NE5 Fiber Latch Solution

Itaru Nakagawa
RIKEN/RBRC

ROC Status Updated

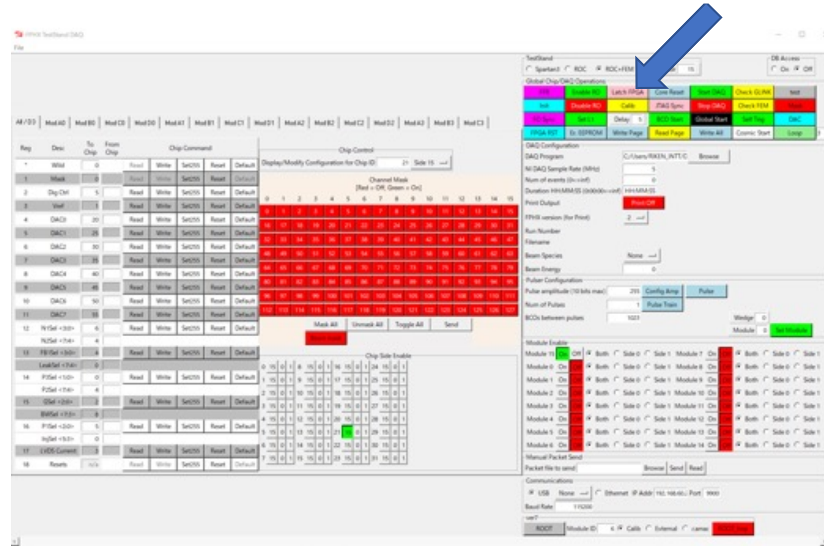
Index	ROC #	FVTX	Regulator Upgrade	Location	Class	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	Issue	Status
1	6	NW2	✓	BNL	1														
2	13	NE4	✓	BNL	1														
3	18	NE1	✓	BNL	1														
4	26	SE3	✓	BNL	1														
5	28	SE0	✓	BNL	1														
6	29	-	✓	BNL	1														
7	20	SW5	✓	BNL	1														
8	22	SE2	✓	BNL	1														
9	23	SE1	✓	BNL	1														
10	31	NW1	✓	BNL	1	R	R	R											
11	32	NE2	✓	BNL	1							R	R	R					
12	9	-	✓	BNL	1			R											
13	10	-	✓	BNL	1					R		R							
14	27	SE5	✓	BNL	1							R			R	R	R		L12 Replaced at Column-D
15	19	NE5	✓	BNL	3										F				TLK2711 Replaced
16	24	SE4	✓	BNL	2			F							F			Fiber Sync	
17	16	NE3	✓	BNL	3				C	C	C							Calib Pulse	Waiting for SC-FPGA downlaod
18	15	NE0	✓	RIKEN	2	R									F	F		Fiber Sync	
18	2	NW4	✓	RIKEN	3					R		R			F	R		Fiber Sync	
19	7	-	✓	RIKEN	3		R	R			R				R				Replaced all DF18
20	21	-	✓	REPIC	3	R			R		R		R	F	R			Fiber Sync	
21	17	NW3	✓	RIKEN	3				F							R		Fiber Sync	
22	3	NW5	✓	RIKEN	3	R		R								R	F	Fiber Sync	
24	14	NE1	✓	REPIC	3					R		C	R	R	P	P	P	Calib Pulse	L12 to be replaced at Column-D

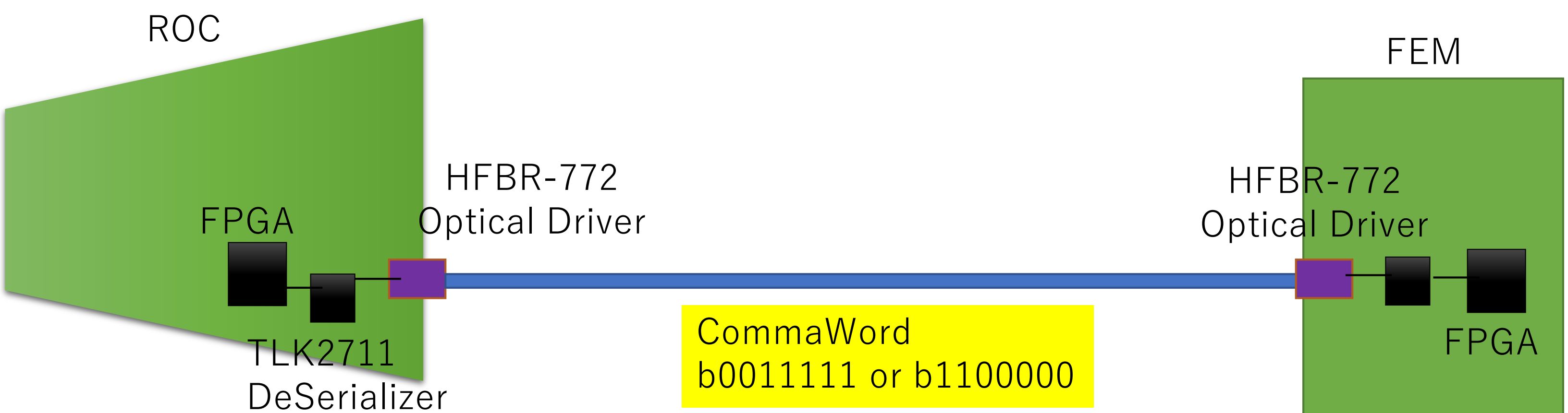
Good
Good, but occasional failure
No data at all

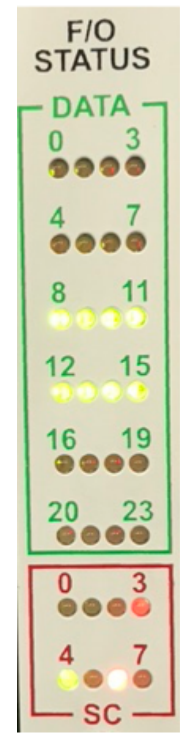
C : Problem in **C**alibration pulse
F : Problem in data **F**iber sync
P : Problem in **P**ower supply
R : **R**ecovered

- There are 7 ROC boards (9 ports) won't latch the fiber.
- 7 bad/24 ROCs = 30% of ROCs
- 9 bad TLKs /24ROCs x 2x3ports/column x 4 +1SC=9TLKs/600TLKs ~ 1%

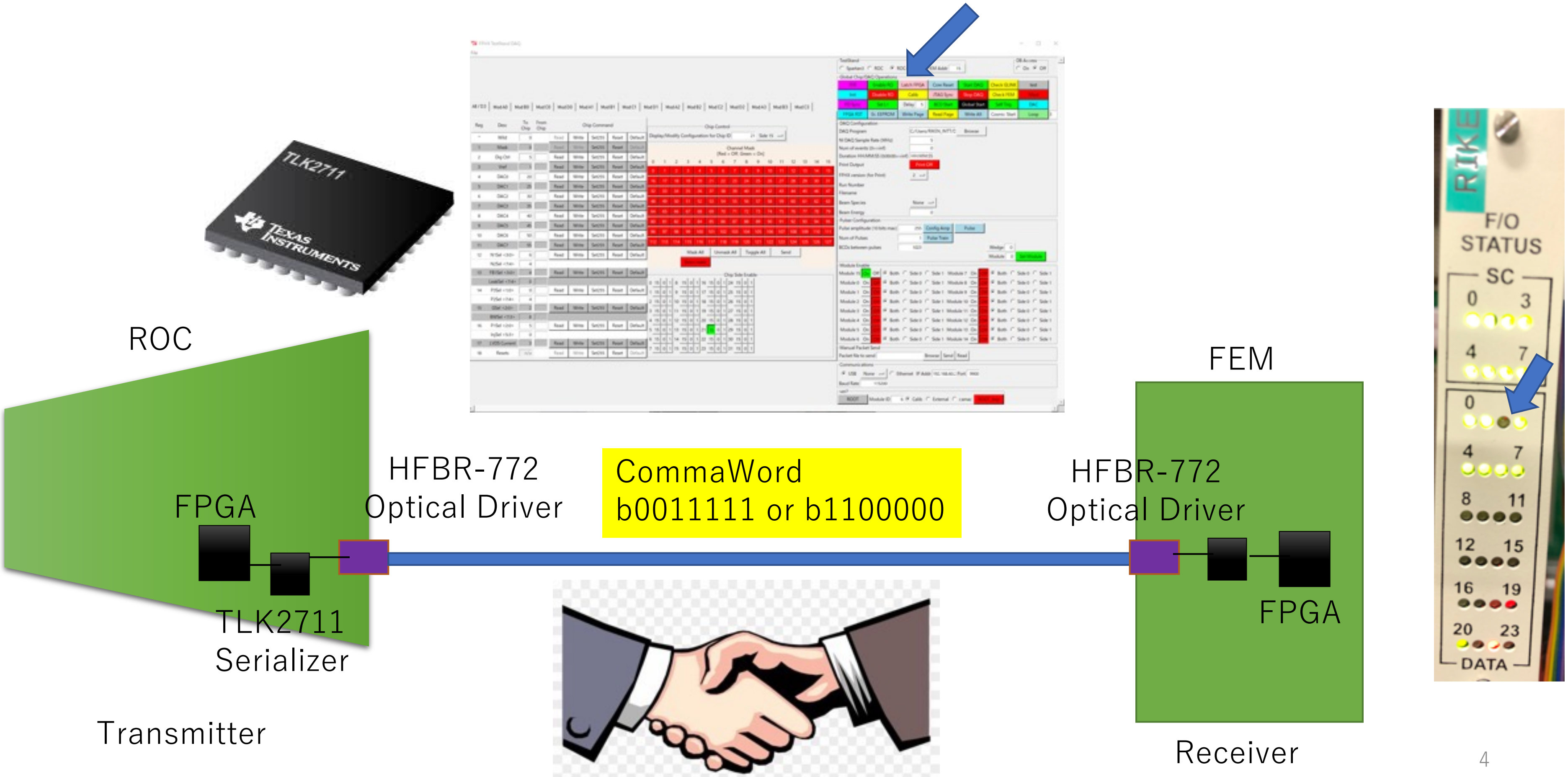
Fiber Synchronization



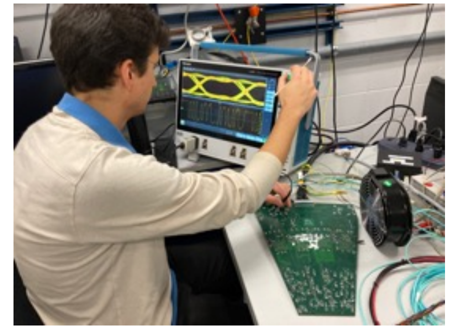




Fiber Synchronization Error



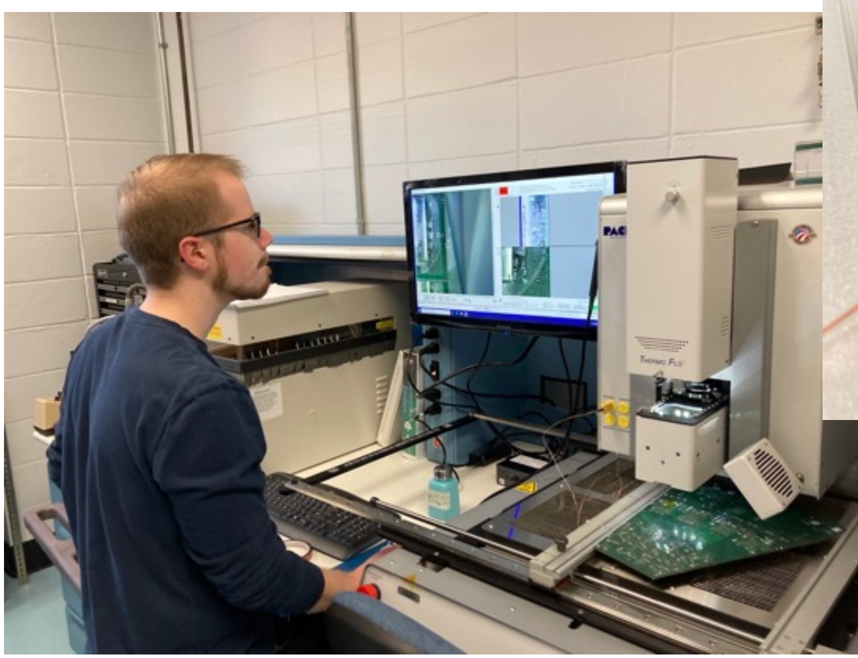
Next Step

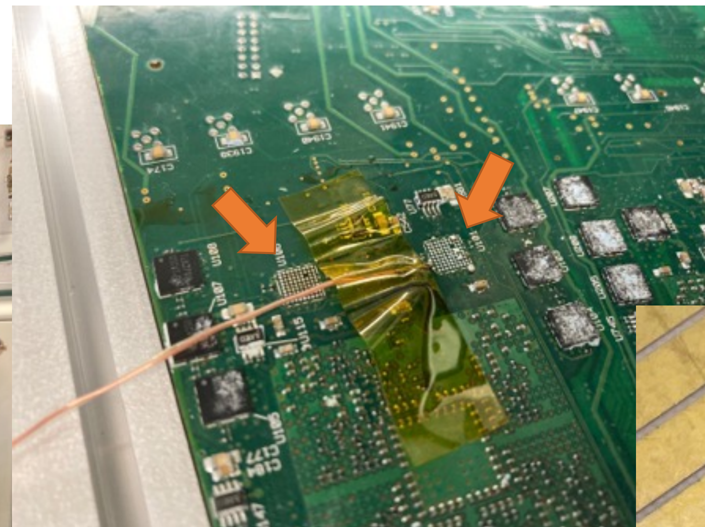


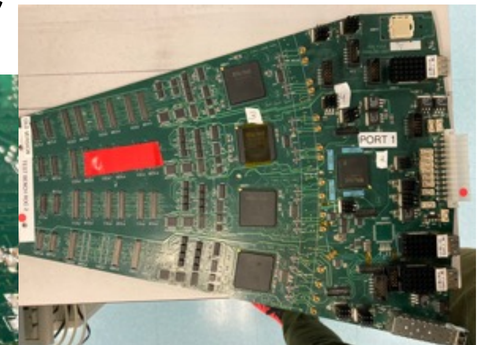
- We couldn't observe anything suspicious in the signal/clocks
- We decided to replace TLK2711 without observing any direct evidence of the cause.
- TLK2711 is discontinued product and not available in the US market. We salvaged "the old ROC", a prototype version and took TLK2711 from it assuming there is no radiation damage.
- There are 33 (8/column+SC) TLK2711 are implemented per ROC.
- Replacing TLK2711 is a certain risk since it is the ball soldering and non-negligible possibility of damaging soldering pads of both TLK2711 and ROC.
- The attempt is done in the instrumentation division.

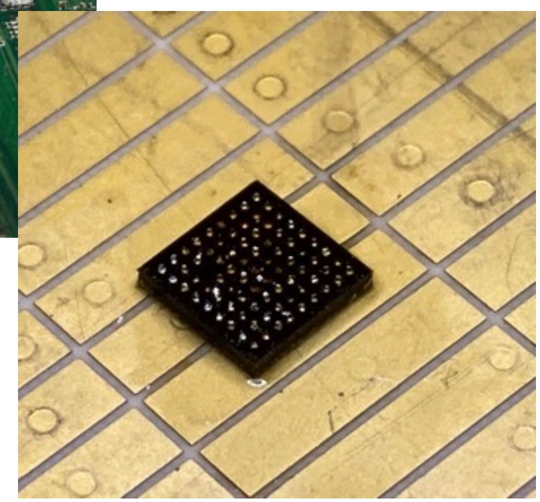
Removal of TLK2711 from “Old ROC”

By Joseph Pinz @ Instrument Div.



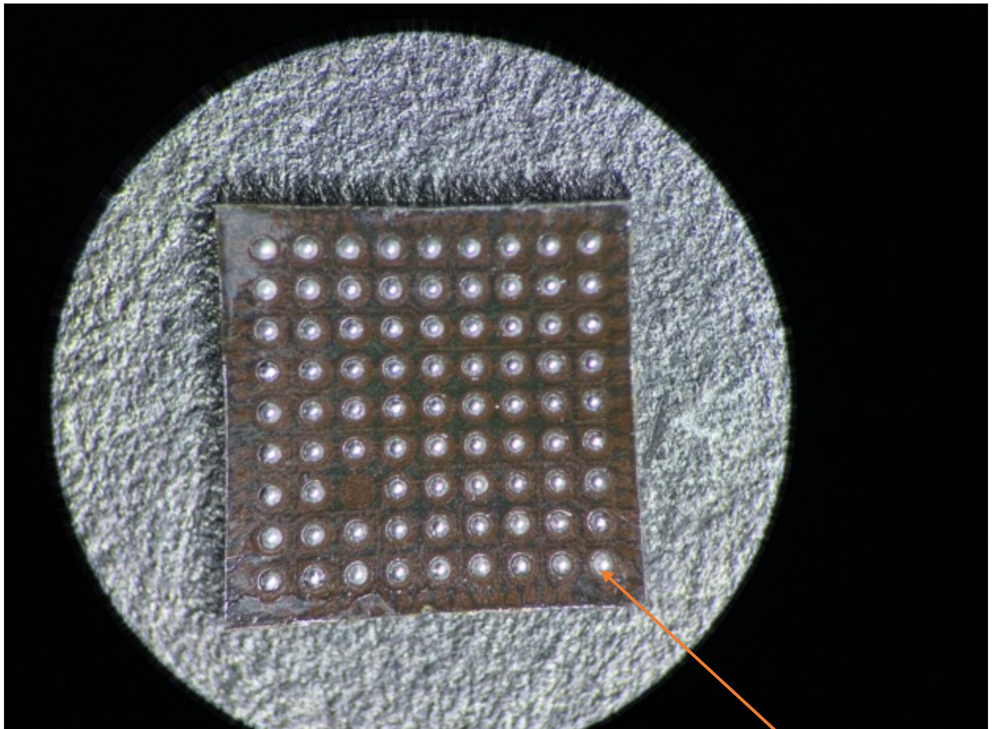


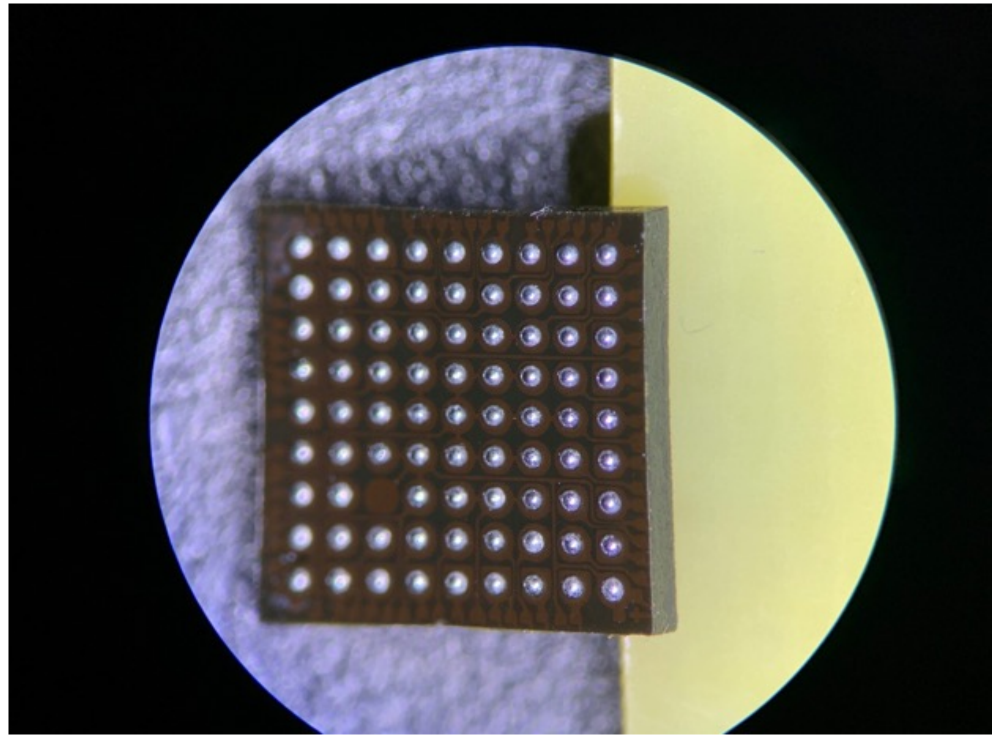




TLK2711 removal from “the old ROC” the version BCO cable input is incompatible with production version

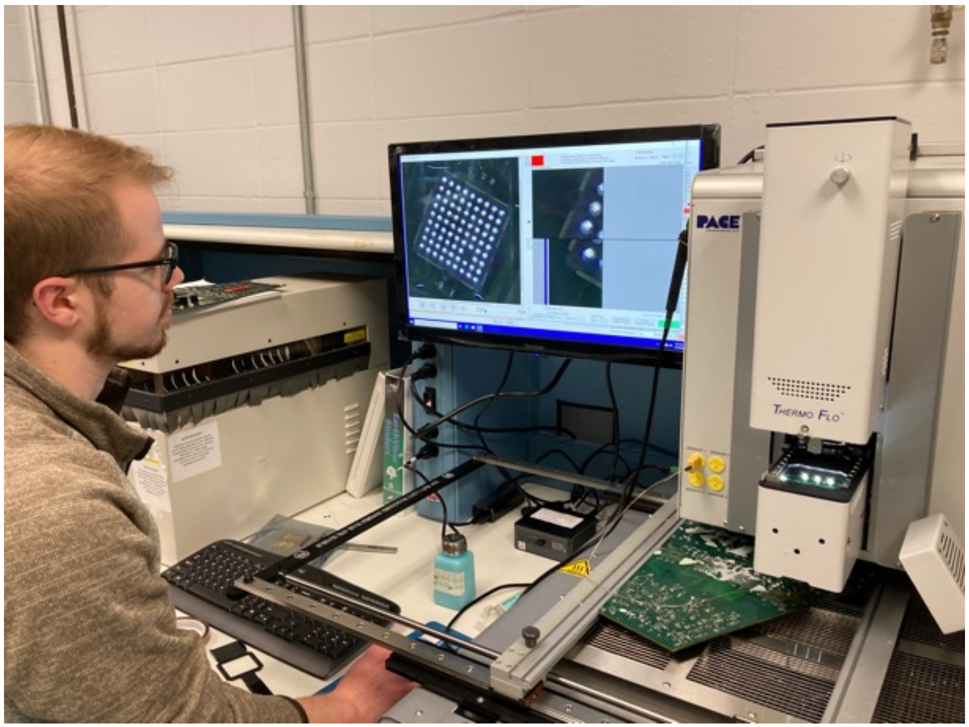
Re-balling solder on the TLK2711

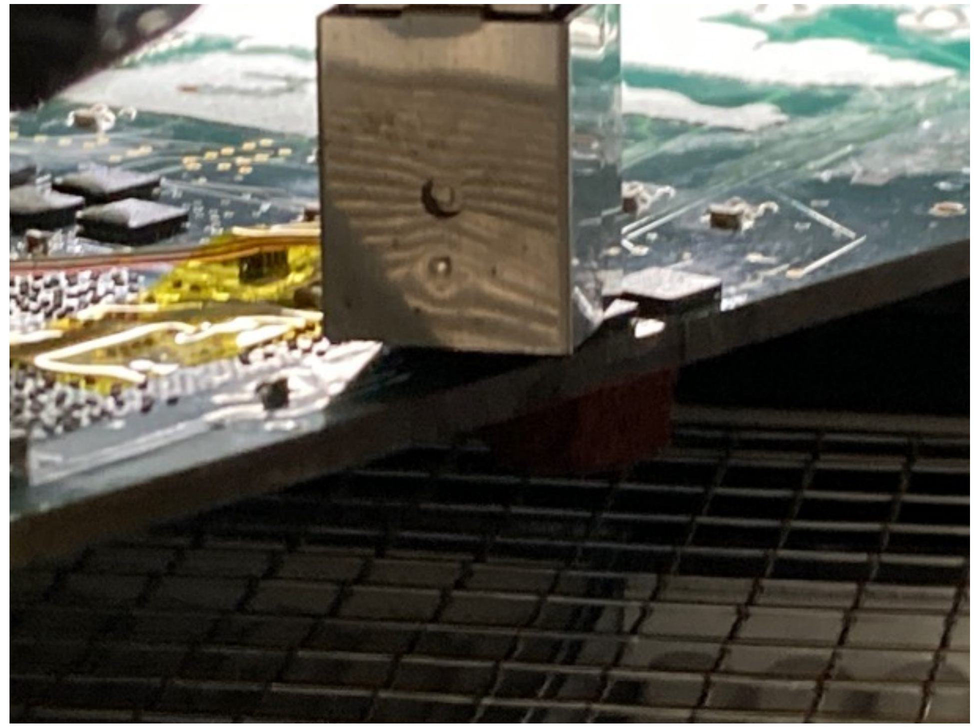




$\phi \sim 500\mu m$

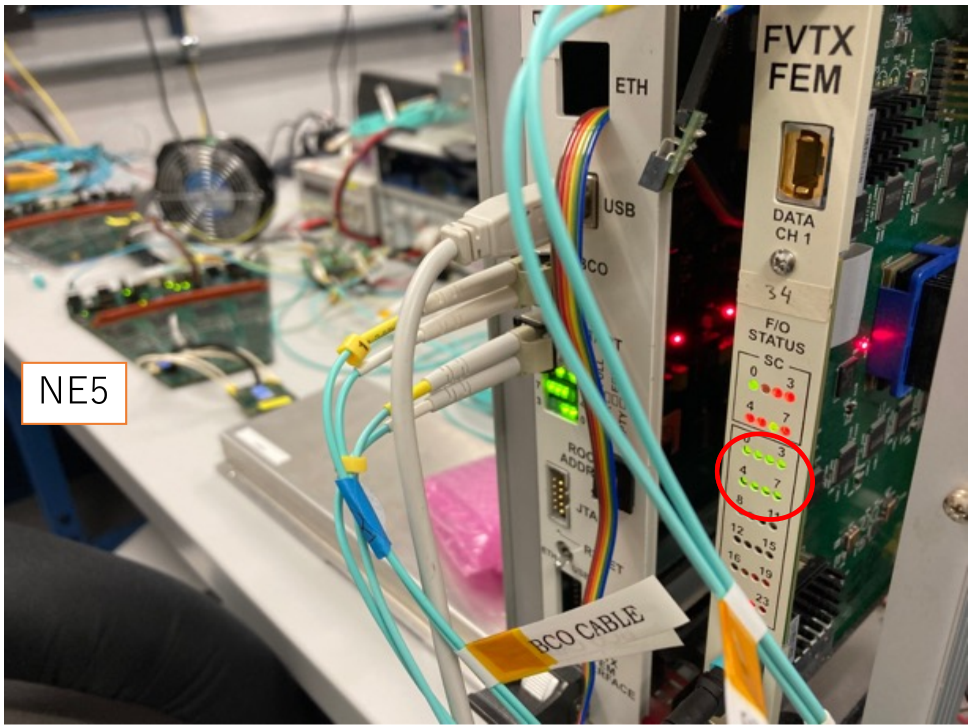
Implementation of TLK2711 on NE5





After removal of bad TLK2711s from NE5, implement TLK2711 took out from the “old ROC”.

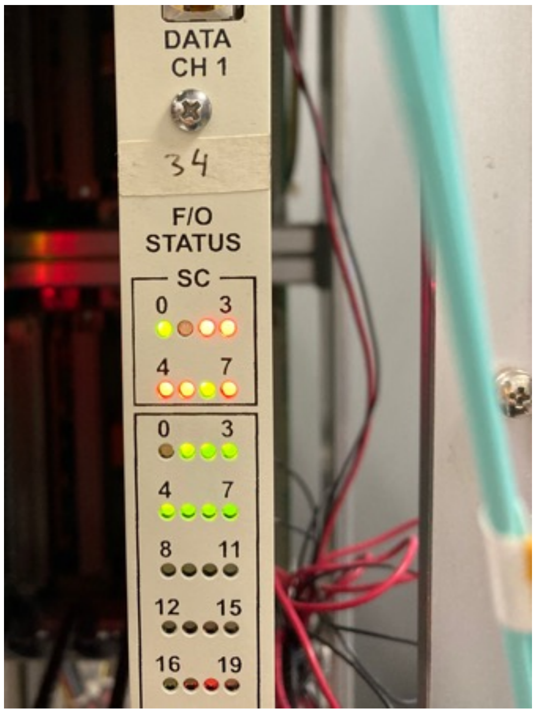
After TLK replacement



2022/11/8

- The fiber latches firmly. Repeated at least 5 times and no latch failure.
- The calibration result looks healthy.
- NE5 has been promoted to be class-1

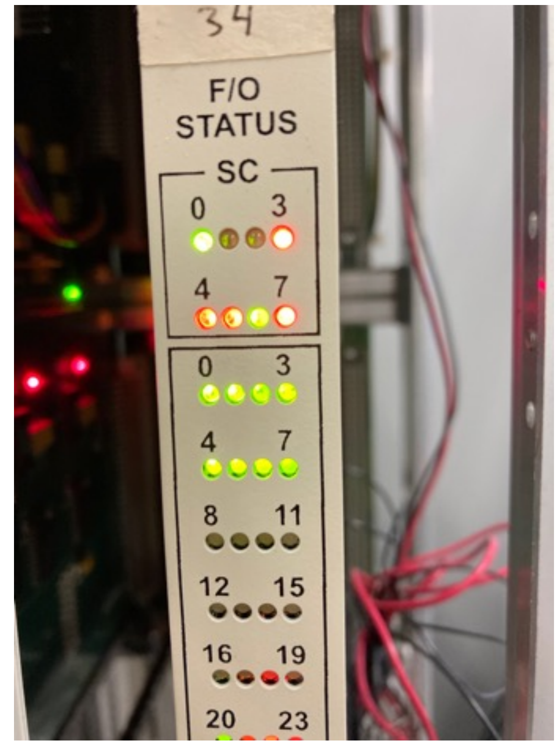
SE4 Test after replacement of TLK



Column-A

- U107 & U108 (A3), U403 & U404 (D1)
- The result is that A3 and D1 data fiber now latches (confirmed 5 times in a row)
- A2 data fiber won't latch. Turned out it has been overlooked in the database.

The conclusion is that consistent with SE5 TLK2711 replacement result. The TLK2711 replacement is the cause of fiber latch issue.



Column-D

ROC Status Updated

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13	10	-	✓	BNL	1					R		R							
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Good
Good, but occasional failure
No data at all

C : Problem in **C**alibration pulse
F : Problem in data **F**iber sync
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R : **R**ecovered

- There are still 6 more ROC boards (8 ports) beside NE5 which are suffered from the fiber latch issue.
- Up to 8x2 can be bad out of 33TLKs x 24ROCs : 1~ 2% TLK shows the same symptom.

Radiation Tolerance of TLK2711

Why quite a few ROCs are suffered from the fiber latch issue?

Product Folder | Order Now | Technical Documents | Tools & Software | Support & Community

TEXAS INSTRUMENTS

TLK2711-SP

SGLS307P – JULY 2006 – REVISED FEBRUARY 2018

TLK2711-SP 1.6-Gbps to 2.5-Gbps Class V Transceiver

1 Features

- 1.6 to 2.5-Gbps (Gigabits Per Second) Serializer/Deserializer
- Hot-Plug Protection
- High-Performance 68-Pin Ceramic Quad Flat Pack Package (HFG)
- Low-Power Operation
- Programmable Preemphasis Levels on Serial Output
- Interfaces to Backplane, Copper Cables, or Optical Converters
- On-Chip 8-Bit/10-Bit Encoding/Decoding, Comma Detect
- On-Chip PLL Provides Clock Synthesis From Low-Speed Reference
- Low Power: < 500 mW
- 3-V Tolerance on Parallel Data Input Signals
- 16-Bit Parallel TTL-Compatible Data Interface
- Ideal for High-Speed Backplane Interconnect and Point-to-Point Data Link
- Military Temperature Range (–55°C to 125°C T_{case})
- Loss of Signal (LOS) Detection
- Integrated 50-Ω Termination Resistors on RX
- Engineering Evaluation (/EM) Samples are Available (1)

2 Applications

- Point-to-Point High-Speed I/O
- Data Acquisition
- Data Processing

(1) These units are intended for engineering evaluation only. They are processed to a non-compliant flow (for example, no burn-in, and so forth) and are tested to temperature rating of 25°C only. These units are not suitable for qualification, production, radiation testing, or flight use. Parts are not warranted for performance on full MIL specified temperature range of –55°C to 125°C or operating life.

3 Description

The TLK2711-SP is a member of the WizardLink transceiver family of multigigabit transceivers, intended for use in ultra-high-speed bidirectional point-to-point data transmission systems. The TLK2711-SP supports an effective serial interface speed of 1.6 Gbps to 2.5 Gbps, providing up to 2 Gbps of data bandwidth.

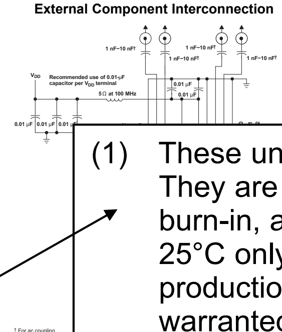
The primary application of the TLK2711-SP is to provide high-speed I/O data channels for point-to-point baseband data transmission over controlled impedance media of approximately 50 Ω. The transmission media can be printed circuit board, copper cables, or fiber-optic cable. The maximum rate and distance of data transfer is dependent upon the attenuation characteristics of the media and the noise coupling to the environment.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TLK2711-SP	CFP (68)	13.97 mm × 13.97 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

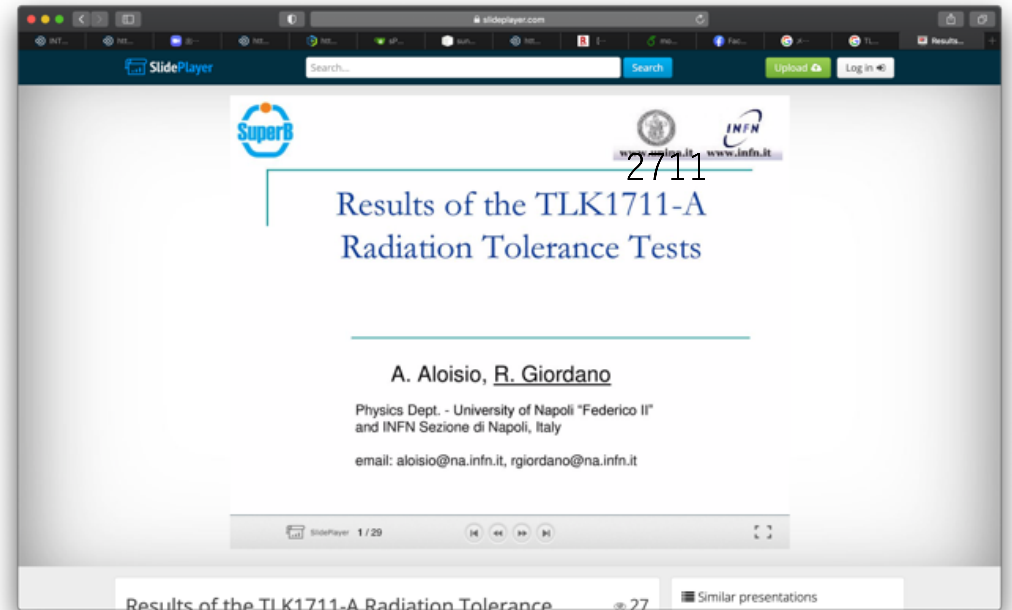
External Component Interconnection

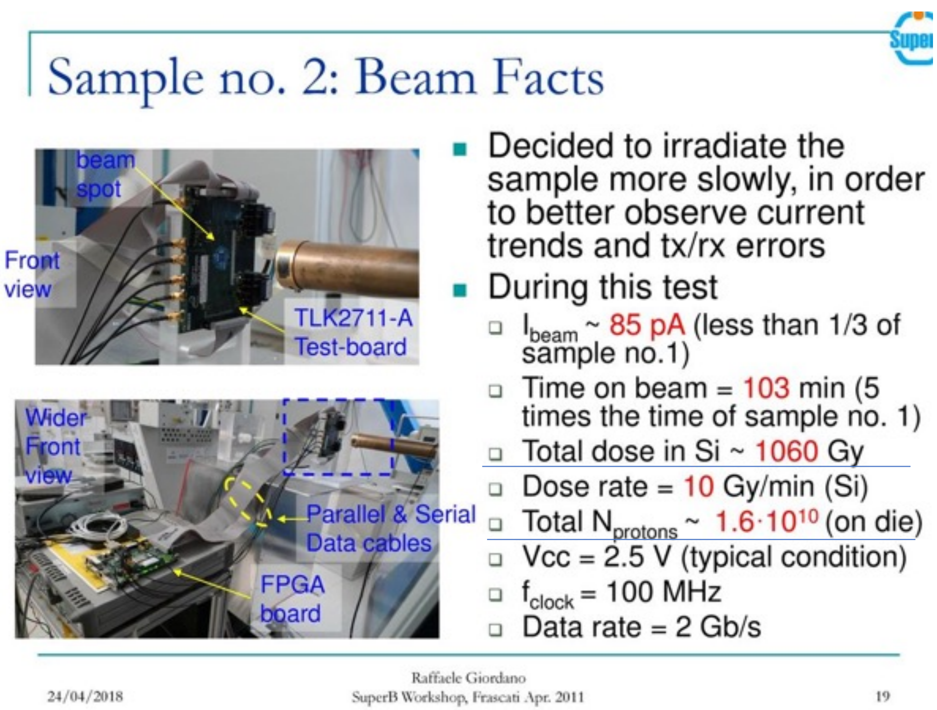


- Radiation damage?
- If so, we have higher chances to be suffered new cases during the beam operation than FVTX since we start from already accumulated dose during FVTX operation.
- We better be prepared.

(1) These units are intended for engineering evaluation only. They are processed to a non-compliant flow (for example, no burn-in, and so forth) and are tested to temperature rating of 25°C only. These units are not suitable for qualification, production, radiation testing, or flight use. Parts are not warranted for performance on full MIL specified temperature range of –55°C to 125°C or operating life.

Radiation Damage Study by INFN

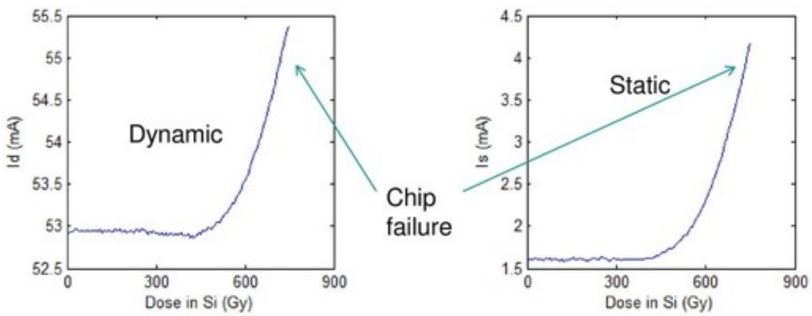




https://slideplayer.com/slide/12764619/

Radiation Damage Study by INFN

Sample no. 1: Analog Current Trend



- Moderate dynamic current increase from 53 mA to 55 mA
- Power down current increment from 1.6 to 4.2 mA, more than 300%

Sample no. 2 : Error Results

- First error appeared at dose = 280 Gy (Si)
- # Tx errors = 2 single and 1 burst (7 consecutive errored symbols)

$\sigma_{tx(single)}$=4.3 10^{-12} cm^2

$\sigma_{tx(burst)}$=2.1 10^{-12} cm^2

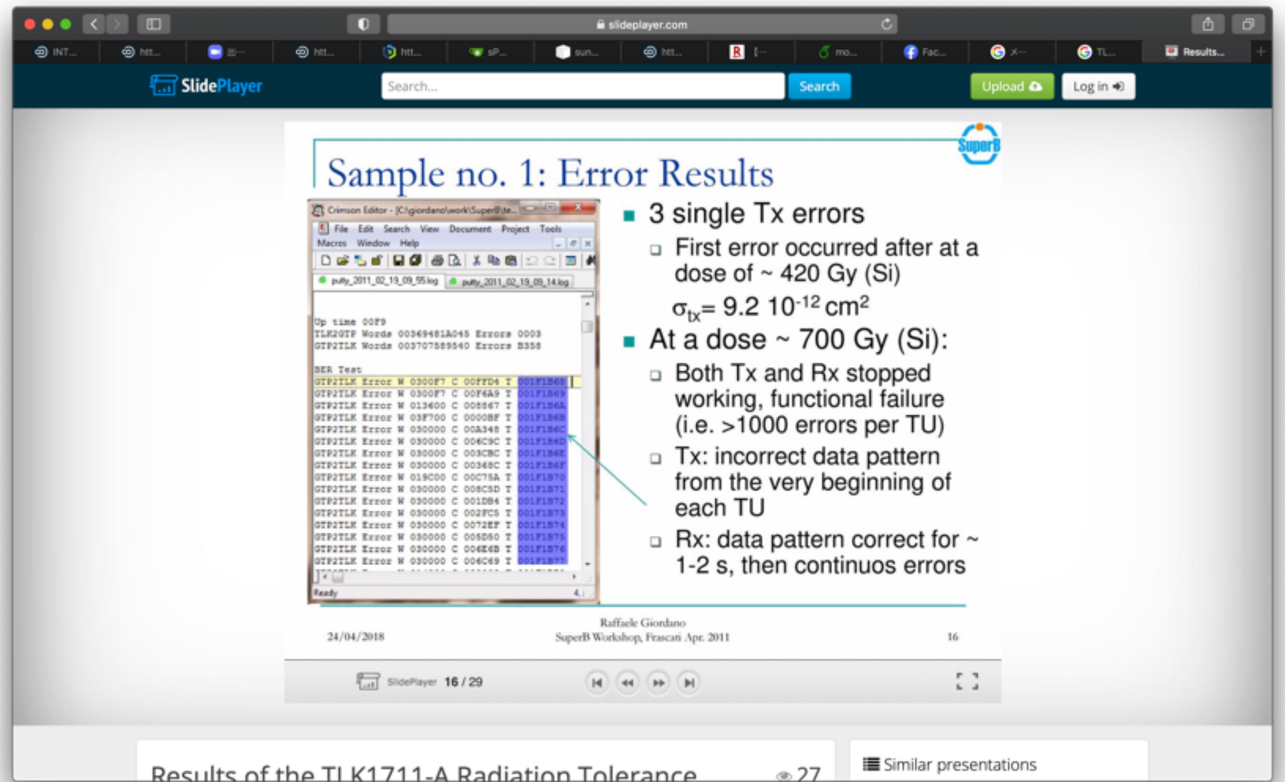
- # Rx errors = 0 single and 2 burst (12,11 consecutive symbols)

$\sigma_{rx(burst)}$= 4.3 10^{-12} cm^2

- At dose = 800 Gy (Si), the device underwent functional failure

https://slideplayer.com/slide/12764619/

Radiation Damage Study by INFN



TLK starts to output "wrong pattern" after certain exposure to radiation. This explains wrong comma word detection but no jitter or deformation of eye diagram.

Plan

- Replace 2 bad ports of SE4 ROC board, which is already in Joe's hand in the instrumentation division.
- In the meantime, procure 20 new TLK2711 available in stock in Japan. Also asking for another 30 new TLK2711's availability (1 week).
- Test repaired 2 bad ROCs in BNL and see if they are recovered by TLK2711 replacement.
- If they are recovered then
  1. Repair 5 other ROCs (ROC2,3,15,17,21; 6 bad ports) in Japan. (Leadtime 3 weeks)
  2. Repair TLK2711 of the slow control ROC of class-1 ROCs in BNL. Repair work better be done in BNL to save shipping time between Japan and US. New TLK2711s are to be provided to BNL from Japan.

ROC SE4

- Scenario-1
- Keep trying to extract TLK2711 from prototype ROC at Instrumentation division. (1~2 weeks)

- Scenario-2
- PO 20 new TLK2711 available in Japanese market (2 ~ 3 + 1 weeks delivery and shipping to BNL.)

2 ~ 3 weeks

4 ~ 5 weeks

- Implement TLK2711 in BNL (1 week)
- Test in BNL (1 day)
- Repair (Shipping to Japan if needed)

Judgement for 4 more ROCs to be repaired

Plan

- Replaced 6 TLKs and 3 ports are recovered.
- Given this fact, we go ahead and try to fix the rest of ROCs (5ROCs, 7 Ports).
- 50 new TLK chips are purchased. (20 are delivered to RIKEN)
- Repair work is to be done in Japan.

Urgent Replacement

- Total TLK2711 per ROC

port	column	ROC	SC	Total
2	8	32	1	33

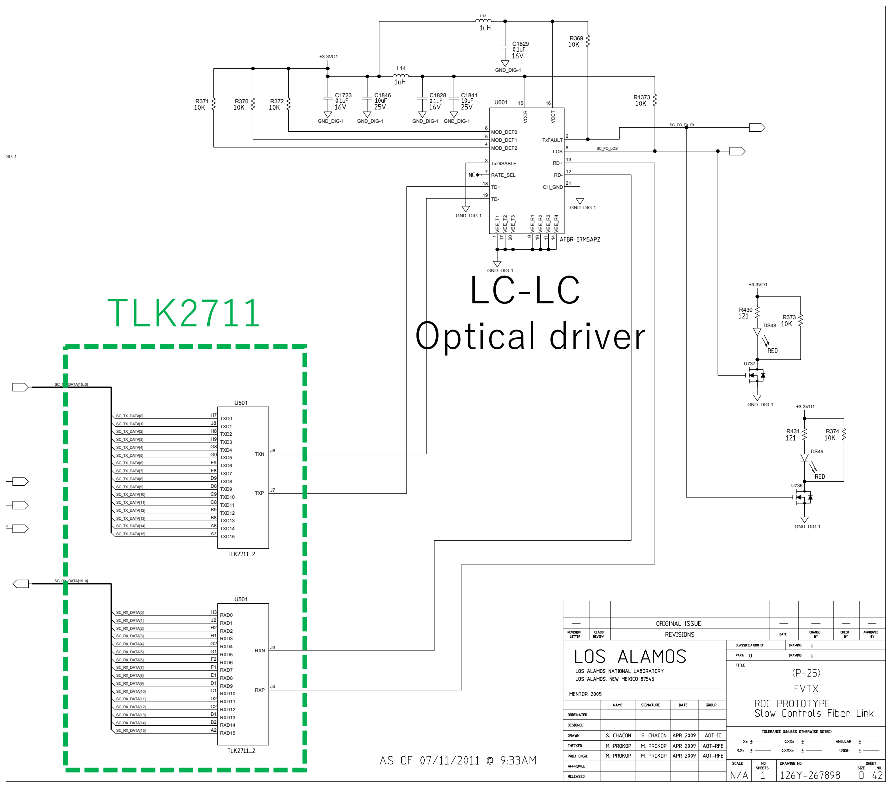
- **Excluding Station-0 TLK2711 per ROC**

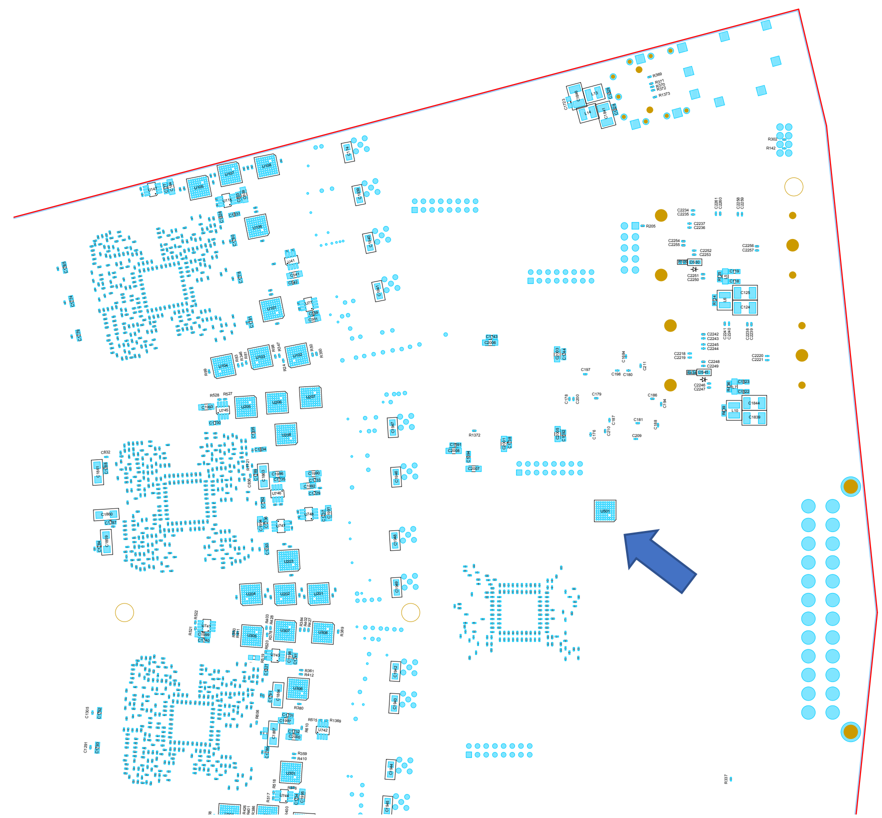
port	**column**	**ROC**	**SC**	**Total**
2	**6**	**24**	**1**	**25**

TLK2711 had been discontinued. There are 20pieces available in stock found in Japanese market. There may be more, but it takes a week to search and get a quote. Delivery is 2 to 3 weeks.

- TLK2711 for Slow Control
- Impact of 1 TLK2711:
  - Data : Loose 1 port
  - SC : Loose entire ROC (7/112 half ladder).
- If the cause of misbehavior of TLK2711 is due to the radiation damage, any TLK2711 can goes wrong anytime during sPHENIX run.
- Thus we better replace the slow control TLK2711 of 16 class-1 ROCs before the commissioning.

Slow Control Serializer





1 TLK2711 per slow control of a given ROC board.

Slow Control TLK Replacement

- 30 new TLK chips are to be shipped to BNL in December.
- Slow Control TLKs of Class-1 ROCs are to be replaced by new ones in BNL instrumentation division.
- According to Joe, the estimated replacement time is one hour per 1 TLK chip and the risk is low.

Repair work cost estimate

No.　　　　　(　　)

御　見　積　書

令和　4　年　11　月　21　日

国立研究開発法人理化学研究所　御中

御照会番号　第

御照会月日　　年　　月　　日

REPIC
ハヤシレピック株式会社
第4事業部

本社　東京都豊島区北大塚1丁目28番3号
〒170-0004　TEL：03(3918)5326(代)
FAX：03(3918)5712
代表取締役　林　厚

毎々格別のお引き立てを頂き有難くお礼申し上げます。
今般ご照会を賜りました件、下記の通りお見積り申上げます。
何とぞご用命下さいますようお願い申し上げます。

合計金額　¥573,111

納期	受注後5-6週間	取引条件	従来通り
受取場所	御研究所	見積有効期間	発行後30日間
荷造費及び運賃	弊社負担	備考	

項	品名および内容明細	数量	単価	金額
	【sPHENIX-INTT検出器の読出し実機用ROCボードのTLK交換】	4 枚		
	電子部品代　TLK2711AJRZQE	1 式	160,000	160,000
	労務費			
	状態確認,部品調査	3 H	6,500	19,500
	メタルマスク製作	4 H	6,500	26,000
	部品除去,再実装,洗浄,目視確認等	32 H	6,500	208,000
	総原価			413,500
	一般管理費及び利益	26.0 %		107,510
	【以下余白】			
	小計			521,010
	消費税			52,101

- 570,000 yen/12 chips (47,500yes/chip)
- JFY2022 : 12 chips @ Japan & 16 chips @ BNL (Total estimate 1M yen for JFY2022
- JFY2023 : 50 chips x 47,500yen = 2.3Myen

Total Radiation Dose Estimate for TLK2711

RIKEN/RBRC

Itaru Nakagawa

[18] J. Asai, et al., arXiv:0710.2676.

Radiation Damage Study for PHENIX Silicon Stripixel Sensors

J. Asai[a], S. Batsouli[b], K. Boyle[c], V. Castillo[d], V. Cianciolo[b], D. Fields[e], C. Haegeman[e], M. Hoeferkamp[e], Y. Hosoi[f], R. Ichimiya[a], Y. Inoue[f], M. Kawashima[f], T. Komatsubara[g], K. Kurita[f], Z. Li[h], D. Lynch[j], M. Nguyen[c], T. Murakami[i], R. Nouicer[j], H. Ohnishi[a], R. Pak[j], K. Sakashita[k], T.-A. Shibata[k], K. Suga[f], A. Taketani[a], J. Tojo[a]

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[b] *Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[c] *Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794-3800, USA*
[d] *Brookhaven National Laboratory, C-A Department, Upton, NY 11973-5000, USA*
[e] *University of New Mexico, Albuquerque, NM 87131, USA*
[f] *Rikkyo University, Toshima, Tokyo 171-8501, Japan*
[g] *Tandem Accelerator Complex, Research Facility Center for Science and Technology, University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan*
[h] *Brookhaven National Laboratory, Instrumentation Division, Upton, NY 11973-5000, USA*
[i] *Department of Physics, Kyoto University, Kyoto, Kyoto, 606-8502, Japan*
[j] *Brookhaven National Laboratory, Physics Department, Upton, NY 11973-5000, USA*
[k] *Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan*

the strip and the ones attached at the BLMs and chipmunks that were in the area only for part of the run with a delivered luminosity of 12 pb^{-1}. Therefore the accumulated radiation values for these TLDs are higher. The measurements from these TLDs indicate a dependence on the distance from the beam line that is in accordance with the radial dependence in Figure 15. In Figure 15 the nose cone TLD values (blue points), scaled at 12 pb^{-1}, have been overlaid with the values of the rest of the TLDs (red points).

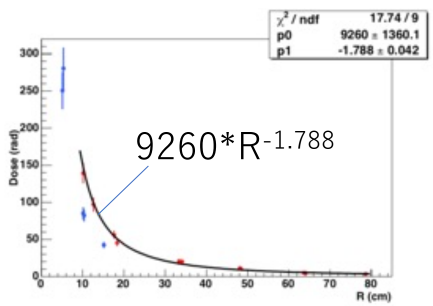


Fig. 15. Red points: TLD radiation measurements versus their distance R from the beam line and fit to the function $p0 * R^{p1}$. Blue points: TLDs placed on the nose cone, scaled to the same luminosity as the red points, versus their distance R from the beam line

Z=41cm, 42/pb

There were two kinds of test diodes with different volumes which were 0.01 cm^3 and 0.004 cm^3. The increase of the leakage current of the diodes and the relevant fluences are summarized in Table 5. Only fifteen diodes are listed since the other diode was found to be defective during the leakage current measurement. The average fluence of the diodes was 1.0×10^{10} N_{eq}/cm^2. The estimated z dependence of the diode fluence is shown in Fig. 17 which is in agreement with the TLDs.

The sensor was irradiated at Z=25.2 cm for about 50 days and the integrated luminosity during this time was 12 pb^{-1}. The current related damage rate α was estimated to be 3.2×10^{-17} A/cm using the temperature history of the temperature loggers in the PHENIX IR. The increase of leakage current of a single strip was 2.2×10^{-10} A/strip as seen in Table 5. Figure 18 shows the IV and CV measurements, where the leakage current and capacitance were measured before and after irradiation. The fluence of irradiated stripixel sensor was estimated to be 9.4×10^{9} N_{eq}/cm^2 which is consistent with the average fluence of the reference diodes.

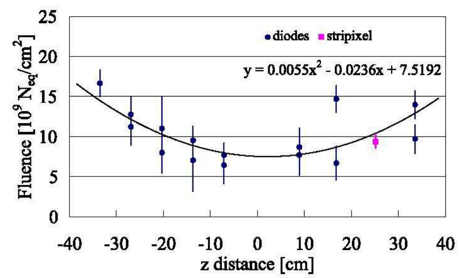
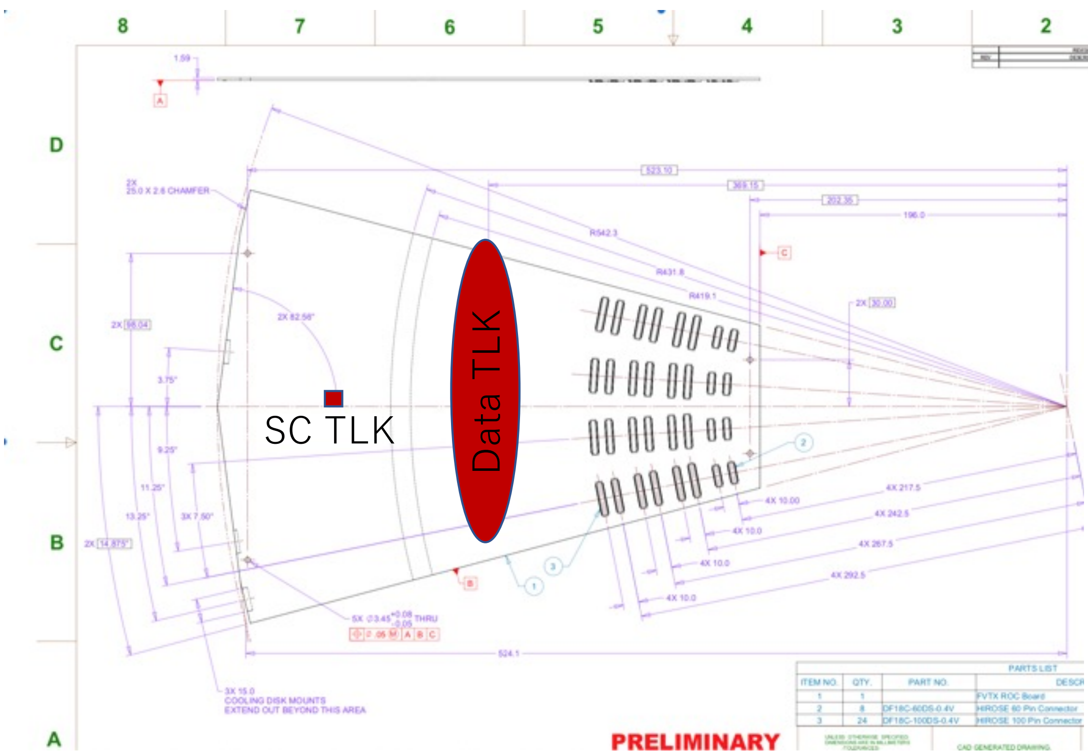
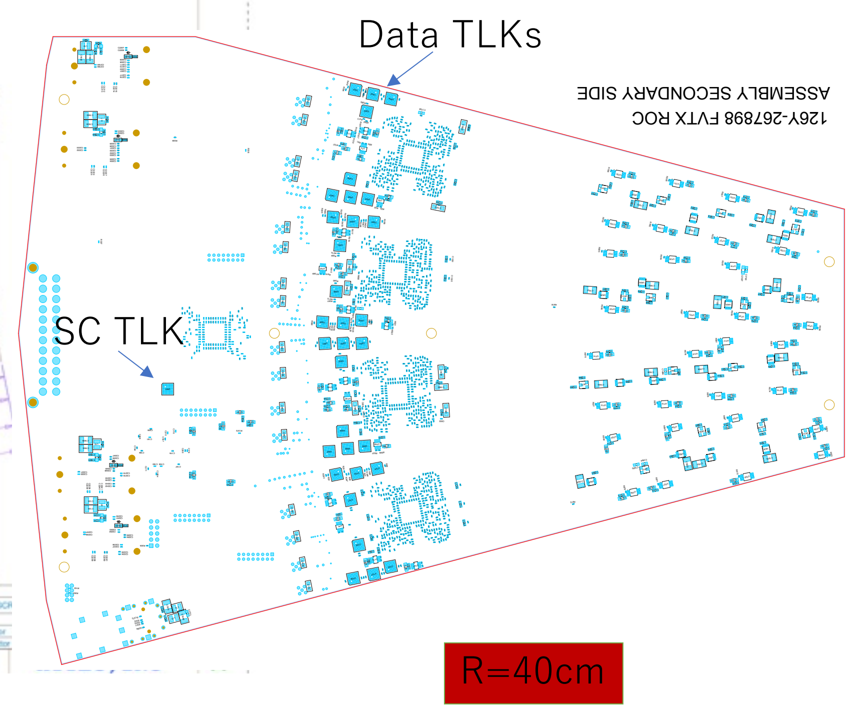


Fig. 17. Fluence of irradiated stripixel sensor and diodes at R=10 cm in PHENIX IR.

Run6 p+p
Delivered Luminosity: 12/pb (50days)
Number of Equivalent Neutrons: $10^{10}/cm^2$
Location: R=10cm, z=25cm, η=1.65

Location of TLK Chips in FVTX





FVTX ROC Layout

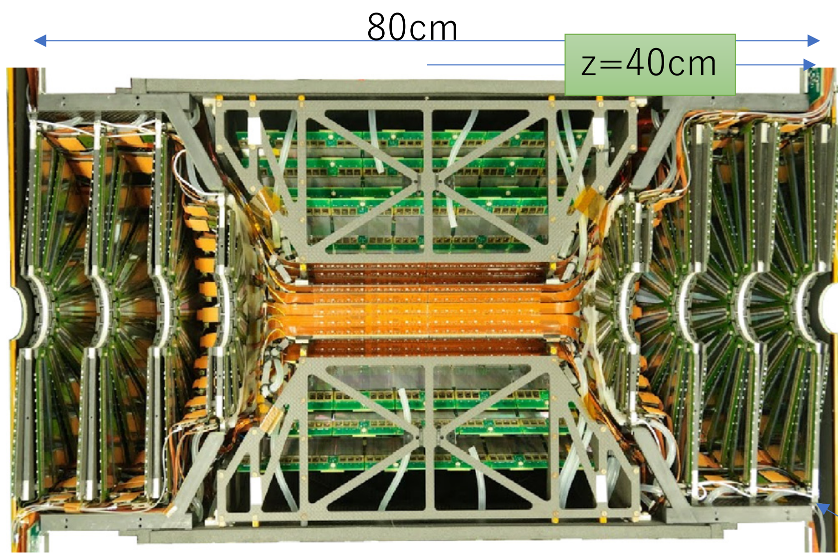
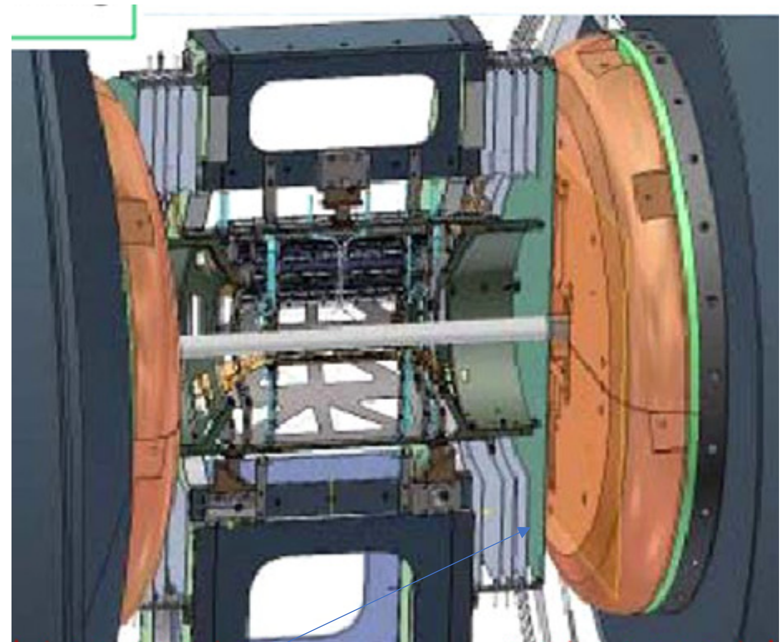
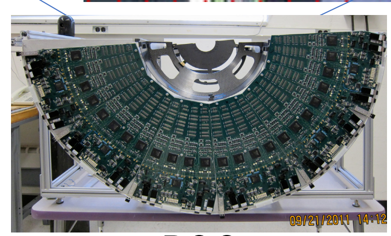


Fig. 20. A completed half-detector, with the VTX barrels in the center, and the two FVTX endcaps on either end. The overall length is 80 cm.

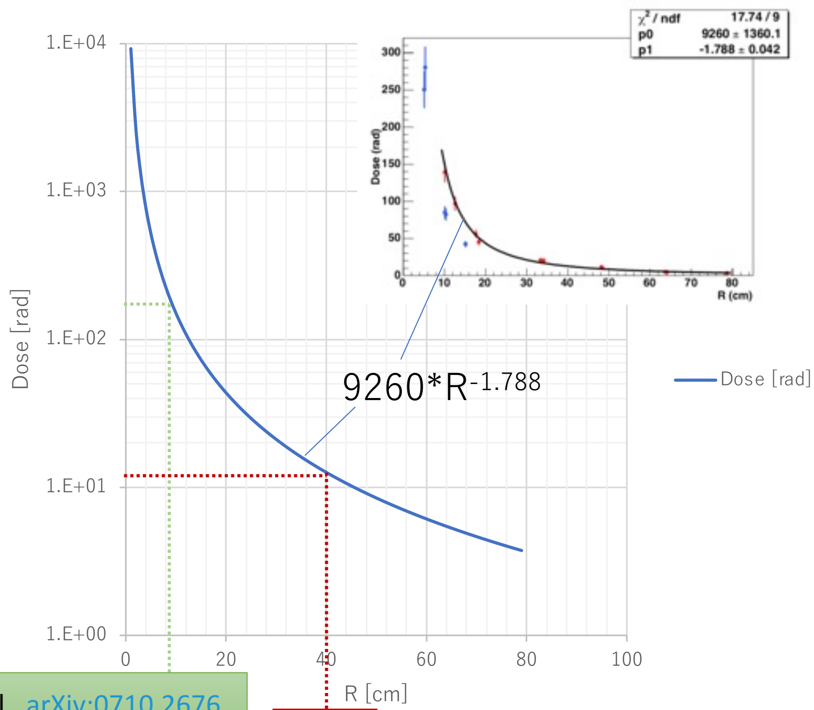




ROC

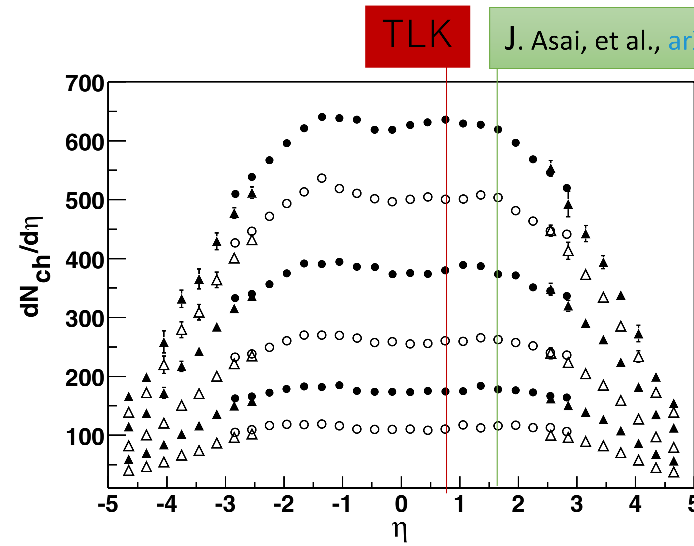
$R = 40\text{cm}$
$z = 40\text{cm}$
$\eta = 0.88$

Radiation Dose at FVTX-TLK2711 Location



J. Asai, et al., arXiv:0710.2676.

Radius Scale Factor ε_R = 0.08



J. Asai, et al., arXiv:0710.2676.

FIG. 1. Distributions of $dN_{ch}/d\eta$ for centrality ranges of, top to bottom, (0−5)%, (5−10)%, (10−20)%, (20−30)%, (30−40)%, and (40−50)%. The SiMA and BBC results are indicated by circles and triangles, respectively. Statistical errors are shown for all points where they are larger than the symbol size.

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Rapidity Scale Factor ε_η = 1

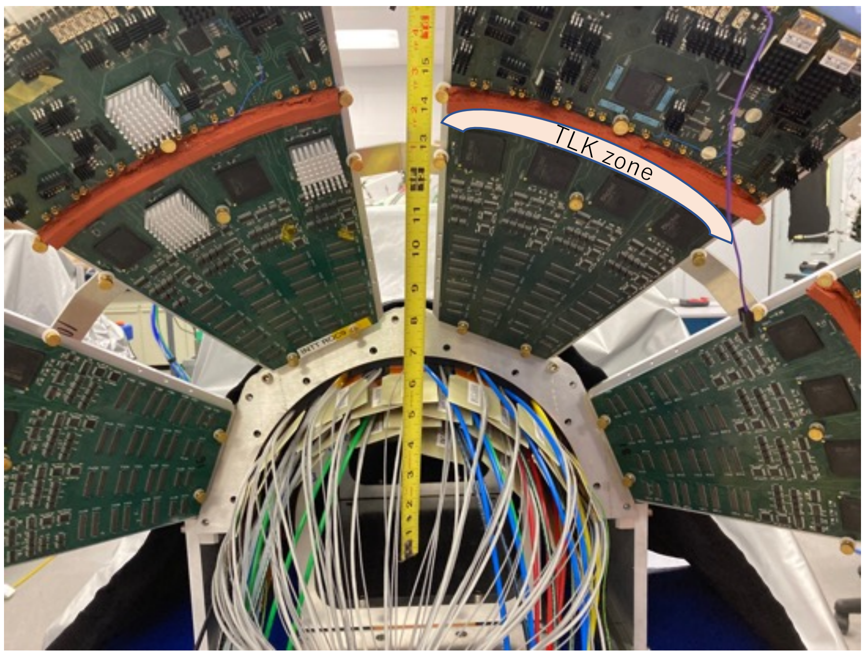
FVTX Operation Run12 ~ Run16

Run	species	total particle energy [GeV/nucleon]	calendar time in physics	total delivered luminosity	average store polarization, (H-jet)*
Run-12 CY2011/12, FY2012 22.9 cryo-weeks	polarized p + p	100.2	4.4 weeks	74.0 pb^{-1}	59%
	polarized p + p	254.9	4.9 weeks	283 pb^{-1}	52%
	$^{238}U^{92+} + ^{238}U^{92+}$	96.4	3.1 weeks	736 μb^{-1}	–
	$^{63}Cu^{29+} + ^{197}Au^{79+}$	99.9 + 100.0	5.4 weeks	27.0 nb^{-1}	–
Run-13 CY2012/13, FY2013 17.0 cryo-weeks	polarized p + p	254.9	13.3 weeks	1.04 fb^{-1}	53%
Run-14 CY2013/14, FY2014 22.0 cryo-weeks	$^{197}Au^{79+} + ^{197}Au^{79+}$	7.3	3.4 weeks	44.2 μb^{-1}	–
	$^{197}Au^{79+} + ^{197}Au^{79+}$	100.0	13.3 weeks	43.9 nb^{-1}	–
	h + $^{197}Au^{79+}$	103.5 + 100.0	2.4 weeks	134 nb^{-1}	–
Run-15 CY2014/15, FY2015 22.4 cryo-weeks	polarized p + p	100.2	10.9 weeks	382 pb^{-1}	55%
	polarized p + $^{197}Au^{79+}$	103.9 + 98.6	5.1 weeks	1.27 pb^{-1}	60%
	polarized p + $^{27}Al^{13+}$	103.9 + 98.7	1.9 weeks	3.87 pb^{-1}	54%
Run-16 CY2015/16, FY2016 23.3 cryo-weeks	$^{197}Au^{79+} + ^{197}Au^{79+}$	100.0	14.4 weeks	52.2 nb^{-1}	–
	d + $^{197}Au^{79+}$	100.7 + 100.0	8 days	289 nb^{-1}	–
	d + $^{197}Au^{79+}$	31.3 + 31.1	6 days	44.0 nb^{-1}	–
	d + $^{197}Au^{79+}$	9.9 + 9.8	11 days	7.20 nb^{-1}	–
	d + $^{197}Au^{79+}$	19.6 + 19.4	7 days	19.5 nb^{-1}	–

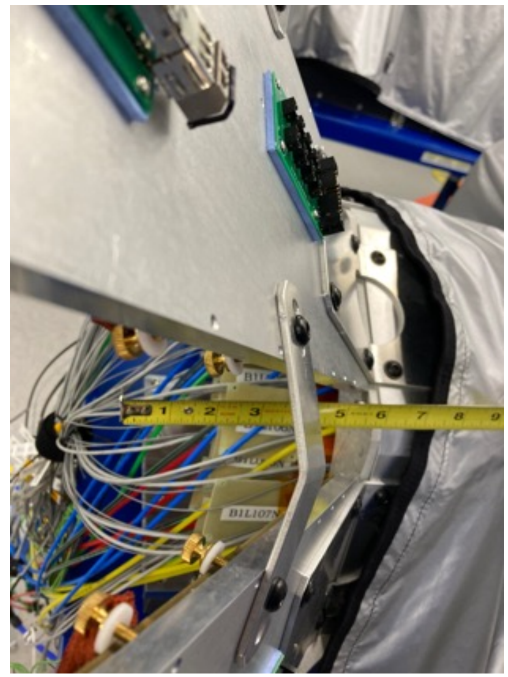
Total Delivered Luminosity = 1785/pb

https://www.rhichome.bnl.gov/RHIC/Runs/

Location of TLK chips for INTT

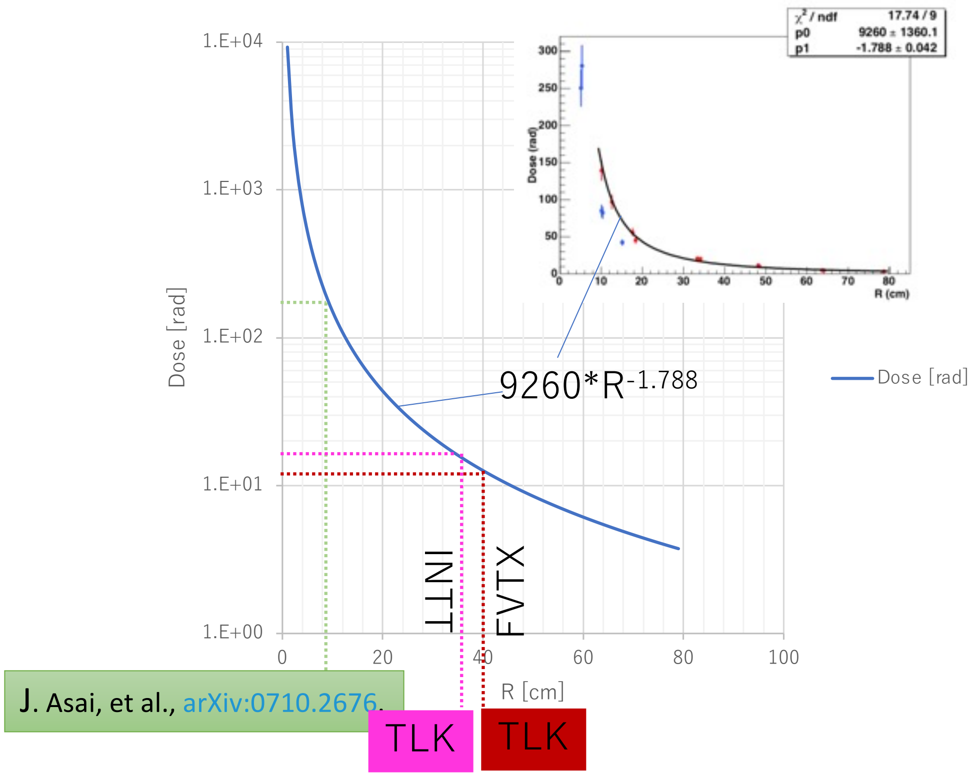


R~35cm



z=40cm(HDI)+110cm(BEX)+7.6cm (ROC)
=157.6cm
η=4.5

Radiation Dose at INTT-TLK2711 Location



Radius Scale Factor $\varepsilon_R = 0.11$

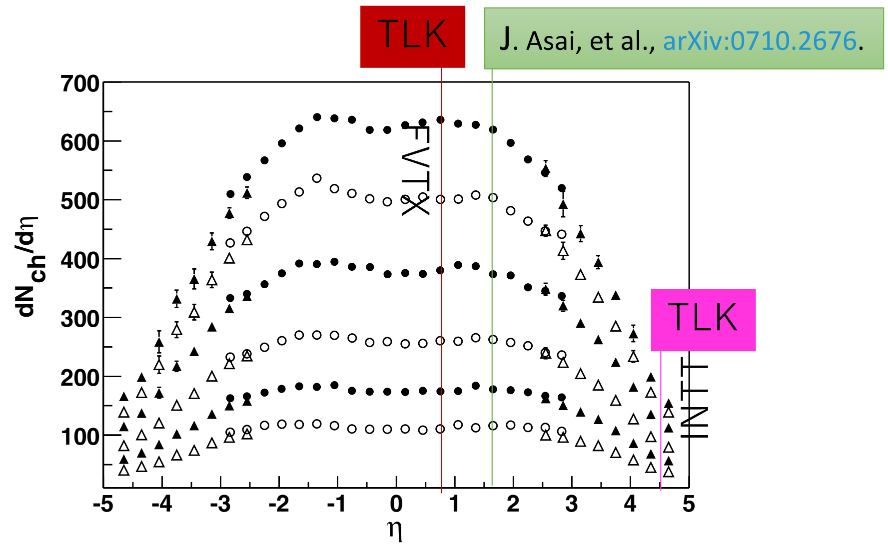


FIG. 1. Distributions of $dN_{ch}/d\eta$ for centrality ranges of, top to bottom, (0−5)%, (5−10)%, (10−20)%, (20−30)%, (30−40)%, and (40−50)%. The SiMA and BBC results are indicated by circles and triangles, respectively. Statistical errors are shown for all points where they are larger than the symbol size.

Phys. Rev. Lett. **88**, 202301

Rapidity Scale Factor $\varepsilon_\eta = 0.3$

sPHENIX Delivered Luminosity Estimate

RHIC Collider Projections (FY 2023 – FY 2025)

W. Fischer, A. Drees, H. Huang, M. Minty, D. Raparia, T. Shrey, and M. Valette

Last update: 3 May 2022

Table 2: Demonstrated and projected luminosities for 100 GeV/nucleon Au+Au runs.

Parameter	**Unit**	**FY2007**	**2010**	**2011**	**2014**	**2016**	**2023E**	**2025E**
No of bunches k_b	…	103	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	1.1	1.1	1.3	1.6	2.0	2.4	2.90
Average beam current/ring I_{avg}	mA	112	121	147	176	224	265	319
Stored beam energy	MJ	0.36	0.39	0.47	0.56	0.71	0.84	1.0
Envelope function at IP β^*	m	0.85	0.75	0.75	0.70	0.70	0.70	0.65
Beam-beam parameter ξ/IP	10^{-3}	-1.7	-1.5	-2.1	-2.5	-3.9	-4.6	-5.6
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**30**	**40**	**50**	**80**	**155**	**215**	**336**
Events per bunch-bunch crossing μ	…	0.08	0.10	0.13	0.21	0.40	0.55	0.86
Average/initial luminosity	%	40	50	60	62	56	58	60
Average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**12**	**20**	**30**	**50**	**87**	**125**	**200**
Time in store	%	48	53	59	68	65	60	60
Max. luminosity/week	μb^{-1}	380	650	1000	2200	3000	4530	7260
Min. luminosity/week	μb^{-1}						3000	3000
L within $\|z\|<10$ cm, $\theta = 0$ mrad, r_0/r_θ*	%						39/39	39/39
L within $\|z\|<10$ cm, $\theta = 2$ mrad, r_0/r_θ*	%						31/81	31/81

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,0)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

Table 3: Demonstrated and max projected luminosities and polarization for p↑+p↑ and p↑+Au runs at 100 GeV.

		p↑+p↑					p↑+Au	
Parameter	Unit	FY2008	2009	2012	2015	2024E	FY2015	2024E
No of colliding bunches k_b	…	109	109	109	111	111	111	111
Protons/bunch, initial N_b	10^{11}	1.5	1.3	1.6	2.25	2.5	225/1.6	250/2.4
Average beam current/ring I_{avg}	mA	198	179	214	312	347	313/176	348/266
Stored beam energy	MJ	0.25	0.23	0.27	0.40	0.45	0.40/0.56	0.45/0.84
Envelope function at IP β^*	m	1.00	0.70	0.85	0.85	0.85	0.85/0.70	0.85/0.70
Hourglass factor H	…	0.77	0.72	0.74	0.75	0.84	0.72	0.72
Beam-beam parameter ξ/IP	10^{-3}	-5.3	-6.3	-5.8	-9.7	-11.7	-5.3/-4.1	-11.7/-4.3
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**35**	**50**	**46**	**115**	**176**	**88**	**168**
Events per bunch-bunch crossing μ	…	0.2	0.3	0.3	0.7	1.1		
Average/initial luminosity	%	65	56	71	55	57	51	54
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**23**	**28**	**33**	**63**	**100**	**45**	**90**
Time in store	%	60	53	59	64	60	65	60
Max. luminosity/week	pb^{-1}	7.5	8.3	9.3	25	36	140	326
Min. luminosity/week	pb^{-1}					25		140
L within $\|z\|<10$ cm, $\theta = 0$ mrad, r_0/r_θ*	%					22/22		29/29
L within $\|z\|<10$ cm, $\theta = 2$ mrad, r_0/r_θ*	%					19/69		24/75
AGS extraction, P_{max}	%	55	65	72	68	68	68	68
RHIC store average, P_{max}	**%**	**45**	**56**	**59**	**57**	**60**	**60**	**60**
RHIC store average, P_{min}	%					57		57

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,0)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

Year	Species	Max Lumi/Week	28 weeks Year Total
2023	Au+Au	4.53 /nb	0.1/pb
2024	p+p	36 /pb	768/pb
	p+Au	326 /pb	2173/pb
2025	Au+Au	7.26 /nb	0.2/pb

Integrated Luminosity

2941/pb

Total Radiation Dose Estimate

	Delivered Luminosity [/pb]	R [cm]	z [cm]	η	ε_R	ε_η	N_{eq}
Asai et al.	12	2	25	3.2	1	1	10^{10}
FVTX TLK	1785	40	40	0.88	0.08	1	1.2×10^{11}
INTT TLK	2940	35	157	4.5	0.11	0.3	7.3×10^{11}