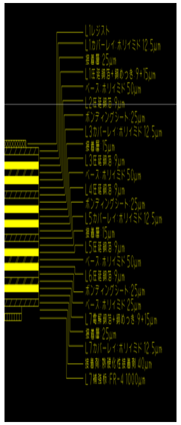
Cheers,
Dan Cacace
sPHENIX & ePIC
Physics Department
Office: 631.344.2197
dcacace@bnl.gov

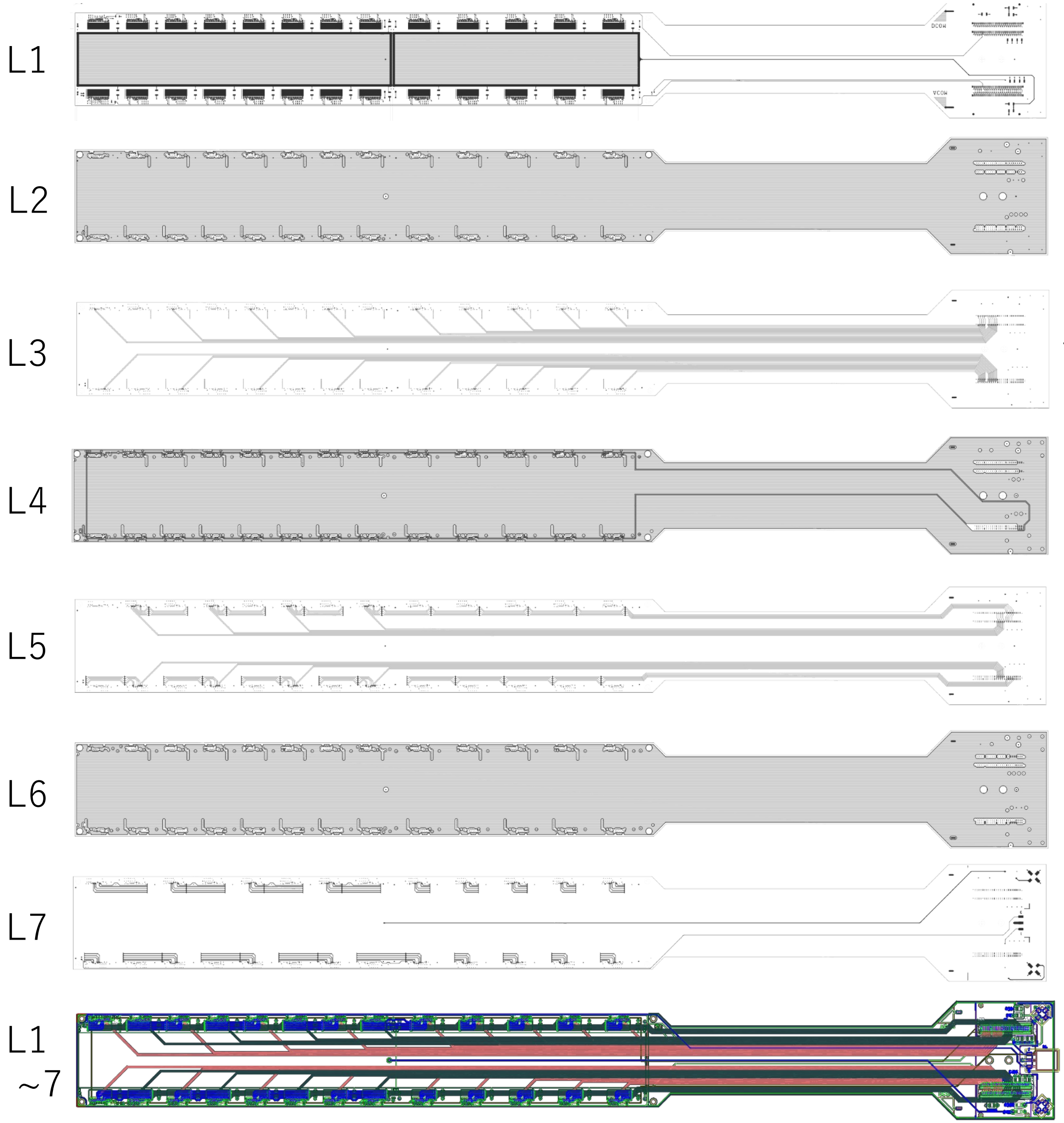


INTT_ActiveArea.xlsx

L123層用HDI読み出し用　残銅率

Top side (Si sensor側)	導体厚	残銅率
1圧延銅箔+銅めっ	9+15um	71.26%
L2圧延銅箔	9um	93.54%
L3圧延銅箔	9um	6.50%
L4圧延銅箔	9um	94%
L5圧延銅箔	9um	7.20%
L6圧延銅箔	9um	93.15%
L7電解銅箔	9+15um	4.68%
Bot side		





INTT_LadderMaterialBudget.xlsx

HDI Serial #271~398 (Batch-3)

Total 128HDIs

Delivery Day	Batch	Order #	LOT #	Quantity	HDI Serial No.		Incremented Quantity	Inspection	Result	Shipped to Taiwan
2019/1/23	Preproduction	349670	302382	6						
2019/2/6		349670	302725	4						
2019/9/11		350963	306716	20						
2019/11/20		Exchanged	307469	1						
2020/4/2	Batch-1A	352075	310184	9	1	9	9			
2020/4/2		352075	310185_1	7	10	16	16			
2020/4/2		352075	310185_2	13	17	29	29			
2020/4/2		352075	310186	29	30	59	59	50	Good?	
2020/4/28	Batch-1B	352075	310188	17	60	76	76	70	bad	
2020/4/28		352075	310189	24	77	100	100	80, 94	bad	
2020/6/8		352075	311139	2	101	102	102			
2020/6/8		352075	311587_1	7	103	109	109	105		6
2020/6/17		352075	311587_2	2	110	111	111		1 bad	
2020/6/17		352075	311614	15	112	126	126	122		14
2020/6/24		352075	311615	21	127	147	147	127		20
2020/7/9		352075	312095	20	148	167	167		3 bad	
2020/7/9		352075	312096_1	6	168	173	173			
2020/7/21		352075	312096_2_1	7	174	180	180			
2020/7/28	Batch-1A	Exchanged	312096_2_2	1	24	24	180			
2020/9/28	Batch-2	353110	312532	20	181	200	200		1 bad	
2020/9/28		353110	312533	16	201	216	216			
2020/9/29		353110	312534	7	217	223	223			
2020/9/29		353110	312535	14	224	237	237			
2020/9/29		353110	312536	7	238	244	244			
2020/10/27		353110	313304	24	245	268	268	265		3
2020/11/27		353110	313673	2	269	270	270			2
2021/6/28	Batch-3		317333_2_2	11	271	281	281			
2021/7/5			317338	14	282	295	295		1 bad	
2021/7/19			317341	23	296	319	319			
2021/8/6			318459	22	319	340	342			
2021/8/6			31860	13	341	353	353			

Bad through holes

Increased cupper plate on the surface layers from 15 to 20μm in batch-3

HDI Serial #001~270 (Batch#1,2)

理化学研究所様向け　次期ピクセルパス7層FPC層構成案1

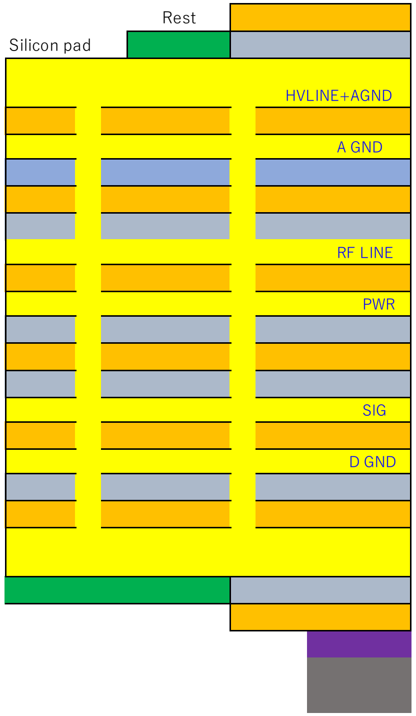
2025/3/3 銅メッキの厚みも残同率に考慮

山下の井上さんからの報告を元に残銅率を更新(190530) -> ページ下に記載

Acceptance |eta|<1.1

Regist	20	µm
Copper　plated	15	µm
L1 Electrolytic copper foil	9	µm
Base　Polyimide	50	µm
L2 Electrolytic copper foil	9	µm
Glue	25	µm
Base Polyimide	12.5	µm
Glue	15	µm
L :Electrolytic copper foil	9	µm
Base　Polyimide	50	µm
L4 Electrolytic copper foil	9	µm
Glue	25	µm
Base　Polyimide	12.5	µm
Glue	15	µm
L5 Electrolytic copper foil	9	µm
Base　Polyimide	50	µm
L6 Electrolytic copper foil	9	µm
Glue	25	µm
Base　Polyimide	25	µm
L7 Electrolytic copper foil	9	µm
Copper　plated	15	µm
Regist	20	µm
		µm
	438	µm
TOTAL厚	438	µm

418



Sub Component Thickness

Layer	Thickness	Unit	Occupancy	Effective[µm]	Real [µm]	Rest (silicon pad area) [µm]	Rest [µm]		
				Copper Layers					
Coverlay Polyide	12.5	µm							
Coverlay Glue	25	µm					25		
Copper　plated	15	µm	71.3%	17.10	15				
L1 Electrolytic copper fo	9	µm			9				
Base　Polyimide	50	µm				50	50		
L2 Electrolytic copper fo	9	µm	93.5%	8.42	9				
Glue	25	µm				25	25		
Base Polyimide	12.5	µm				12.5	12.5		
Glue	15	µm				15	15		
L :Electrolytic copper fo	9	µm	6.50%	0.59	9				
Base　Polyimide	50	µm				50	50		
L4 Electrolytic copper fo	9	µm	94.0%	8.46	9				
Glue	25	µm				25	25		
Base　Polyimide	12.5	µm				12.5	12.5	µm	
Glue	15	µm				15	15	µm	
L5 Electrolytic copper fo	9	µm	7.20%	0.65	9				
Base　Polyimide	50	µm				50	50	µm	
L6 Electrolytic copper fo	9	µm	93.2%	8.38	9				
Glue	25	µm				25	25		25
Base　Polyimide	25	µm				25	25	µm	
L7 Electrolytic copper fo	9	µm	4.68%	1.12	9				
Copper　plated	15	µm			15				
Coverlay Glue	25	µm				20	20		
Coverlay Polyimide	12.5	µm							
Glue for support plate	40	µm							
Support Plate　FR-4 1	1000	µm							
TOTAL厚	473	µm	Total	44.7207	93	325	350		Effective/Re 0.4809
			Radiation Length [c	1.435		28.6	28.6	Silicon Area Total	
			X/Xrad [%]	0.312		0.11	0.12	0.43	
					Area[cm^2]	52.2	35.96	88.16	
					Area*X/Xrad	5.93	4.40		
					Weighted Mean X/Xrad by Area			**0.117201877**	
					Thickness [um]	418	438		

パッド/端子部はパラジウム金メッキ仕様

INTT_LadderMaterialBudget.xlsx

HDI Serial #271~398 (Batch-3)

Total 128HDIs

理化学研究所様向け　次期ピクセルパス7層FPC層構成案1

5/3/3 銅メッキの厚みも残同率に考慮

山下の井上さんからの報告を元に残銅率を更新(190530) -> ページ下に記載

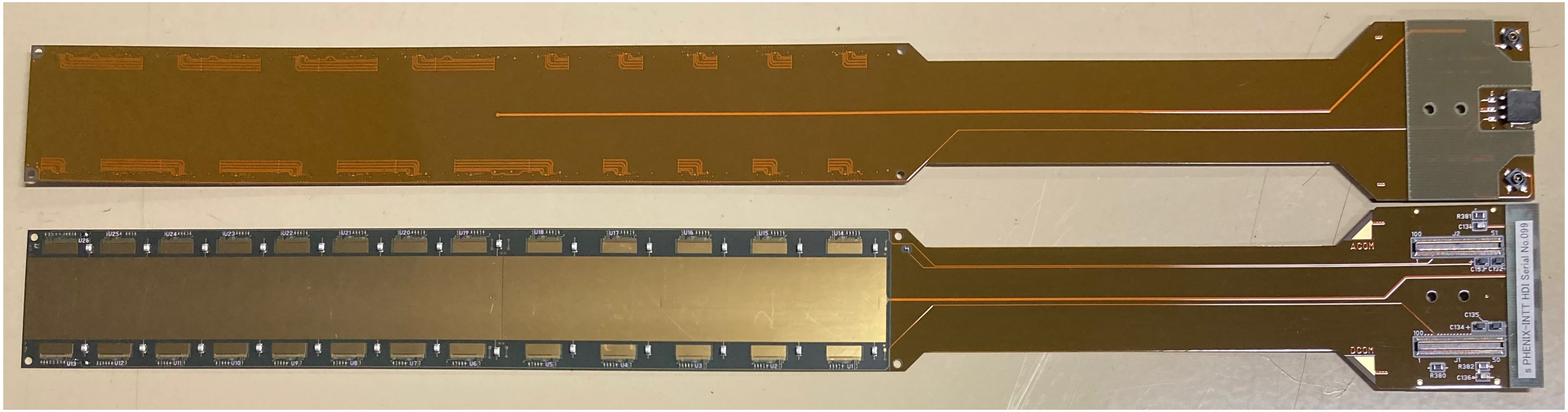
Layer	Thickness	Unit
Regist	20	μm
Copper plated	20	μm
L1 Electrolytic copper foil	9	μm
Base Polyimide	50	μm
L2 Electrolytic copper foil	9	μm
Glue	25	μm
Base Polyimide	12.5	μm
Glue	15	μm
L :Electrolytic copper foil	9	μm
Base Polyimide	50	μm
L4 Electrolytic copper foil	9	μm
Glue	25	μm
Base Polyimide	12.5	μm
Glue	15	μm
L5 Electrolytic copper foil	9	μm
Base Polyimide	50	μm
L6 Electrolytic copper foil	9	μm
Glue	25	μm
Base Polyimide	25	μm
L7 Electrolytic copper foil	9	μm
Copper plated	20	μm
Regist	20	μm
		μm
	448	μm

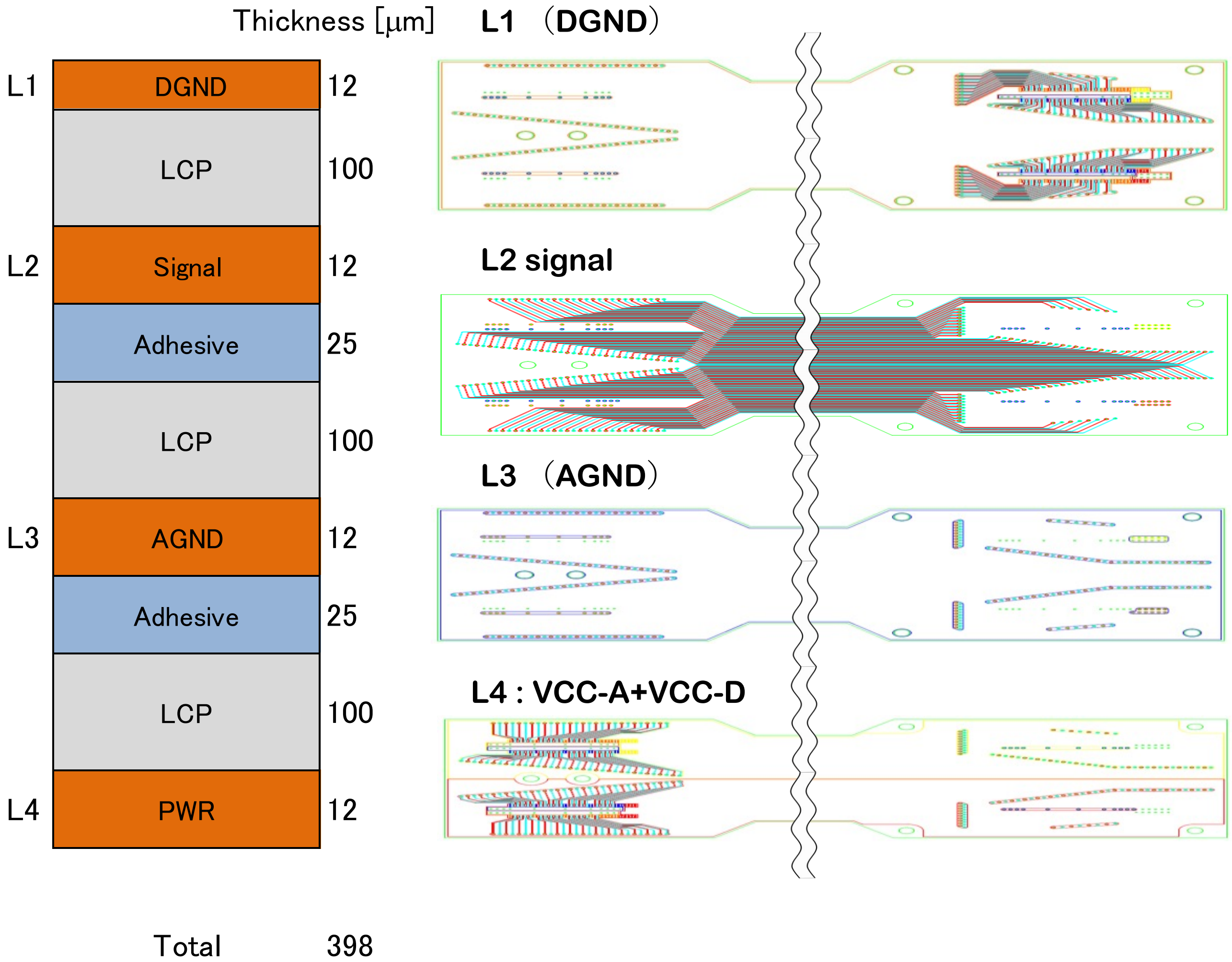
Sub Component Thickness

Layer	Thickness	Occupancy	Copper Layers Effective[μm]	Real [μm]	Rest (silicon pad area) [μm]	Rest [μm]		
Coverlay Polyide	12.5 μm							
Coverlay Glue	25 μm					25		
Copper plated	20 μm	71.3%	20.67	20				
L1 Electrolytic copper fo	9 μm			9				
Base Polyimide	50 μm				50	50		
L2 Electrolytic copper fo	9 μm	93.5%	8.42	9				
Glue	25 μm				25	25		
Base Polyimide	12.5 μm				12.5	12.5		
Glue	15 μm				15	15		
L :Electrolytic copper fo	9 μm	6.50%	0.59	9				
Base Polyimide	50 μm				50	50		
L4 Electrolytic copper fo	9 μm	94.0%	8.46	9				
Glue	25 μm				25	25		
Base Polyimide	12.5 μm				12.5	12.5 μm		
Glue	15 μm				15	15 μm		
L5 Electrolytic copper fo	9 μm	7.20%	0.65	9				
Base Polyimide	50 μm				50	50 μm		
L6 Electrolytic copper fo	9 μm	93.2%	8.38	9				
Glue	25 μm				25	25	25	
Base Polyimide	25 μm				25	25 μm		
L7 Electrolytic copper fo	9 μm	4.68%	1.36	9				
Copper plated	20 μm			20				
Coverlay Glue	25 μm				20	20		
Coverlay Polyimide	12.5 μm							
Glue for support plate	40 μm							
Support Plate FR-4 1	1000 μm							Effective/Re
TOTAL厚	483 μm	Total	48.5177	103	325	350		0.471
		Radiation Length [	1.435		28.6	28.6	Silicon Area Total	
		X/Xrad [%]	0.338		0.11	0.12	0.45	
				Area[cm^2]	52.2	35.96	88.16	
				Area*X/Xrad	5.93	4.40		
				Weighted Mean X/Xrad by Area			**0.117201877**	
				Thickness [um]	418	438		

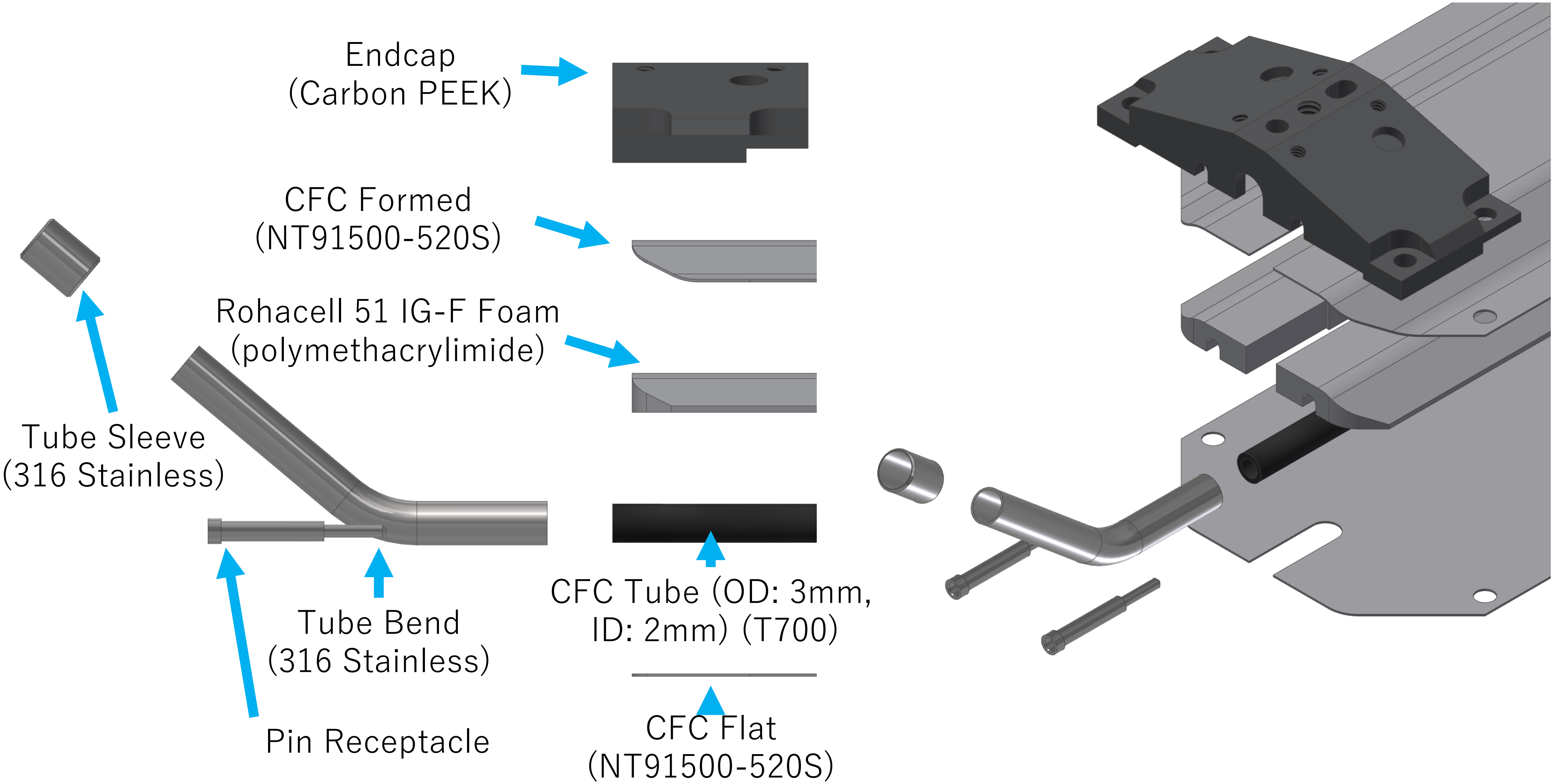
Relatively small impact to the material budget due to small copper residual fraction.

INTT_LadderMaterialBudget.xlsx


ACOM
DCOM
J2
J1
PHENIX-INTT HDI Serial No.099



Thickness [μm]
L1
DGND
12
LCP
100
L2
Signal
12
Adhesive
25
LCP
100
L3
AGND
12
Adhesive
25
LCP
100
L4
PWR
12
Total
398
L1 （DGND）
L2 signal
L3 （AGND）
L4 : VCC-A+VCC-D


Endcap
(Carbon PEEK)
CFC Formed
(NT91500-520S)
Rohacell 51 IG-F Foam
(polymethacrylimide)
Tube Sleeve
(316 Stainless)
CFC Tube (OD: 3mm,
ID: 2mm) (T700)
Tube Bend
(316 Stainless)
CFC Flat
(NT91500-520S)
Pin Receptacle

INTT_Meeting_Minutes_200722.pdf

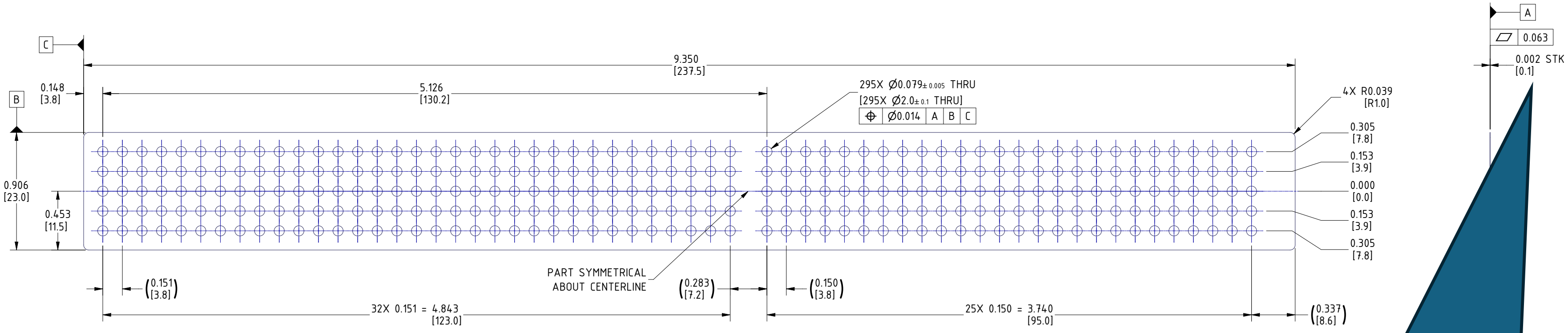
o Estimated effective thickness of the silver epoxy based on the volume of the glue mask provided from Rachid in the last meeting. The resulting effective thickness is 14um which is 28% of full thickness 50um. As a consequence, the contribution of the silver epoxy is now 0.04% instead of 0.14%. The total material budget was 1.12% before his update, and now 1.14%, very tiny increase. Although the carbon fiber stave thickness and silver epoxy glue are increased, these additional thickness were pretty much compensated by effective Cu thickness of HDI.

o **Although the effective thickness based on the BNL mask is implemented to GEANT INTT model, NCU crews should also measure the amount of glue actually used in Taiwan assembly.** The contribution of the silver epoxy in the material budget is not negligible if the effective thickness is near 50um, we should know realistic amount for the Taiwan ladders as well.

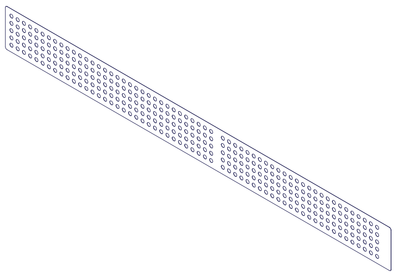
REVISION HISTORY					
REV	ECN NUMBER	ZONE	DESCRIPTION	DATE	APPROVED
A					

NOTES:
1. MATERIAL: Stainless Steel AISI 304 OR EQUIVALENT
2. UNTOLERANCED DIMENSIONS ARE BASIC ⌓ 0.010 | A | B | C
3. DIMENSIONS & TOLERANCES IN BRACKETS ARE FOR REFERENCE ONLY.
4. DRAWING MAY BE USED WITH MODEL "Sensor Glue Mask.STP" AND VALUES QUERIED FROM 3-D DIGITAL MODEL ARE BASIC.
5. FINISHED ARTICLE SHALL BE FREE OF DIMPLES AND WRINKLES.

Silver Epoxy Glue Mask



On 2025/02/01 20:28, Cacace, Daniel wrote:
Hi Itaru,
All the dimensions in inches are correct, the dimensions in mm are for reference only and are rounded to the nearest tenth of a mm. So the thickness is 0.002" or 0.0508mm.
Cheers,
-Dan



THIRD ANGLE PROJECTION

INTERPRET IN GENERAL ACCORDANCE WITH ASME Y14.5-2009
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES [mm]
DECIMAL TOLERANCES
X.X ± 0
.XX ± 0
.XXX ± 0
.XXXX ± 0
ANGLES ± 0

OUTSTANDING ECN NUMBERS

FINISH | BREAK EDGES MIN: 0 MAX: 0

DRAWN BY / CHECKED BY / ENGINEER APPROVAL / SUPERVISOR APPROVAL / DESIGN APPROVAL / Q.A. APPROVAL / SAFETY ENGINEER

sPHENIX

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES
UPTON, NY 11973

PROJECT: INTT

DESCRIPTION: Sensor Glue Mask

SIZE: D | DRAWING NUMBER: | REV: A

Q.A. CAT: A3 | SCALE: 5 : 2 | WEIGHT: 0 lbmass | SHEET: 1 OF 1

Input from Cheng-Wei

Please see the following drawing, this drawing is from Dan Caca, should be more reliable than what Rachid says😆.
The calculation of 18 um of glue thickness is in the following.

The total holes: (33 + 26) * 5 = *295* holes for one half-ladder
The diameter of one hole : 2 mm
The area of the one hole : 1 * 1 * π = π mm^2
The thickness of the mask: 0.1 mm
The total amount of glue : 295 * π * 0.1 = 29.5 π

0 .1 -> 0.05

14.8pi

The area of the silicon area : (130 + 102)* 22.5 = *5,220*

The effective glue thickness : total_amount_of_glue / area_of_silicon_area =

29.5 π / 5220 = 0.018 mm -> 18 um.

14.8pi/5220=0.0085=8.5um

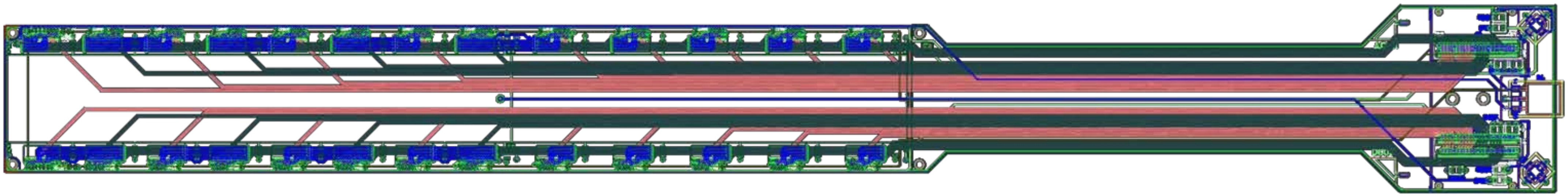
Epoxy tab of INTT_LadderMaterialBudget.xlsx

Radiation Length of INTT Ladder

Material	Thickness [μm]	X/X_0
Silicon	320	0.34%
HDI	473	0.49%
Stave	500	0.25%
Total	1293	1.08%

HDI Material	Thickness [μm]	X/X_0
Copper*	52	0.36%
Polyimide	380	0.13%
Total**	432	0.49%

*Copper thickness is not physical thickness, but effective thickness.
**Total thickness is not 473μm, because of copper effective thickness.



The HDI is composed of 7 copper layers. 4 layers are solid ground or power layers.
The remaining 3 layers are signal line layers containing a few percent of solid copper per layer.

INTT Material Budget		HDI batch 1,2	HDI batch 3
	Thickness [mm]	X/X0 [%]	X/X0 [%]
Silicon Sensor	0.32	0.34	0.34
Silver epoxy	0.009	0.02	0.02
HDI	0.418	0.43	0.45
Thermally conductive epoxy	0.05	0.02	0.02
Stave	3.76	0.33	0.33
Total	**4.56**	**1.14**	**1.16**

To be confirmed in the INTT GEANT model.

MaterialBudget tab in INTT_LadderMaterialBudget.xlsx

金メッキについて

On 2025/02/03 6:51, 柳川 大輔 wrote:

中川　様

ご連絡頂きまして、ありがとうございます。

金メッキの構成は、下記のねらい値となるそうです。

下地ニッケル：3～6μm厚

パラジウム：0.1～0.3μm厚

金：0.09～0.2μm厚

（標準的な無電金メッキの仕様になってます。）

Ni : 0.006mm/14.24mm=0.00042=0.04%
小さいのでここでは無視する。

Atomic and nuclear properties of nickel (Ni)

Quantity	Value	Units	Value	Units
Atomic number	28			
Atomic mass	58.6934(4)	$g\ mol^{-1}$		
Density	8.902	$g\ cm^{-3}$		
Mean excitation energy	311.0	eV		
Minimum ionization	1.468	$MeV\ g^{-1}cm^2$	13.07	$MeV\ cm^{-1}$
Nuclear interaction length	134.1	$g\ cm^{-2}$	15.06	cm
Nuclear collision length	82.6	$g\ cm^{-2}$	9.279	cm
Pion interaction length	162.6	$g\ cm^{-2}$	18.26	cm
Pion collision length	107.9	$g\ cm^{-2}$	12.12	cm
Radiation length	12.68	$g\ cm^{-2}$	1.424	cm
Critical energy	20.05	MeV (for e^-)	19.41	MeV (for e^+)
Muon critical energy	326.	GeV		
Molière radius	13.41	$g\ cm^{-2}$	1.506	cm
Plasma energy $\hbar\omega_p$	59.38	eV		

For muons, $dE/dx = a(E) + b(E)\ E$. Tables of $b(E)$: PDF TEXT

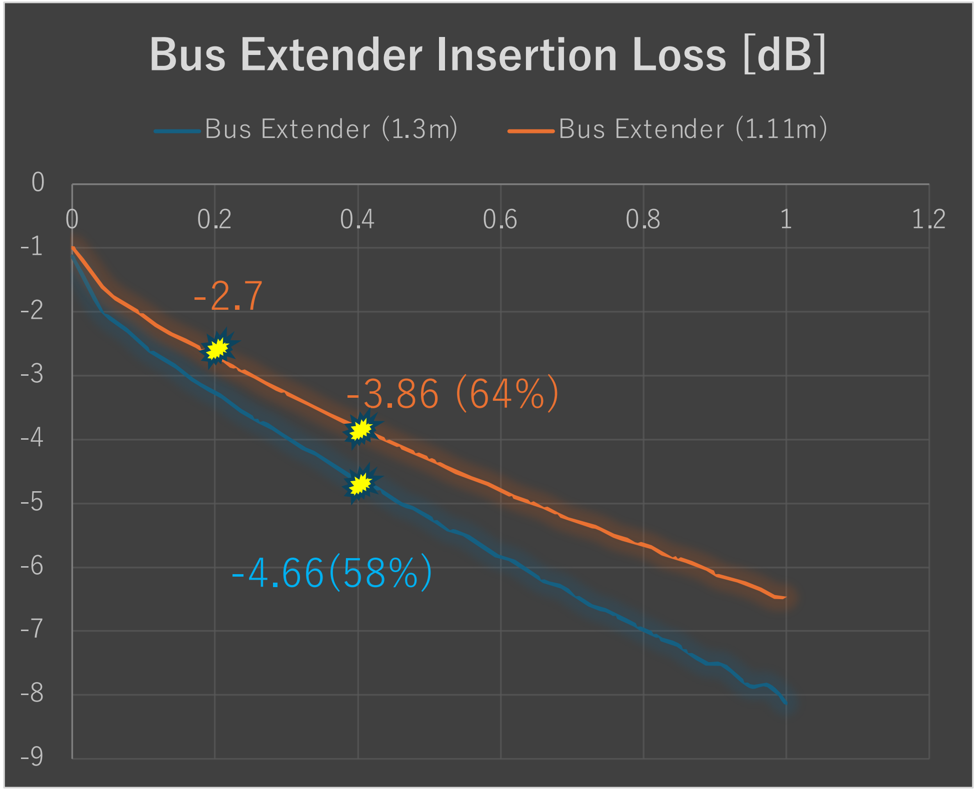
Table of muon dE/dx and Range: PDF TEXT

Explanation of some entries

Table of isotopes via WIKIPEDIA

x ray mass attenuation coefficients from NIST

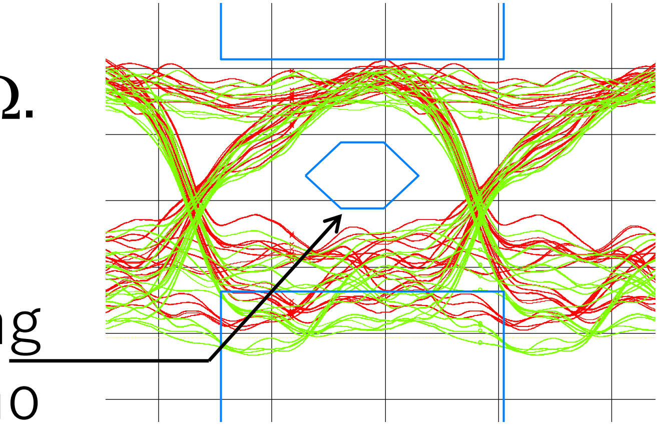
INTT_Cables_Performance.pptx



sPara_GrandSammry.xlsx

Eye Diagram Specifications

- The receiver is designed for regular LVDS f.i. 4mA@100Ω. This translates to be $\Delta V=$ 400mV.
- The receiver is not employing any commercial device, so no clear specification is defined.
- However Tom considers $\Delta V=$ 100mV should work, but $\Delta V=$ 50mV is a bit uncomfortable level.



This figure is presented by Doug in FVTX review. The center diamond is not provided by Tom.

FPHX_dicussion_190930.pptx

VoltageDrop.xlsx

HDI Resistance

Calculation from the cross section of the power layer

D14 =D13*26/1000

	A	B	C	D
1	HDI Power Layer Dimension			
2	Width [mm]	38	38	38
3	Thickness [um]	9	9	9
4	Length [m]	0.2	0.2	0.2
5	Area [m^2]	3.E-07	3.E-07	3.E-07
6	Mesh facto r[%]	100	90	10
7	Electric Resistivity (Cu) rho	1.68E-08	2.E-08	2.E-07
8	Resistance R=rho*L/A [ohm]	0.010	0.011	0.098
9				
10	FPHX Chip			
11	Power consumption/Chip [mW	65	65	65
12	Operation Voltage [V]	3	3	3
13	Current Draw/Chip [mA]	21.67	21.67	21.67
14	Current Draw for 26 chips [A]	0.56	0.56	0.56
15				
16	Voltage Drop in Length B4 [V]	0.006	0.006	0.055
17				
18	Voltage Drop in 40cm [V]	0.011	0.012	0.111
19				
20				
21				

電気抵抗率の比較（でんきていこうりつのひかく）では、電気抵抗率を比較できるよう、昇順に表にする。

長さL[m]、断面積A[m^2]の物体の電気抵抗R[Ω]は、次式で求めることができる。

$$R = \rho \cdot L/A$$

このρが電気抵抗率であり、単位はΩmである。

因数	単位	値 (Ωm)	物質	温度特性 (毎ケルビン)
$10^{-\infty}$		0	超伝導	
…				
10^{-8}	10 nΩm	1.59×10^{-8}	銀	.0061
		1.68×10^{-8}	銅	.0068
		2.21×10^{-8}	金	
		2.65×10^{-8}	アルミニウム	.00429
		4.42×10^{-8}	マグネシウム	
		5.29×10^{-8}	タングステン	.0045
		5.81×10^{-8}	コバルト	

Drawing Current for FPHX Chips

FPHX chip consumes about 1/3 power in analogue and 2/3 in digital sections, respectively.

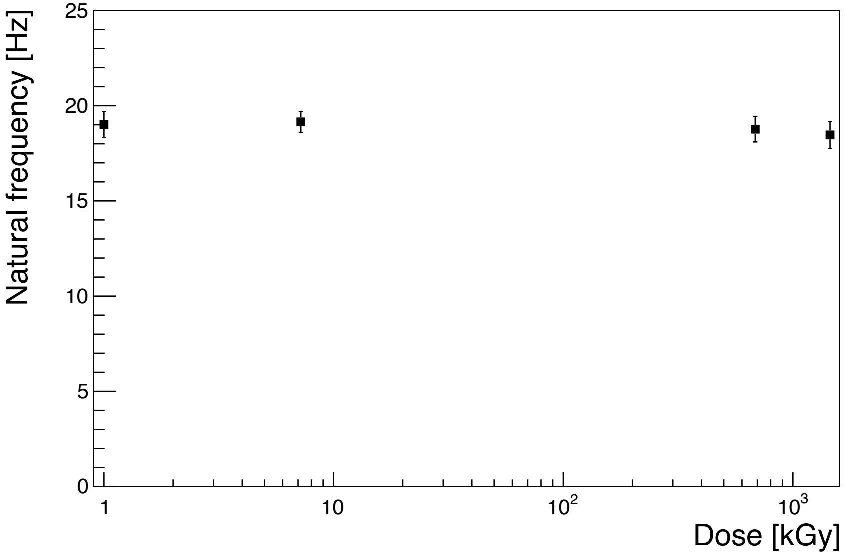
	Total	Digital	Analogue
LVDS min.	0.54 A	0.36 A	0.18 A
LVDS max.	0.64 A	0.42 A	0.21 A

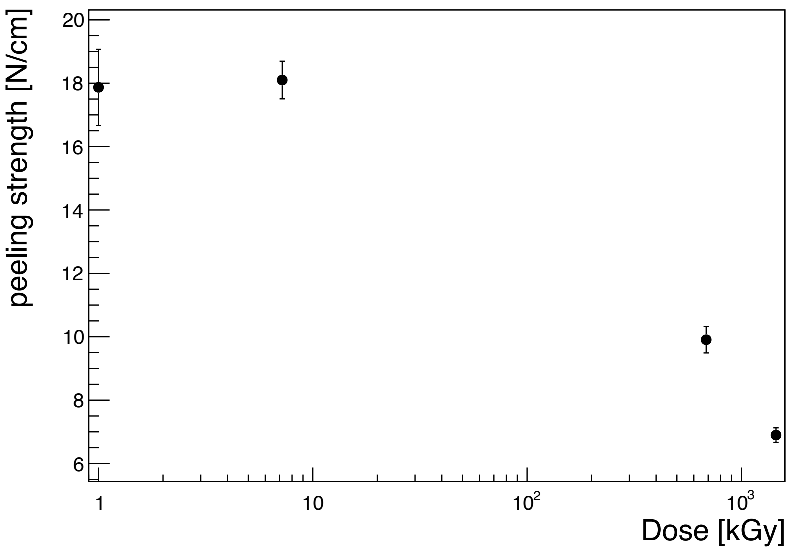
Typical currents after 'INIT'

	Total	Partial	Conversion Cable		Bus Extender	HDI
	Current [A]	Current [A]	20cm [Ω]	40cm[Ω]	Resistance [Ω]	40cm[Ω]
LVDS min.	0.54		0.2	0.4	0.3	0.1
Digital		0.36	0.07	0.14	0.11	0.04
Analogue		0.18	0.04	0.07	0.05	0.02
LVDS max.	0.64					
Digital		0.42	0.08	0.17	0.13	0.04
Analogue		0.21	0.04	0.08	0.06	0.02

Anticipated Voltage Drop in each cables

Radiation Hardness of the BEX





H. Imai Diploma Thesis

Origin of 5 kGy in sPHENIX

[Technical Paper]

Development of Long and High-Density Flexible Printed Circuits

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Abstract

The super Pioneering High-Energy Nuclear Interaction eXperiment (sPHENIX), which aims to unravel the mysteries of the creation of the universe, is scheduled to be launched in 2023 at Brookhaven National Laboratory, U.S.A, using the relativistic heavy ion collider. As a typical high-energy particle accelerator-based experiment, the collision area of sPHENIX is to be tightly occupied with various radiation detectors, requiring a minimal special budget to run cables and transmit massive signals generated by these detectors to downstream electronics for data processing located in a remote distance. Accordingly, a long, high signal line-density cable has been developed based on the flexible printed circuit

more than the minimum required bit error rate of 50 ppm.

4.2 Mechanical characteristics

In sPHENIX, high reliability is required for the FPC because it is difficult to access the inside the radiation area during the experiment. This reliability was evaluated by the peeling and thermal-shock tests.

The objective of the peel test is to verify that the laminate substrate has sufficient peel strength between layers. We prepared a test sample of the same stackup as the prototype, but with no pattern in every layers, and then tested it by peeling it up and down at an angle of 180° in the second or third layer using a tensile tester. The test results are presented in Fig. 14. The peel strength is defined at the point of the observed tensile force where the stress samples demonstrated higher peel strength than the required 10 N/cm (a typical peel strength of conventional polyimide). This result is an improvement over the initial prototype test sample. This improvement was a biproduct of the new bonding sheet introduced in Section 3.3.

The observed peel strength can be degraded after daily use in the radiation environment. Therefore, the peel strength was measured for the samples under radiation exposure by 5 kGy. In addition, 5 kGy is the expected radiation dose for five years of operation in sPHENIX. We did not observe obvious degradation in the peel strength within the accuracy of the measurement.

Because the cable comprises 4 layers of 12-μm thick

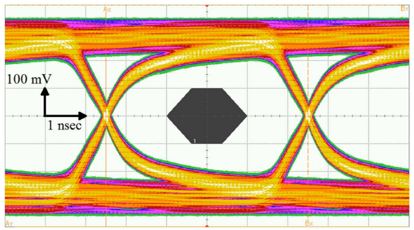


Fig. 13 Measurement result of eye-diagram

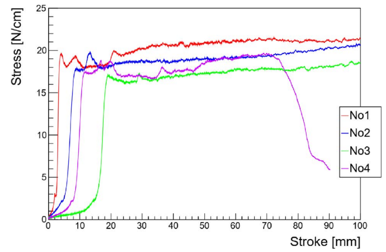
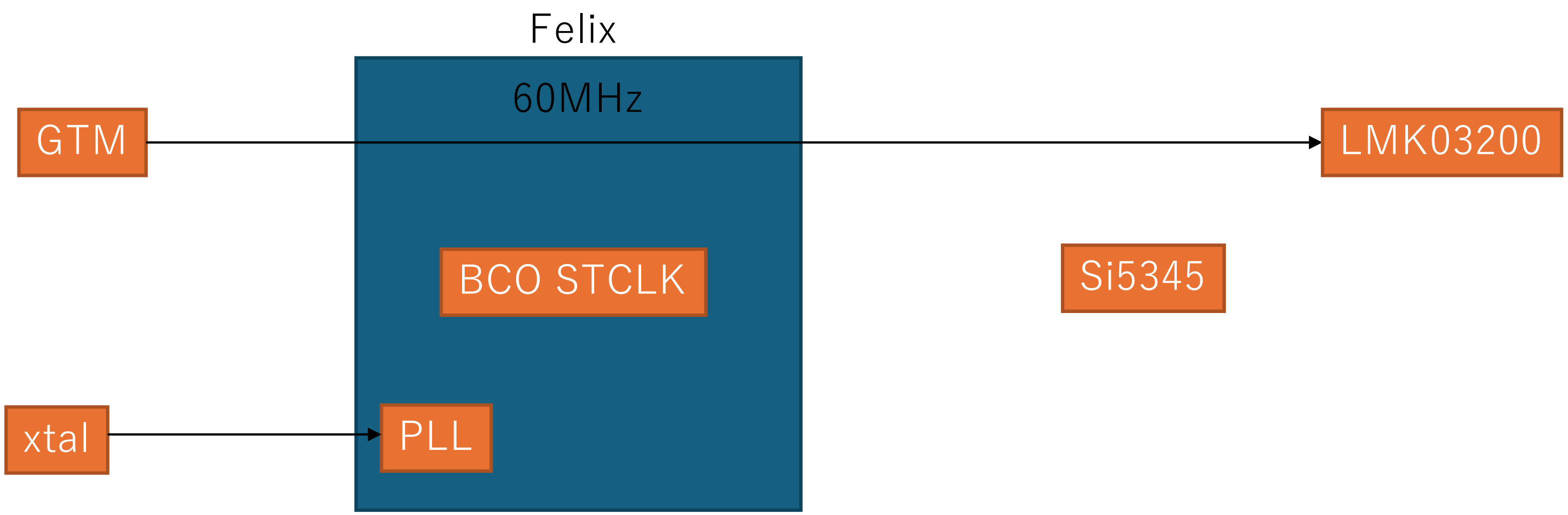


Fig. 14 Measurement result of peel strength

The origin of 5 kGy in sPHENIX needs to be double checked (Itaru)

230403_FelixPlan.pptx

Felix Clock Block Diagram



This is underdevelopment.