INTT Publication Plan

RIKEN/RBRC

Itaru Nakagawa

Proposed plan for INTT Publications

Topics	Target Journal	Leading Author	Timeline	Remaining Issues
Bus Extender ✓ (Electric)	The Japan Institute of Electronics Packaging	Takashi Kondo (TIRI)	2022/May → published Aug. 2022	To be announced from Takashi later
2021 Beam Test✓	ELPH Ann. Rprt.	Genki/Cheng-Wei/Yuka	2022/Winter	Efficiency (Thick tail by MC, BG contamination)
2021 Beam Test	NIM		2023/Winter	
Bus Extender (Mechanical)	NIM	Takashi	2023/Winter	Final evaluation of the yield rate
INTT Ladder	NIM	Itaru	2023/Winter	Mirco-Coax Conversion Cable/(Commisioning*)
INTT Barrel	NIM	Itaru/Rachid	2024/Summer	Barrel

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Plan discussed in INTT Stuff meeting on April 21, 2022

Proposed plan for INTT Publications (Update)

Topics	Target Journal	Leading Author	Timeline	Remaining Issues
Bus Extender ✓ (Electrical)	The Japan Institute of Electronics Packaging	Takashi Kondo (TIRI)	2022/May → published Aug. 2022	To be announced from Takashi later
2021 Beam Test✓	ELPH Ann. Rprt.	Genki/Cheng-Wei	2022/Winter	ADC distribution, Resolution, Efficiency, cluster size
2021 Beam Test	NIM		2025/Summer	
Bus Extender (Mechanical)	NIM	Takashi	2025?	Final evaluation of the yield rate
INTT Ladder	**NIM**	**Itaru**	**2025/Winter**	**Ladder, BEX, CC, ROC**
INTT Barrel	NIM	Itaru/Rachid	2025/Summer	Felix, mechanical structure, cooling/power system, dead region, S/N, vtx reconstruction, etc.

Bus Extender Published Paper ✓

[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 (FPC) technology. FPC comprises multilayers and has extraordinarily long and thin transmission lines. Liquid crystal polymer was employed to suppress losses in transmission lines. Electrical characteristics were evaluated using S-parameters, time domain reflectometry, and eye-diagrams. Furthermore, we have developed manufacturing technology to achieve high-precision microfabrication and improved reliability, which has been demonstrated in peel strength and thermal shock tests. FPC is currently in the mass production phase.

Keywords: FPC, LCP, S-parameter, TDR, Eye-diagram, Peel Strength, Through-hole Plating, Radiation Detector Cable

- Only Japanese authors (Students involved in R&D ~2021)
- Focus on electrical property of the bus extender
- Mechanical property such as radiation hardness or mass production technologies are to be discussed in other NIM paper.

1. Introduction

Scheduled to start in 2023, sPHENIX is a novel experiment set up to study a deconfined state of nuclear matter, the quark-gluon plasma (QGP) created in high-energy heavy-ion collisions at the Relativistic Heavy Ion Collider.[1] The intermediate tracker (INTT) is a novel silicon strip detector that can measure more than 1,000 particles generated in collisions. The massive raw data generated from INTT are transmitted at high-speed to downstream electronics for signal-processing through the narrow, curved cable path for longer than 1 m.

Because no commercial cable satisfies the requirement, a novel cable has been developed based on flexible printed circuits (FPC). This technology can simultaneously satisfy high-density signal lines, length, and flexibility.[2–7]

*: Corresponding author

2. Design

2.1 Requirements

Long and high-density signal lines FPCs are required a signal transmission medium for the INTT detector to newly developed for the sPHENIX. Because the transn sion lines are required to be long and thin, in the devel ment, it is severely challenging to suppress the sig attenuation and manufacture the fine lines with high ac racy. In addition, high mechanical reliability is requi owing to strictly limited access for the maintenance of isolated detector region. The region is to be designated a radiation area during the experiment; hence, detect are fully operated remotely. Furthermore, the FPC installed in a confined space of the sPHENIX detec complex, and is exposed to a high radiation environm from the collision point and external noise from other nal cables running close to each other. These constrai facilitate the structure of multilayered FPC design,

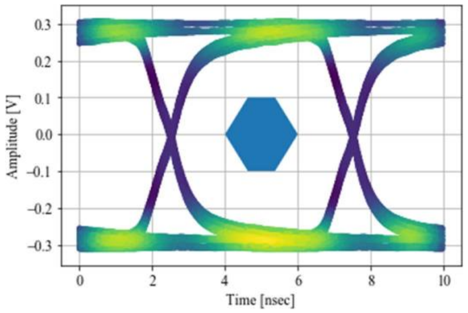

Fig. 4 Simulation results for eye-diagram

(a) Overall view

(b) Connector section

Fig. 5 FPC prototype

line was also confirmed. The gradual increase in the impedance in the time axis direction is a significant characteristic; however, it is known as the effect of the reflected signals that are gradually attenuated by long and thin transmission lines.

To verify that the square-shaped digital signal can be transmitted to a receiver with minimum distortion, the

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2021 Beam Test Results ✓

(ELPH Experiment : #2984)

Performance evaluation of the Intermediate Tracker for sPHENIX

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Three leading authors: Genki, Cheng-Wei, Yuka for their major contribution to the analysis

Coarse introduction of INTT→

§2. INTT

INTT is a silicon strip barrel detector consisting of two layers of silicon strip sensors surrounding the collision point seven to ten centimeters away (Figure 1). Hits detected by this detector are used not only for interpolation of tacking between MVTX and TPC but also bunch-crossing identification to suppress event-pileup background thanks to the best timing resolution of all tracking detectors in sPHENIX. 24 or 32 INTT ladders form the inner and outer layers. The INTT ladder (Figure 2) consists

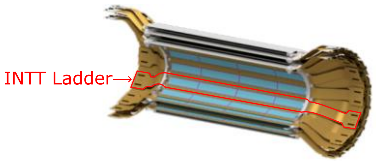

Fig.1. A half part of the INTT barrel. The inner and the outer barrels consist of 24 and 32 INTT ladders, respectively. The red box indicates an INTT ladder.

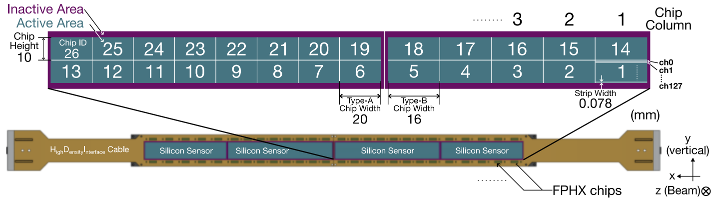

Fig.2. The INTT ladder consists of two types of silicon sensors, FPHX chips, High-Density Interconnect cable, and CFC stave. The sensors are divided into 10 or 16 cells. The silicon cells have 128 strips with 78 µm width and 320 µm thickness. The x-, y-, and z-axes in the test beam experiment are also shown.

DAC Scan→

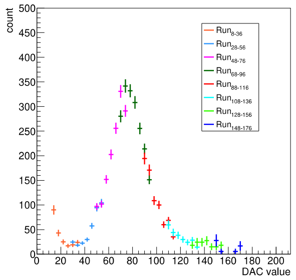

Fig.4. The ADC distribution of the eight runs after normalization. The legend indicates the scanning region of the runs.

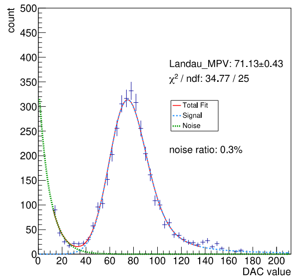

Fig.5. The energy deposit curve as a function of DAC value. Fitting to the distribution with the sum (red) of a Landau-Gaussian convolution function (dotted blue) and an exponential function (dashed green) is also shown.

position, as we expected. In the experiment, the runs with different beam-spot positions were conducted. The efficiency from the run is shown on the right-hand side of Figure 10. The detection efficiency was over 99% at the edge. Therefore, the performance of the INTT ladder was excellent over the column.

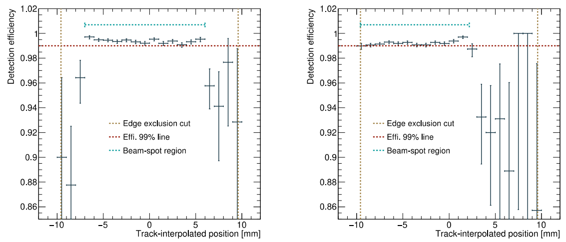

Fig.10. The detection efficiency as a function of the track position. (Left) The beam spot is in the middle. (Right) The beam spot aligns with the edge. The error bars indicate the statistic uncertainties.

→ Detection Efficiency ~ 99%

Ladder NIM Status

- 1st Release on Jan.3rd 2025
- Author list: INTT collaboration up to ~2024.
- Scope of the Paper
  - Design of the ladder.
  - Excluding the beam test performance.
  - Barrel is not included. No 1008 commissioning neither.
- Under development by Itaru in overleaf

https://www.overleaf.com/project/63680cb8918e6f1961ae3972

The Performance of sPHENIX Intermediate Silicon Strip Ladder

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ARTICLE INFO

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Silicon Detector
FPC

ABSTRACT

A new strip type silicon detector has been developed to provide the sPHENIX experiment with precise charged particle tracking in central rapidity region. sPHENIX is a new detector at the Relativistic Heavy Ion Collider (RHIC) in the Brookhaven National Laboratory. The silicon strip detector is named intermediate tracker (INTT) composing the advanced tracking system of sPHENIX detector complex together with a MAPS-based silicon pixel vertex detector (MVTX) and a time projection chamber (TPC). The INTT detector is barrel shape and consists of 56 silicon ladders. Two different type of strip sensors of 78 μm pitch and 320 μm thick are mounted on an each half ladder, each of which is segmented into 8×2 and 8×2 blocks whose strip length is 20 and 16 mm, respectively. Strips are read out with FPHX chips which was developed for the FVTX detector for the PHENIX experiment at RHIC. The INTT detector construction was completed by the end of 2022 and installed to sPHENIX in Spring 2023. The sPHENIX detector including INTT was commissioned with Au+Au beam collision

Scope of Ladder NIM

Contents

- Introduction
- HPK Silicon Sensor
- FPHX Chip (short ver.)
- HDI
- Carbon Fiber Stave
- Bus Extender
- Conversion Cable
- ROC
- ~~Felix~~

Focus

- Dimensions
- Channels
- Structures
- Electric Properties
- Material (Radiation Length)
- Radiation Hardness
- ~~Performance~~

dN/deta Physics Paper

$$\frac{dN_{particle}}{d\eta} = \frac{1}{N_{evt}} \cdot \frac{1}{\Delta\eta} \cdot N_{particle}(\eta)$$

$$N_{particle}(\eta) = \frac{(N_{hits} - N_{bg})}{\varepsilon_{acc} \cdot \varepsilon_{eff}}$$ for each η range

ε_{eff} : Ideally to be evaluated by 1008 barrel from the commissioning. This is not easy with only 2 INTT layers. One idea is to quote 99.6% from published 2021 beam test NIM.

→Ideally, NIM should be published before dN/dη paper

Signal extraction from data

$$(N_{hits} - N_{bg}) \cong N_{hits} \cdot f_{bkg}$$

Data analysis

- $N_{hits} = Ntracks\ or\ Nhits\ for\ each\ \eta\ bin$
    - $\eta = track/cluster$ position from **(X-Y-Z)-vertex**
- $N_{bg} = estimate\ BG\ using\ data\ and\ BG$
    - Random BG and BG from decay (long-lived)
    - if relative fraction of S/N is known, It is OK
- **Data QA is necessary**

Detector acceptance and efficiency

$\varepsilon_{acc} \cdot \varepsilon_{eff}$

MC (SIM)

- Can be determined with hot&dead and alignment.
- Occupancy effect (by multiplicity) needs to be studied with centrality
    - Good to check it by data

Scope for the Barrel NIM

Contents
- Introduction
- Barrel
- LV/Bias power system
- Cooling System and heat removing performance
- ~~ROC~~
- Felix
- ~~RC-DAQ~~

Beam Commissioning
- # of live channels
- Timing resolution (multiple Felix)
- DAC Scan
- Signal to noise ratio
- Efficiency
- Half entry?
- Clustering
- Tracklet
- Z-vertex reconstruction performance

dN/dη paper?