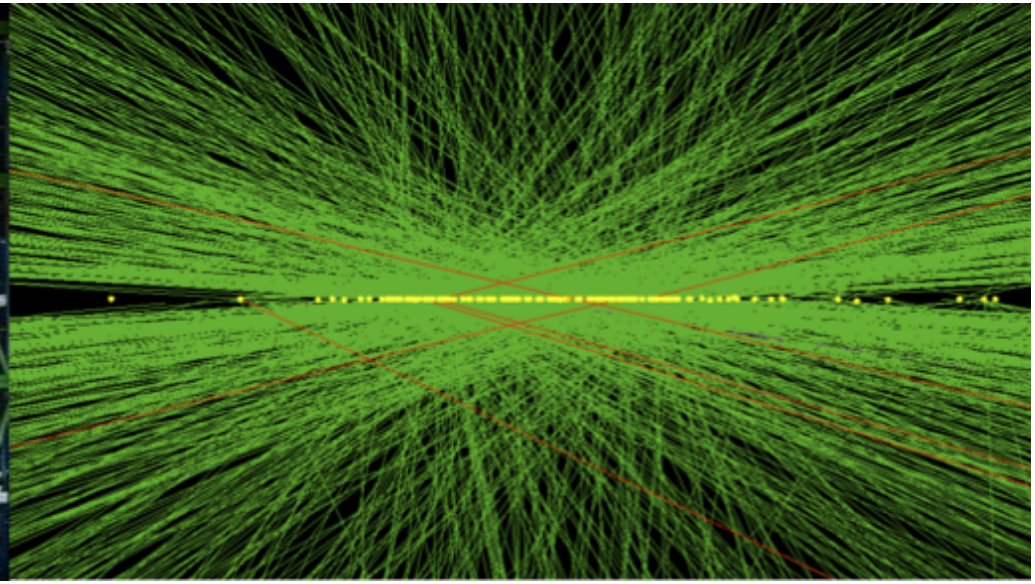
V2 updated 24 Aug 2021

TFPX

Karl Ecklund, Will Johns

MREFC Annual Review

August 25, 2021



Outline

- Overview/Scope
- Completion of R&D
  - FDR Recommendations
- Progress Overview – Technical
  - Current technical status by L3 area
  - Plan to prepare for technical review
- EVM Status
  - Milestones/Schedule
  - Earned Value Summary
  - Summary of Change Control Actions
- Summary of Covid Impacts and Plans
- Plans for 2022 and iCMS updates
- QA/QC Implementation

Biographical Sketch – L2

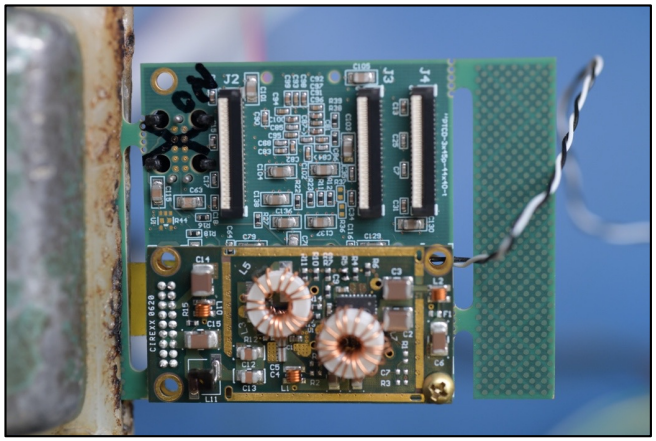
Prof. Karl Ecklund, Rice University 2008 –

- PhD: Stanford University 1996
- Postdoc & Research Associate: Cornell 1996 – 2006

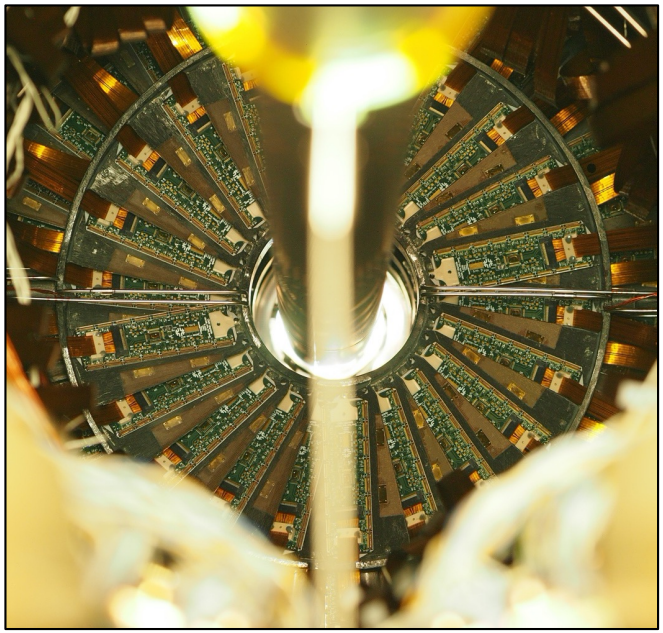
- Pixel Detector experience
  - 2005 – 2010: CMS Pixel Detector (DAQ/online software)
  - 2011 – 2017: CMS Phase 1 Pixel Detector (Pilot System L3 manager)
  - 2016 – Present: CMS Phase 2 Inner Tracker Electronics (Optohybrid/port card, sensor & ASIC irradiations)

- HEP Management experience
  - 2001 – 2003: CLEO Analysis Coordinator
  - 2013 – 2015: CMS Deputy Tracker Project Manager
  - 2015 – 2016: US CMS HL-LHC Tracker Upgrade L2 co-manager
  - 2016 – Present: US CMS HL-LHC TFPX L2 co-manager
  - 2018 – Present : CMS Inner Tracker Coordinator
  - 2013 – Present: CMS Tracker Management Board Member

TFPX Portcard & DC-DC Mezz



CMS Phase 1 Pixel Detector



Biographical Sketch – L2 Deputy

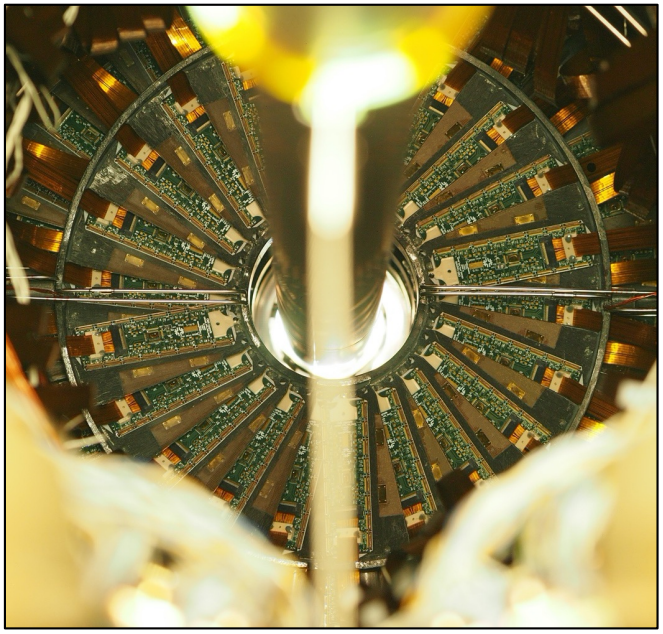
Prof. Will Johns, Vanderbilt University 1999 –

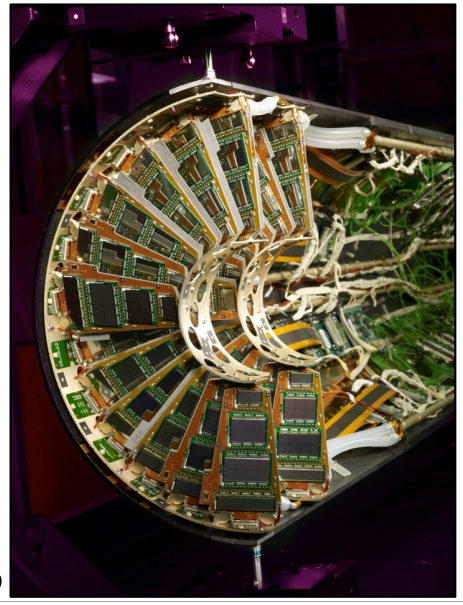
- PhD University of Colorado 1995

- Silicon & Pixel Detector Experience
  - 1995 – 2005: FOCUS Target Silicon electronics, detector assembly, DAQ, firmware, reconstruction, simulation, project leader
  - 2005 – : CMS Pixel Detector DAQ software/firmware
  - 2005 – : CMS Pixel Lumi Telescope DAQ, software, firmware

- HEP Management Experience
  - 2002 – 2005 : BTeV Deputy Muon L3 Manager
  - 2013 – 2014 : USCMS Phase 1 Pixel Upgrade Deputy L2 Manager
  - 2014 – 2017: USCMS Phase 1 Pixel Upgrade L2 Manager
  - 2011 – 2013: USCMS Pixel Ops L2 Deputy Manager
  - 2013: USCMS Pixel Operations L2 Manager
  - 2014 – : USCMS Tracker (Pixel & Strips) L2 Ops Manager
  - CMS Tracker Management Board Member
  - CMS Tracker Finance Board Representative (NSF)

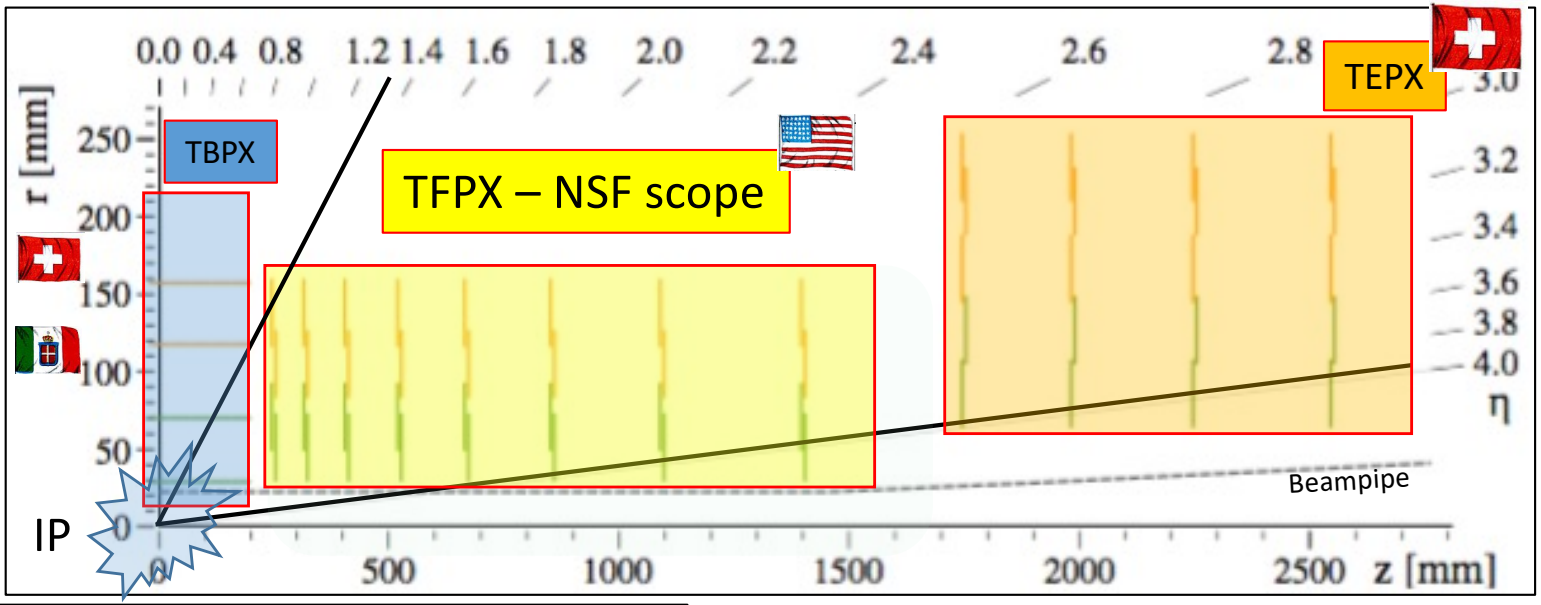
CMS Phase 1 Pixel Detector

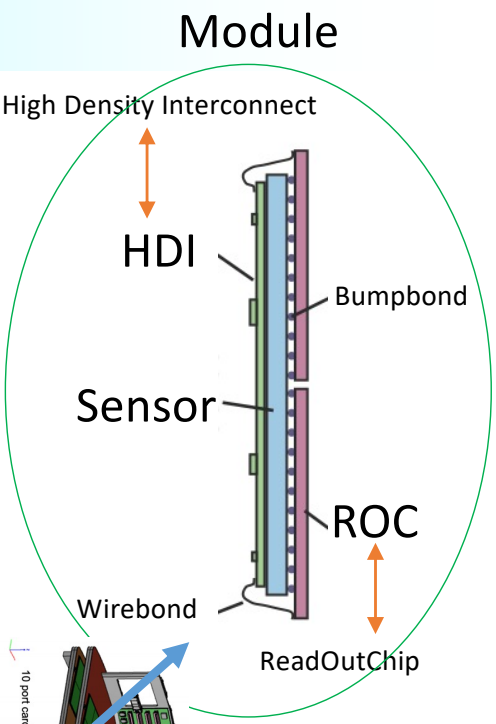




CMS Pixel Detector 2008-2016

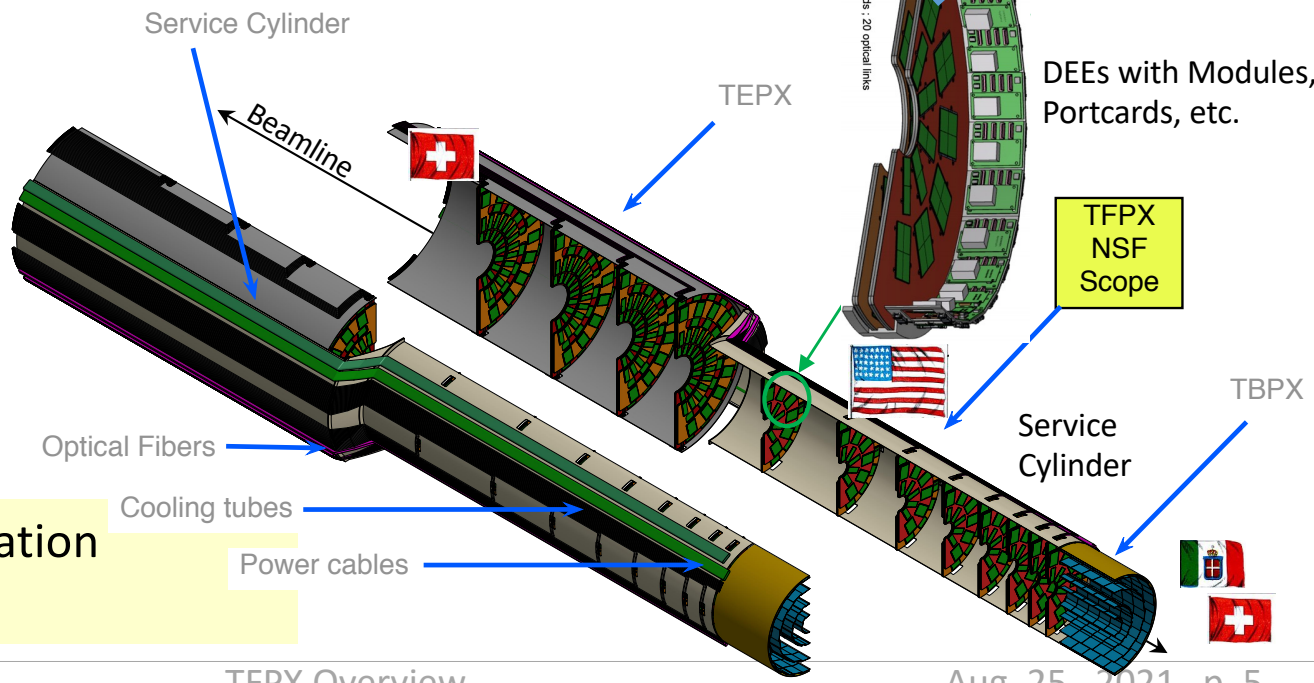
TFPX Scope





TFPX – primary forward tracking device: NSF Scope

- $1.3 < |\eta| < 4$
- 2x8 disks, 1728 modules
- 0.8 Gigapixels
- 1.9 m^2 silicon area
- Module support electronics
- Off detector Electronics



No changes in scope or configuration
Same as at FDR

TFPX Deliverables

- Deliverables ($N_{installed}$)
  - 8+8 small disks (TFPX) tiled with silicon pixel sensor modules (1728)
  - Associated mechanical structures Dees (32), service cylinders (4)
  - Associated readout & control electronics, on and off detector
  - Associated power, cooling pipes, cables, readout & control optical fibers
  - Relevant share for common services (~38%) used by TFPX:
    - power system, cooling plant, detector safety system, monitoring & slow control
    - US Responsibilities for design of common TBPX/TFPX/TEPX items, agreed with international CMS Tracker Project
  - Design & delivery of TFPX+TBPX service cylinders (4)
  - Inner Tracker back-end electronics **D**ata **T**rigger **C**ontrol board (DTC) : (8) engineering, hardware design, firmware (US M&S costs only for TFPX)
  - On-detector optical-electrical interface electronics (port cards): (256) engineering, design, testing (US M&S costs only for TFPX)
  - Design & delivery of Inner Tracker Support Tube (1)
- Scope is same as FDR (only change since PDR is addition of ITST)

R&D Completion

- Budget summary

Sensors

Modules

Electronics

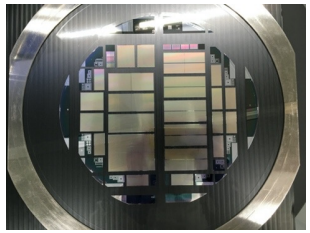
Mechanics

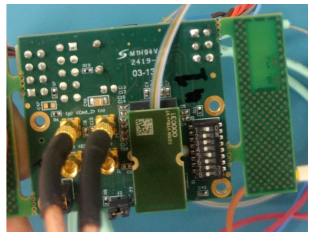
Institution	Spending ($)
Boston	157,753
Buffalo	11,121
Catholic	39,975
Colorado	177,917
Cornell	1,765,516
Kansas	199,683
Kansas State	171,636
Nebraska	231,229
Ohio State	36,229
Puerto Rico	56,805
Purdue	718,748
Purdue Northwest	7,228
Rice	477,851
Riverside	14,045
Tennessee	6,984
UCD	16,211
UI Chicago	151,342
Vanderbilt	4,606
Total	**4,244,890**

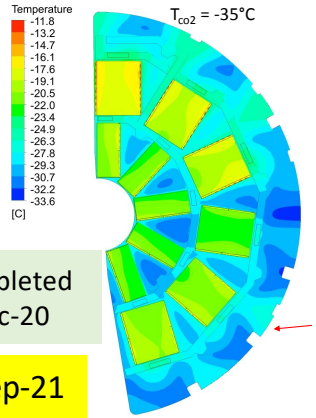
R&D Milestones

1b

WBS	Milestone	Planned Finish Date	Last Month's Finish Date	Forecast Finish Date
TFPX 402.7.3	RD53A received for physical testing	Dec-17	Jan-18	Completed Jan-18
TFPX 402.7.6	Demonstrate structural characteristics of step section	Apr-18	Apr-18	Completed May-18
TFPX 402.7.4	Demonstrage HDI handling in module assembly	Oct-18	Oct-18	Completed Oct-18
TFPX 402.7.6	Demonstrate services mounting on mockup service cylinder	Oct-18	Jan-20	Completed Jan-19
TFPX 402.7.6	Demonstrate thermal properties of prototype dee	Nov-18	Aug-19	Completed Jul-19
TFPX 402.7.5	Demonstrate RD53A readout capability	Nov-18	Nov-18	Completed Sep-18
TFPX 402.7.3	Evaluate irradiated prototype sensor in beam test	Dec-18	Dec-18	Completed Nov-18
TFPX 402.7.3	Complete production of thermal mockup modules	Jan-19	Jan-19	Completed Jan-19
TFPX 402.7.6	Fabricate installation hardware and conduct mock insertion studies	Jun-19	Dec-19	Completed Jan-20
TFPX 402.7.5	Module readout and prototype evaluation system developed	Jun-19	Jun-19	Completed Jun-19
TFPX 402.7.3	Complete irradiation studies of planar sensors to full fluence	Jul-19	Jul-19	Completed Jun-19
TFPX 402.7.5	DTC prototype evaluated	Jul-19	Jul-19	Completed Jul-19
TFPX 402.7.3	Establish that radiation damage gradient in inner rings can be accomodated without efficiency loss	Sep-19	Dec-19	Completed Jan-20
TFPX 402.7.4	Demonstrate functionality of prototype tooling for module assembly	Sep-19	Dec-19	Completed Jan-20
TFPX 402.7.5	Prototype portcard with first version of the LpGBT, Versalink, and DCDC chips fabricated	Sep-19	Sep-19	Completed Sep-19
TFPX 402.7.6	Fabricate first prototype service half-cylinder	Oct-19	Oct-19	Completed Jul-19
TFPX 402.7.3	Submit first version of the CPC ROC for production (external)	Dec-19	Apr-20	Jun-20
TFPX 402.7.4	Establish capabilities of at least one additional module factory	Dec-19	Feb-20	Completed Feb-20
TFPX 402.7.5	Prototype e-link and connector design evaluated	Dec-19	Dec-19	Completed Dec-19
TFPX 402.7.6	Complete initial thermal and mechanical studies for dee	Dec-19	Mar-20	Dec-20
TFPX 402.7.4	Complete selection of materials for preproduction modules based on thermal performance, radiation hardness, and assembly studies	Apr-20	Apr-20	Dec-20
TFPX 402.7.3	3D sensors (or inner ring sensor) irradiated to full fluence	Apr-20	Apr-20	Apr-21







Completed Jun-21

Completed Dec-20

Sep-21

Nov-21

Remaining R&D Milestones: two completed & two remain (nearly complete) in MREFC

FDR Recommendations

1a

Docdb-14309

- (1) Technical Review: status before iCMS IT EDR
  - Assess whether changes of scope are warranted
    - Delays, R&D completion, impacts on/from HL-LHC schedule
  - Validation of component choices, design performance
    - We added additional development to early MREFC activities, matching iCMS schedule, to contribute well to technical readiness & mitigate risks
      - port card prototype (lpGBT, VTRx+, bPOL) and mechanical integration design
      - sensor radiation qualification and test beams
      - RD53 & C-ROC demo module assembly and testing
- (2) TFPX design maturity / remaining development
  - Milestones and deliverables associated with areas of concern should be well established in ~18 months & mitigations developed
    - Status of milestones and deliverables tracked & reported monthly
    - Mitigations have been developed in change control process

FDR Recommendations

1a

- (3) Develop and regularly update compliance tables for planar, 3D sensors, C-ROC, lpGBT, DC-DC converters, VTRx+
  - Project management (L1/L2) pursued these with iCMS, and collects status for MREFC monthly reports
    - RD53 maintains RD53B/C-ROC tables; iCMS reviewed in Jan'21 prior to prototype submission (Jun'21) https://indico.cern.ch/event/987758/
    - CMS Electronics coordination covers lpGBT, bPOL, VTRx+
      - https://twiki.cern.ch/twiki/bin/view/CMS/ElectronicsCommonProjectsCMS
    - CERN ESE maintains these matrixes (for e.g. lpGBT) and regularly provides public updates and schedule progress to users at TWEPP, ACES, talks to experiments
      - https://espace.cern.ch/GBT-Project/LpGBT/Presentations
    - Documentation is maintained in EDMS (lpGBT, bPOL, VTRx+) and referred to by TFPX engineering / design teams
    - CMS Tracker will also use EDMS (sensors, C-ROC)

FDR Recommendations

- (4) Evaluation if VTRx+ can last for HL-LHC duration, avoiding replacement; assess viability if replacement is inevitable
  - Risk of port card redesign added to register (RT-402-7-20-N)
  - Revised radiation estimate for HL-LHC indicates one replacement is likely required (4000 fb^{-1}) at LS5 (50%)
  - Design has replaceable VTRx+, DC-DC mezzanine or entire port card assembly
  - Design revised to mitigate and maintain optical margin as long as possible → fiber length & location, VTRx+ location
- (5) Include separate risks for planar and 3D "Sensor Quality Problem" and "Sensor Vendor Unable to Meet Tech. Requirements"
  - Risks updated after FDR
    - RT-402-7-1-N (Planar) & RT-402-7-18-N (3D) "sensor vendor unable to meet technical requirements"
    - RT-402-7-15-N "Sensor quality problem" will be split at next RMB

Progress Overview

Progress Summary : Sensors [402.7.3]

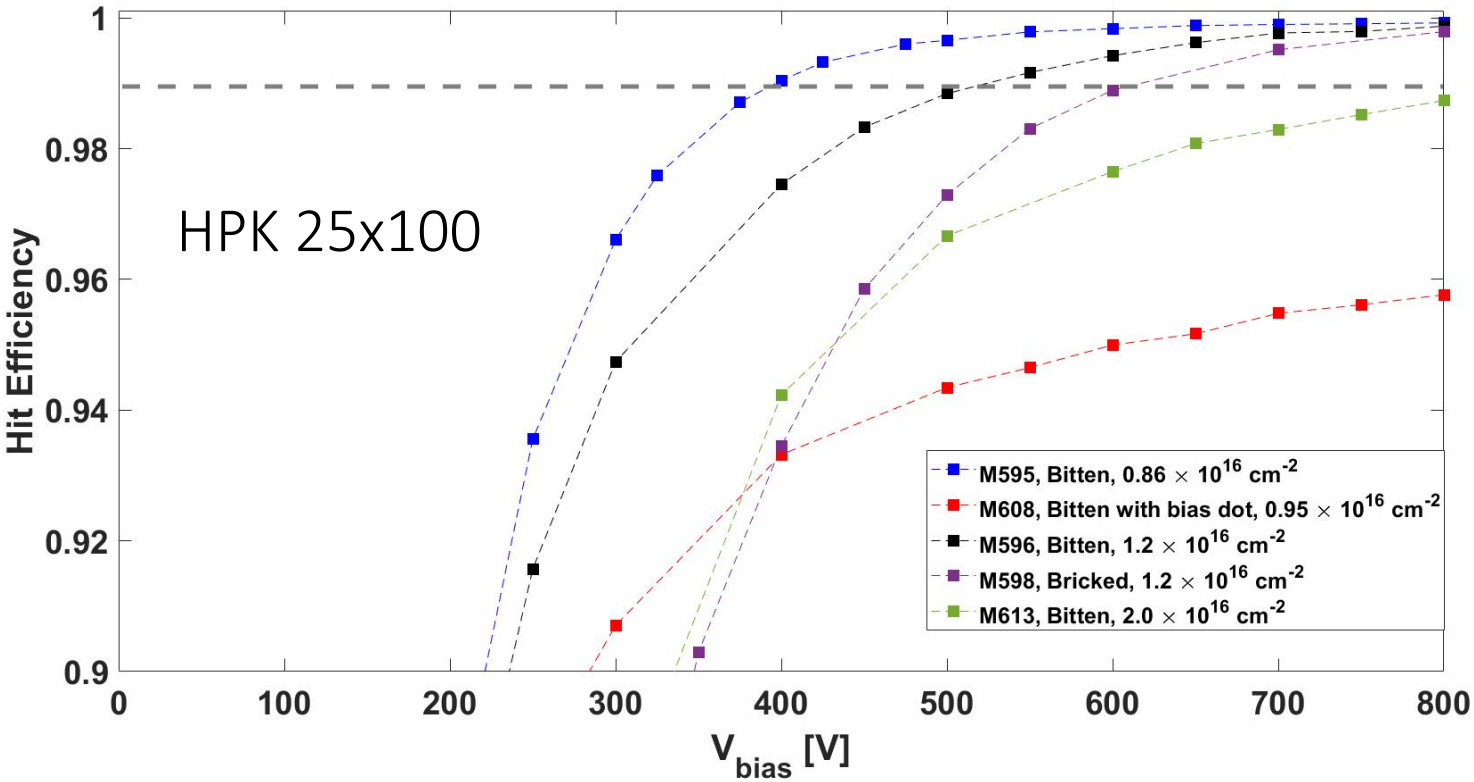
4a

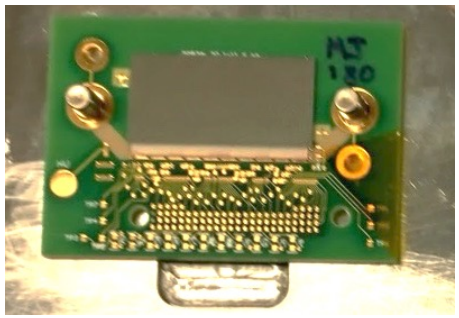
- CMS IT sensors must survive HL-LHC radiation environment:
  - up to 1.9E16 n_{eq}/cm^2 and 1 GRad TID (for TBPX layer 1)
- CMS Revised plan for "Ultimate" Luminosity Scenario for 4000 fb^{-1} by end of HL-LHC (Run 4-5-6)

	RUN 4		RUN 5		RUN 6		Run 4+5		Run 4+5+6	
	1E16 1 MeV n_eq	Grad	1E16 1 MeV n_eq	Grad	1E16 1 MeV n_eq	Grad	1E16 1 MeV n_eq	Grad	1E16 1 MeV n_eq	Grad
BPIX L1	0.73	0.40	1.16	0.63	1.63	0.89	1.88	1.03	3.51	1.91
BPIX L2	0.20	0.11	0.31	0.18	0.44	0.25	0.51	0.29	0.94	0.55
FPIX R1	0.48	0.31	0.77	0.50	1.08	0.70	1.25	0.81	2.34	1.50
FPIX R2	0.23	0.17	0.36	0.27	0.51	0.38	0.59	0.44	1.11	0.82

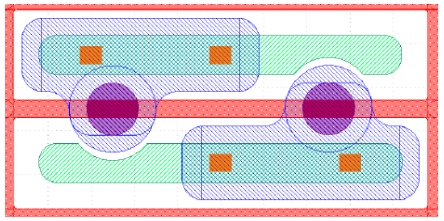
- CMS has defined a baseline that has one set of replacement sensors for BPIX L1 & FPIX Ring 1 in LS 5 (between Run 5 & 6) – consistent with TFPX option for Ring 1
- **TFPX** Requirements (FLUKA simulation)
  - Run 4+5 Ring 1: ϕ=1.25E16 n/cm^2 TID=0.81 Grad
  - Run 4+5+6 Ring 2: ϕ=1.11E16 n/cm^2 TID=0.82 Grad
- Planar silicon qualification now met in low-E proton irradiation & test beams
- 3D silicon offers advantages – lower bias voltage, more fluence margin
- Radiation qualification continues in the US (High-E proton irradiation, test beam)

Progress Summary : Sensors [402.7.3]





Bitten 25x100

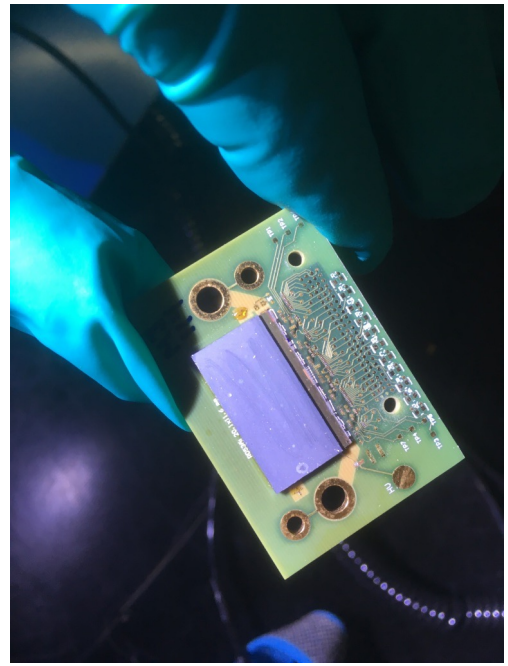


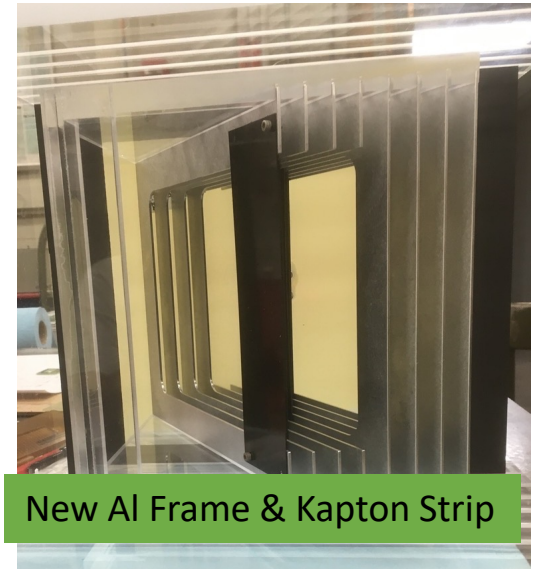
"Bitten" implant design reduces cross talk

- Planar Sensor radiation qualification
  - Hamamatsu 25x100um, n-in-p 150um active thickness with 50um handle wafer
  - Using RD53A read out chips & single-chip sensors on Rice Irradiation Cards
  - Irradiation at KIT cyclotron 23 MeV protons (higher TID per n fluence than HL-LHC)
  - DESY 5.3 GeV electron test beam
  - HPK sensor design exceeds requirement at 2E16 n_{eq}/cm^2
    - >98% efficiency @ Vbias=650 V and ~99% at 800 V
  - US program in progress to confirm results with 400 MeV proton beam at FNAL ITA
    - Especially alternate planar & 3d sensor candidates at highest fluences (2E16)

Sensor Irradiation/Test Beam

- Highest fluences (~2E16 n_{eq}/cm^2) with high-energy protons unique to US
  - FNAL Irradiation Test Area (K=400 MeV)
  - Essential for evaluation of TFPX sensors
  - Decision date mid Nov'21
- ITA Commissioning & Irradiation Runs 1-2
  - [Jan'21] Run 0: Commissioning Run
  - [Feb/Apr'21] Run 1: 8 Sensors irradiated to 1.4E16 (planar/3d)
    - Unexpected removable contamination on sensors/fixtures
    - Damage to wire bonds on many samples, under investigation
    - Radiation safety procedures addressed
  - [June'21] Run 2: 9 sensors irradiated to 1.5E16 (planar/3d)
    - Fixtures modified, sensor Parylene-N coating to reduce contamination
    - Delivered fluence below target and CMS goal of 2E16
- Test Beam
  - Pre-irradiation qualification of sensors
  - 4 runs: Dec'20-Jan'21; Feb'21 ; Apr-May'21; Jun'21
- After COVID delays and lengthened commissioning period, facilities in the US are now contributing to CMS effort
  - US groups also contributing to international program in Europe
- Run 2 samples to be evaluated
  - Will request Run 3 in Fall'21 prior to sensor down select decision



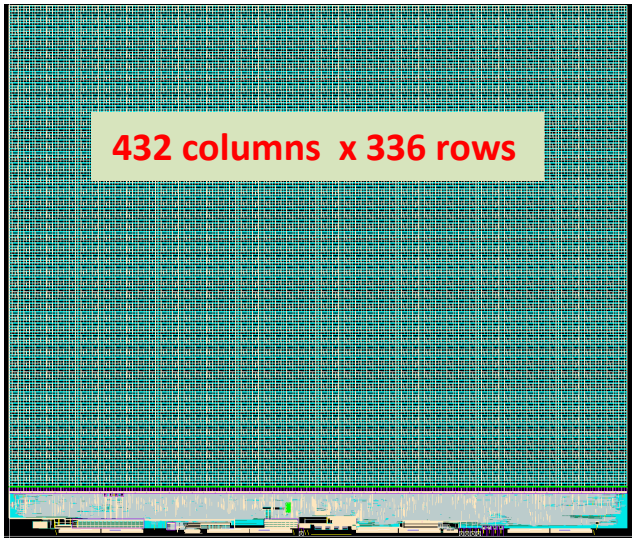


New Al Frame & Kapton Strip

Progress Summary: Read Out Chip [402.7.3]

- RD53 collaboration design
  - Joint effort for ATLAS and CMS ASICs
  - RD53A successful half-size prototype
  - RD53B design jointly developed for ATLAS ITkPix & CMS C-ROC – only small feature differences & size, same framework
- C-ROC Design Review & Verification
  - Bugs in ATLAS ITkPixv1 addressed in C-ROC design
    - 4-bit latch design bug & high-power draw resolved, verified in ATLAS ITkPixv1.1 respin (metal only)
  - Jan'21 CMS & RD53 design review recommended completing verification simulation of critical changes
    - All bugs & design changes since ATLAS ITkPixv1
    - But do not wait for verification of new CMS-only features. All can be disabled by register; basic chip functions will work.
    - Verifications will be developed also for new CMS features
    - One Known bug in CMS added CRC in data stream, only at high data rates
  - Verification work proceeded Jan ~ May 2021
    - Timing closure problems in extreme corners addressed
    - Verifications completed successfully at end of May
    - New personnel added and kept for ongoing verification efforts
- CMS C-ROC Prototype submission status
  - Submitted to IMEC June 2
  - IMEC design checks OK; sent to TSMC June 17
  - Now in manufacturing (CERN received setup wafers in Aug)
  - (Milestone C-ROC Submission, late 4 months)

C-ROC: CMS Read Out Chip
(Pronunciation guide: Sea-Rock)



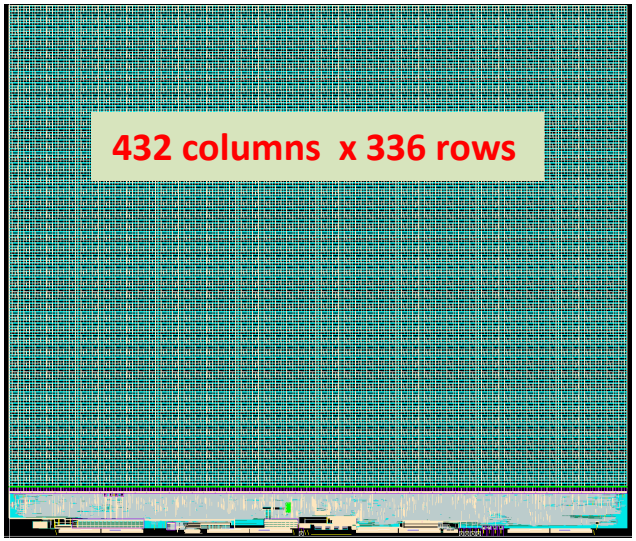
RD53B-CMS (CROC_V1)
Size: 21.65 mm x 18.62 mm

Plans : Read Out Chip

- Oct'21 Expect a functional chip for prototyping
  - Wafer delivery by end of August, initial testing, wafer testing
  - Full-size chip important for flip-chip assembly, modules, system testing
  - Preparations for chip testing continue as planned
  - At Kansas State in US, joint work with Torino
  - 300mm probe station now installed at K-state
  - Support electronics in procurement now – probe cards
  - Readout electronics, firmware also in preparation
- Mitigation of prototype ROC delays – speed verification
  - Run single chip card testing and wafer testing in parallel
  - Irradiation & SEU testing preparations underway (US roles)
  - Build Sensor-less modules immediately (including TFPX designs in US)
  - Send 1st tested wafers for flip chipping to full-size sensors
- Production chip submission planned for June'22
  - Run pre-booked at TSMC, arrangements with CERN & IMEC
  - Close contact with RD53 design and testing team to monitor progress, coordination with ATLAS submission
  - RD53 added experienced engineering for verification support
  - C-ROC chip verification efforts needed for production design revisions by ~March
    - Well-planned in advance of wafer arrival end of Aug

C-ROC: CMS Read Out Chip

(Pronunciation guide: Sea-Rock)



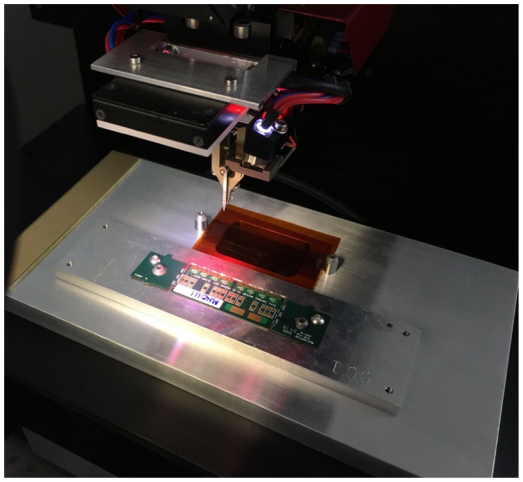
RD53B-CMS (CROC_V1)

Size: 21.65 mm x 18.62 mm

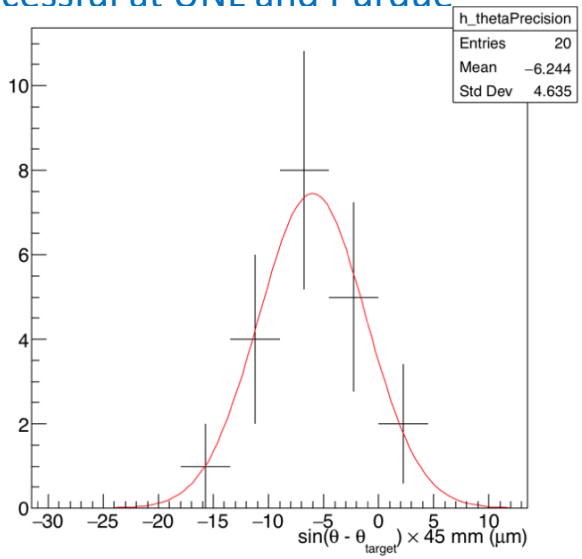
Progress Summary : Modules [402.7.4]

4a

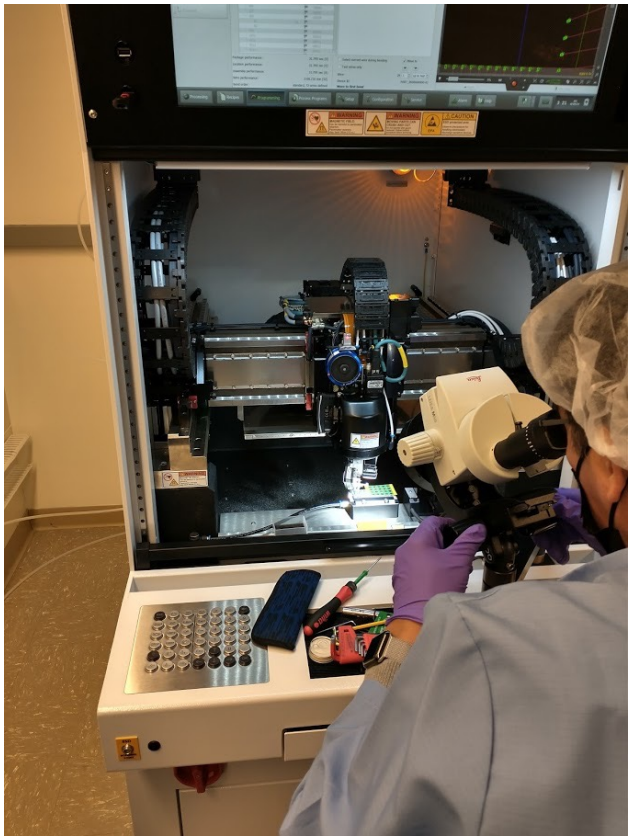
- Wire bonders
  - Hesse BJ855 bonder installed and commissioned at Purdue
  - Same ordered at CUA arriving in August
  - Delvotek (new for phase 1) in use at UNL
- Aerotech Gantry programming with common code base (UNL, PD, CUA)
  - Initial Pick and place precision testing at UNL & Purdue (<10um)
  - Pattern recognition : fiducials and wire bond pads
- Assembly Tests with Mock Modules
  - Mechanical/thermal modules with patterned glass sensors to be used as heaters for mech/thermal testing
  - Glue stencil and deposition studies
  - Assembly and wire bonding successful at UNL and Purdue



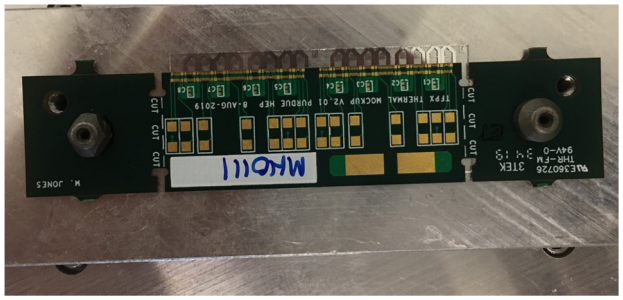
UNL Wire bonder



Placement error from rotation (Purdue)

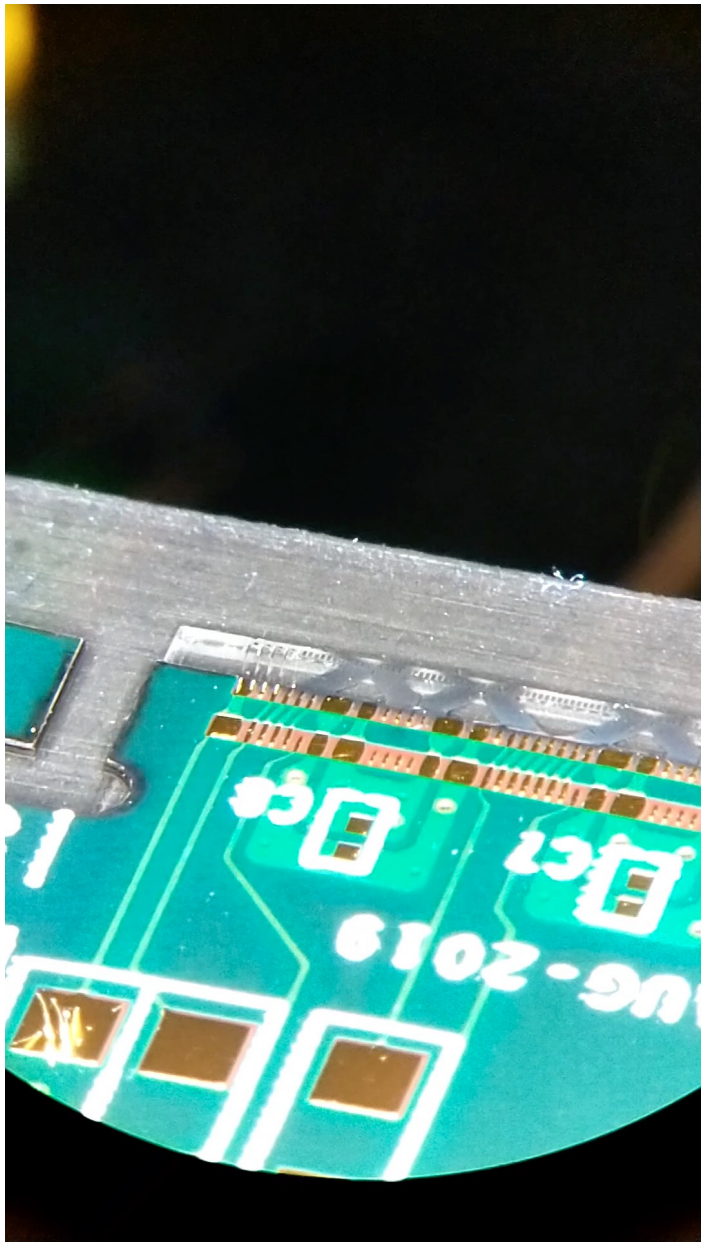


Purdue Wire bonder



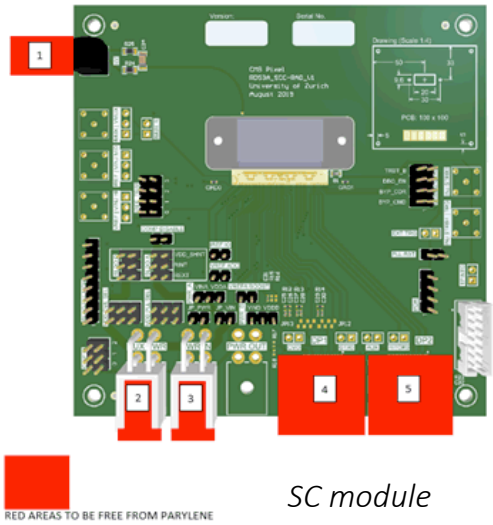
Mock-up thermal module (UNL)

Wire Bonder Movie

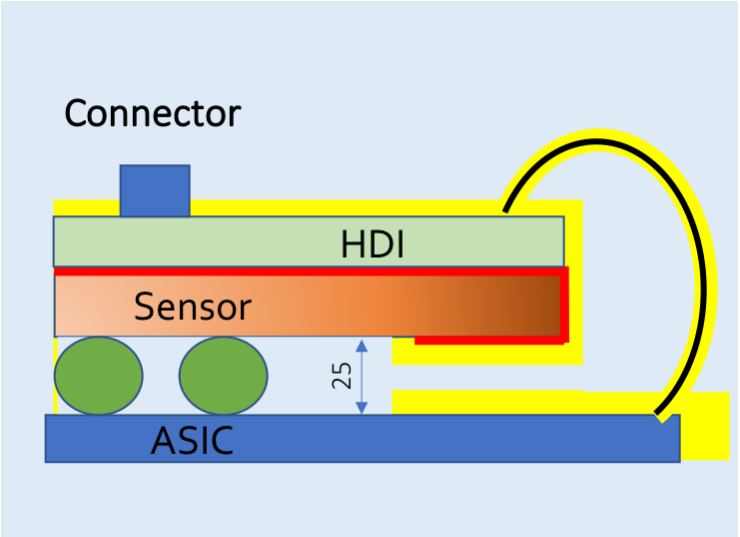


Module Spark Protection Parylene-N

4a

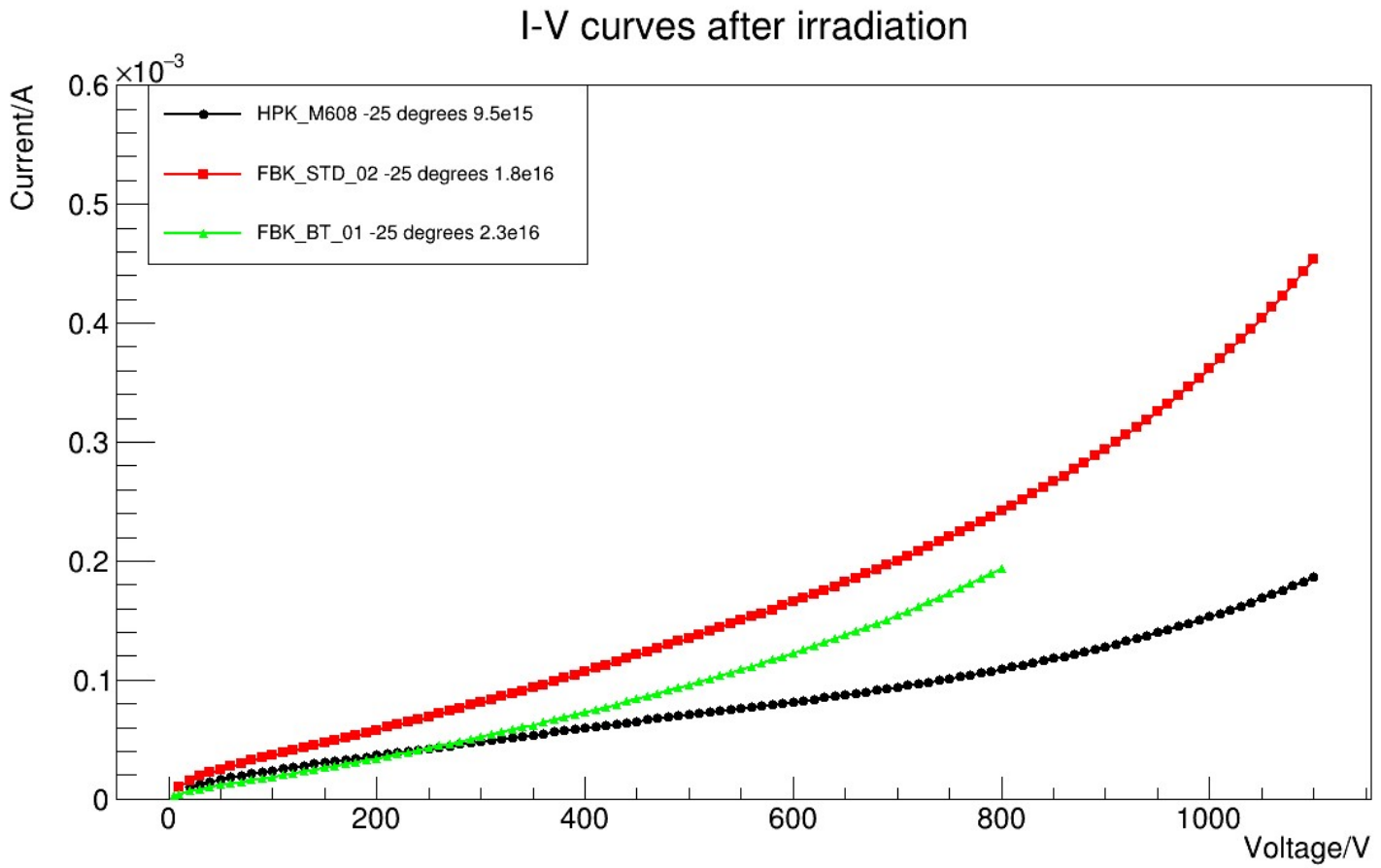


SC module



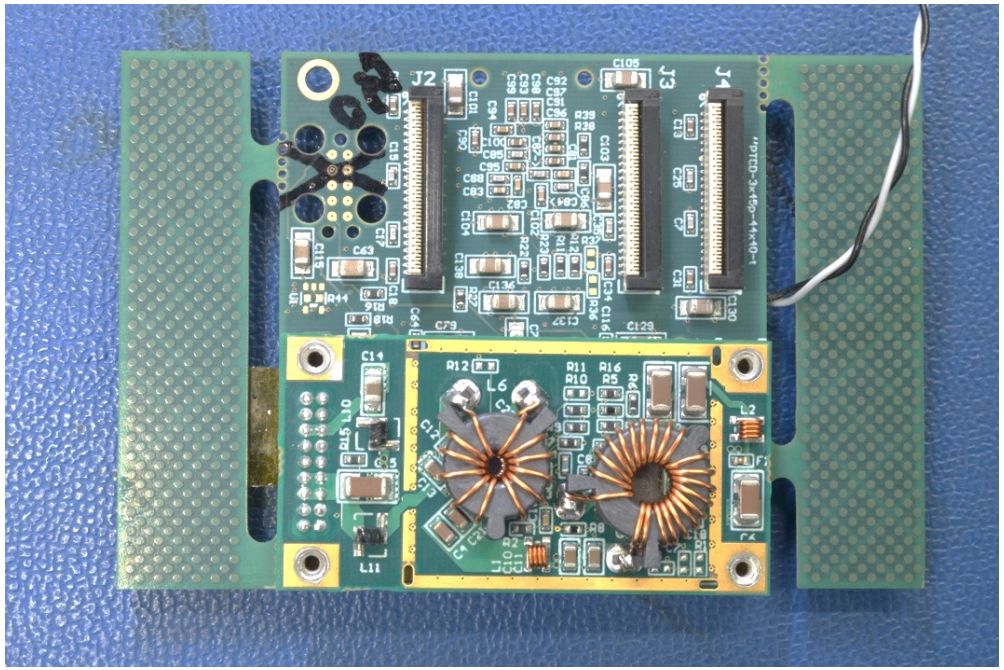
- Evaluation of Parylene-N for Bias Voltage Spark Protection
  - CVD application to assemblies 18 um thickness
  - Mitigates sparking at cut edge of sensor to Read Out ASIC
  - Single chip modules coated, irradiated, measured by Swiss TEPX collaborators
  - Fluences up to 2.3E16 n/cm^2
  - HV up to 1.1 kV with no problems
  - Multi-chip modules also coated – ongoing work with SCS Coatings in UK
  - US has coated 8 modules at Purdue & irradiated in Run 2 to 1.4E16 n/cm^2
  - US will work with same vendor in US (SCS Coatings) to qualify TFPX modules
- Identification of radiation hard encapsulants for wire bond protection
  - US irradiation campaign at Sandia has identified candidates

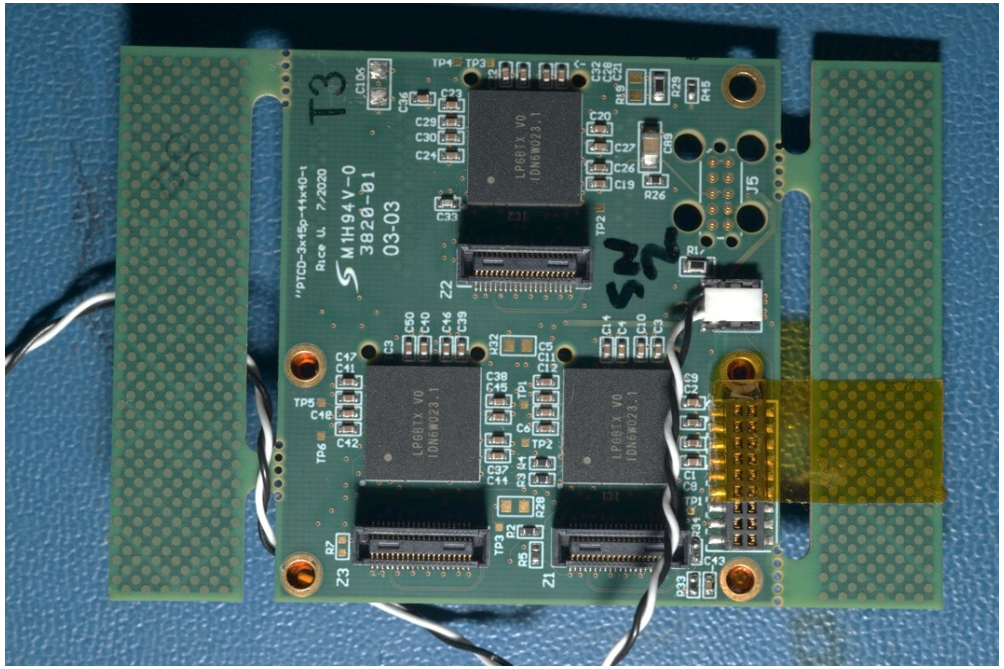
Parylene-N Test Results



- 3 single chip sensors 25x100, 450 um edge (expected final geometry)
- Parylene-N coated at SCS coatings, irradiated 1~2E16 n/cm^2 at KIT
- No breakdown up to 1.1 kV in climate-controlled chamber
  - N.B. one sample was limited to 800 V until after test beam

Progress Summary : Electronics [402.7.5]

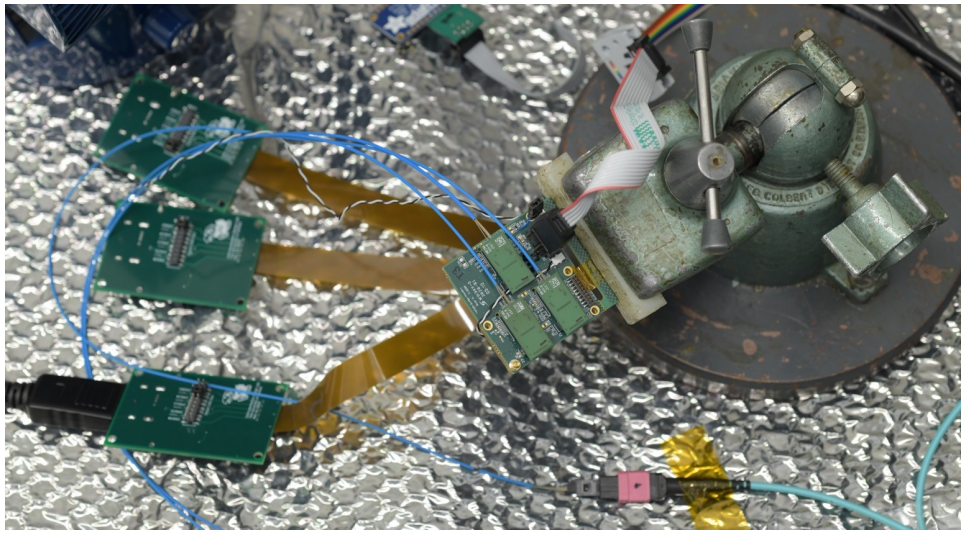


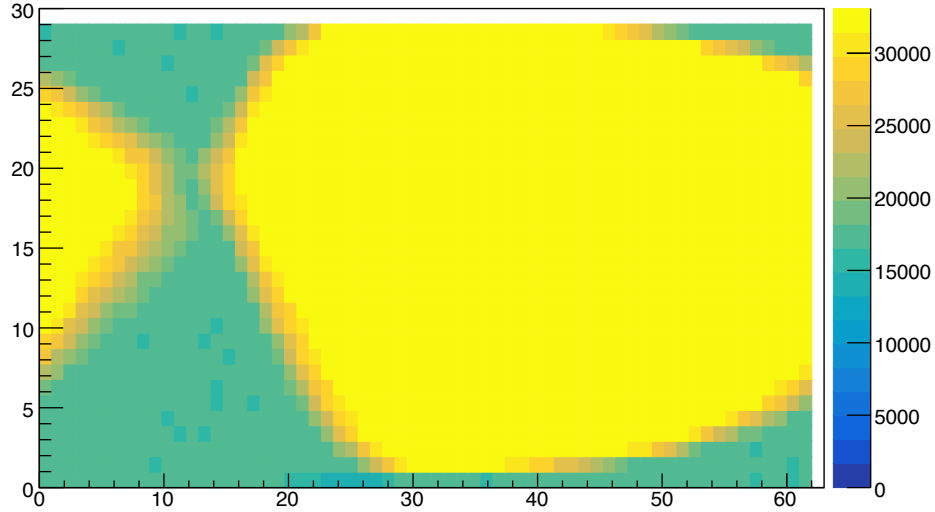


- Port card prototypes
  - Uses lpGBT, bPOL2V5, bPOL12V ASICs and VTRx+ transceivers from CERN
    - Post FDR strategy for mitigating risks → Early prototyping with major external deliverables from CERN
  - Demonstrator with one lpGBT
  - TFPX Prototype with 3 lpGBT for full function & mechanical integration design
    - Assembled with available v0 prototype ASICs; compatible with v1 final version, available Sep'21
  - Status:
    - Optical readout of RD53A modules (single chip & 2x2) working
    - DC-DC mezzanine used for powering
    - Testing with lpGBTv0 – all functions verified, detailed characterization in progress

Port Card Test Results [402.7.5.1]

4a

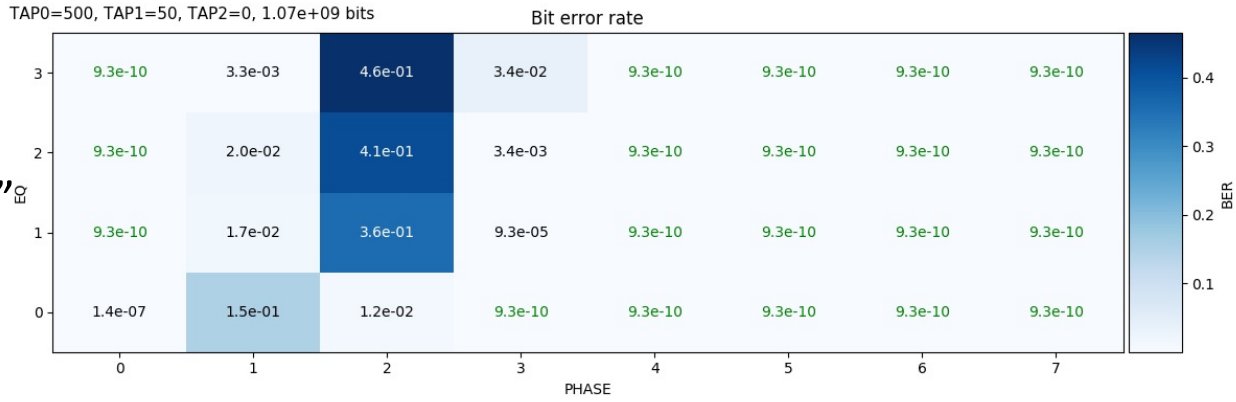




lpGBT Optical Eye Opening Monitor

Rice Test Bench:

- RD53A single chip card
- E-link cables DP/flex
- Port card(lpGBT, VTRx+)
- Optical readout via FC7 as “uDTC”

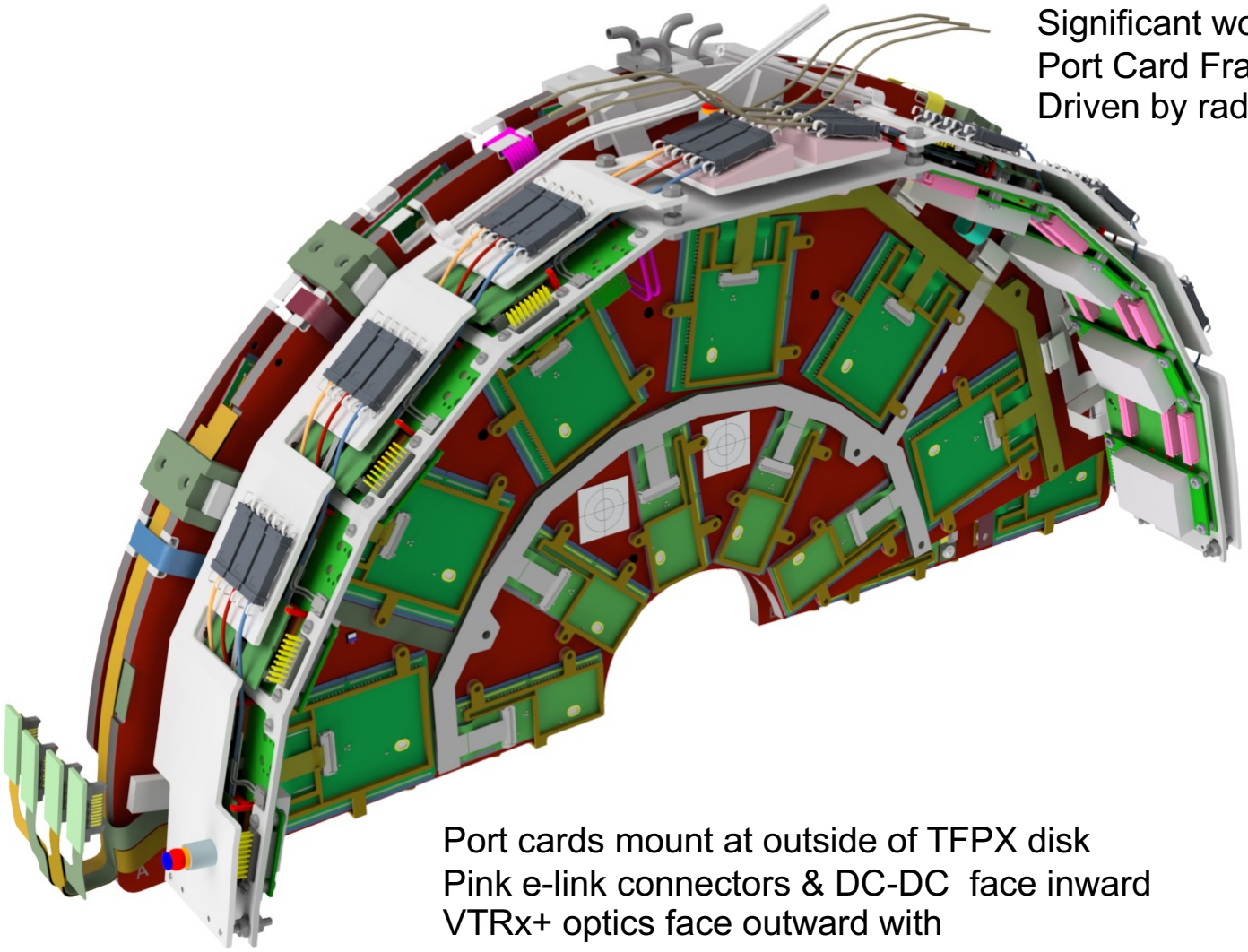


Used to check prototype cards
4/4 working 11/12 lpGBT @ 100%
All functions working

- 18 Data & 15 command links
- Slow control ADC & i2C master
- Full characterization ongoing

Bit Error Rate Test for Electrical Links / lpGBT e-ports
PRBS7 generator on RD53A and checker in lpGBT
Scan vs clock phase shows expected region w/ 0 errors

TFPX Port Card Mechanics



Significant work on Port Card – Dee mounting
Port Card Frame at outer radius of disk
Driven by radiation tolerance of VTRx+

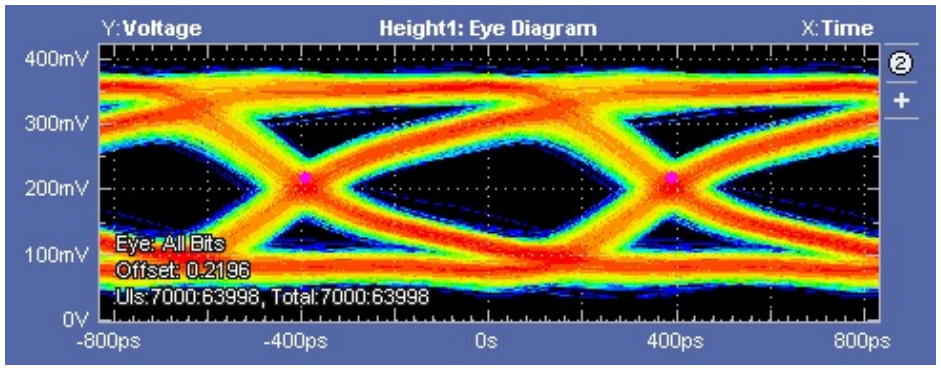
VTRx+ was a concern at FDR
- TID and fluence limits
- Replacement planning
- Activation of mechanics?

Note:
Baseline includes one
Replacement of VTRx+

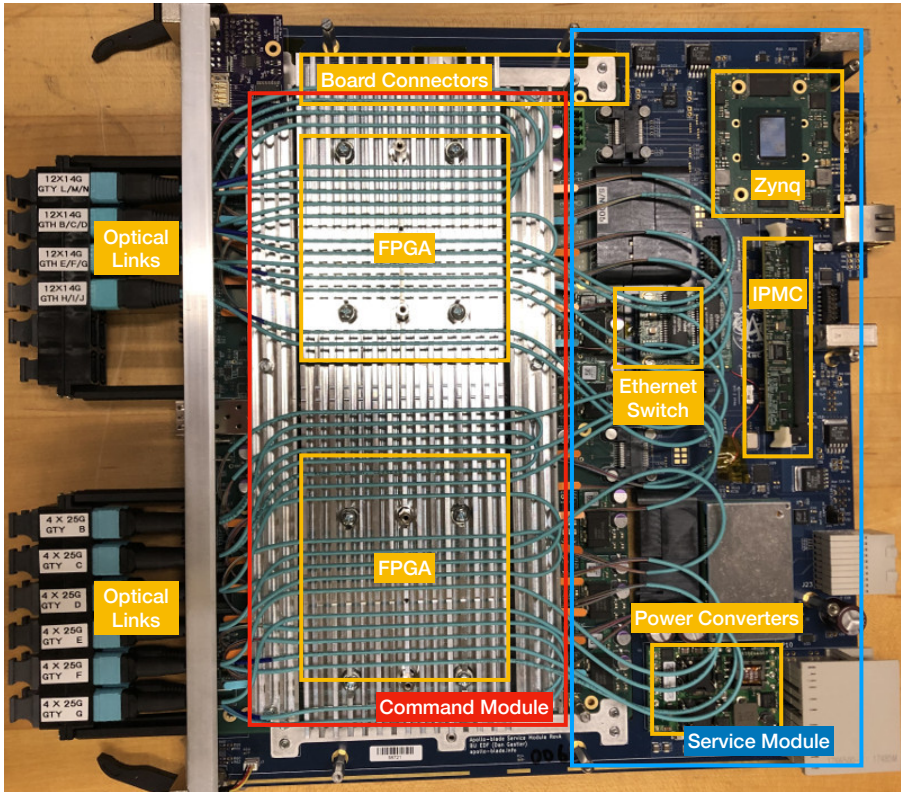
Port cards mount at outside of TFPX disk
Pink e-link connectors & DC-DC face inward
VTRx+ optics face outward with
Fiber optic pigtails and power routed on “mezzanine” just inside service cylinder
New design reduced length of fiber pigtails to minimize radiation induced attenuation
VTRx+ optical transceiver and pigtails replaced in LS5 due to fluence limit 2E15 n/cm^2
Design remains serviceable for replacement during LS5 or Year End Tech. Stop

Progress Summary: Electronics [402.7.5]

- E-link cable prototypes & testing
  - Module to port card twisted pairs, electrical & ^{60}Co ɣ irradiation testing

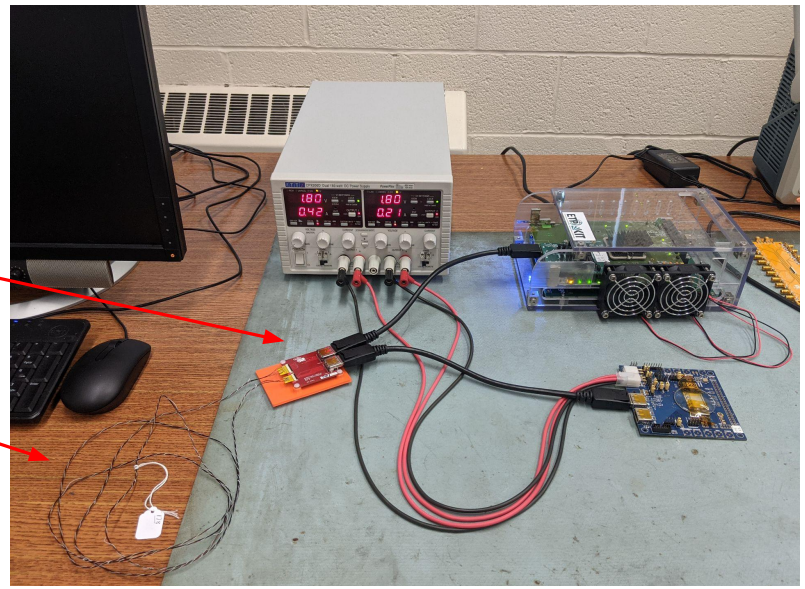


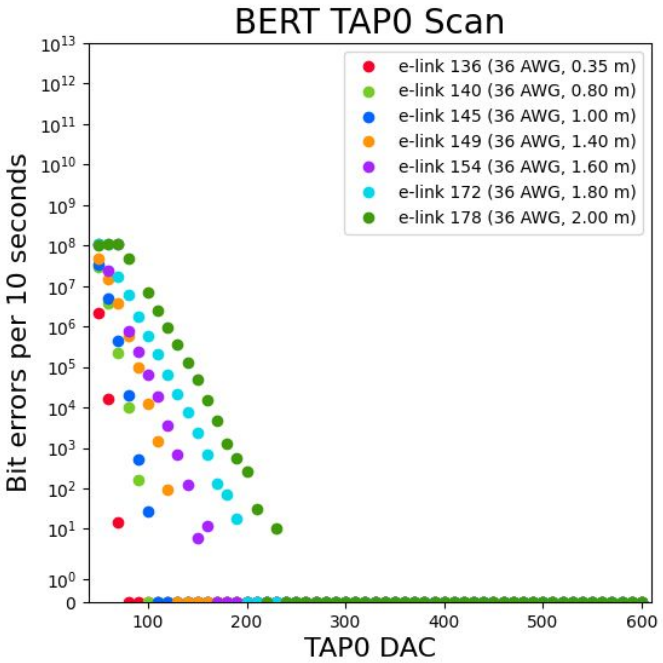
36 AWG twisted pair 35 cm at 1200 MRad



- Data-Trigger-Control (DTC) back-end electronics
  - ATCA Apollo Command and Service Modules
  - Prototype designs tested, revised prototypes now in fabrication
  - 10G optical receivers; 25G optical data links; US+ Xilinx FPGA

E-link test results [402.7.5]

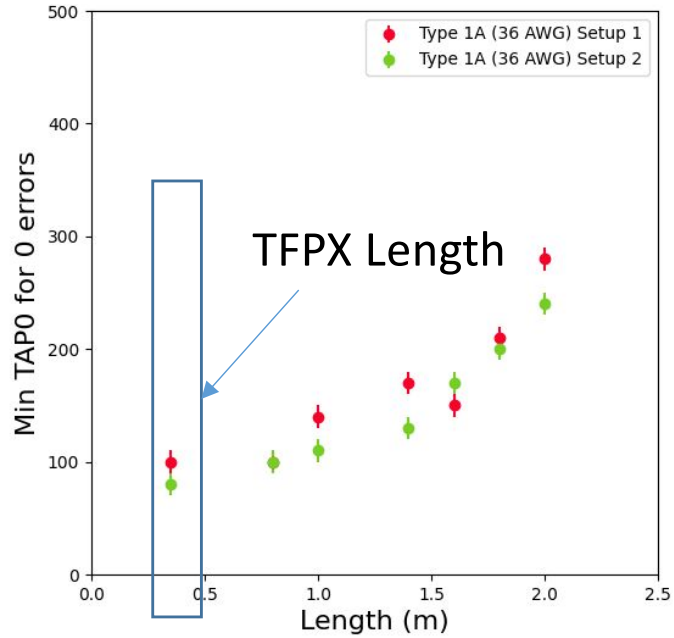




Kansas Univ. E-Link Test Stand

- RD53A SCC DP cables
- DP Adapter for DUT e-links
- FC7 FPGA carrier (uTCA) with electrical FMC adapter
- Firmware/software for BERT using RD53A PRBS7 generator

E-link candidates (AWG36,34) tested showing acceptable performance
→ BER vs e-link length and RD53A CML driver strength (TAP0)
Cross talk tests in progress also show acceptable performance
Testing continues for full characterization of e-links
System testing in fall with port card (lpGBT as receiver) and C-ROC



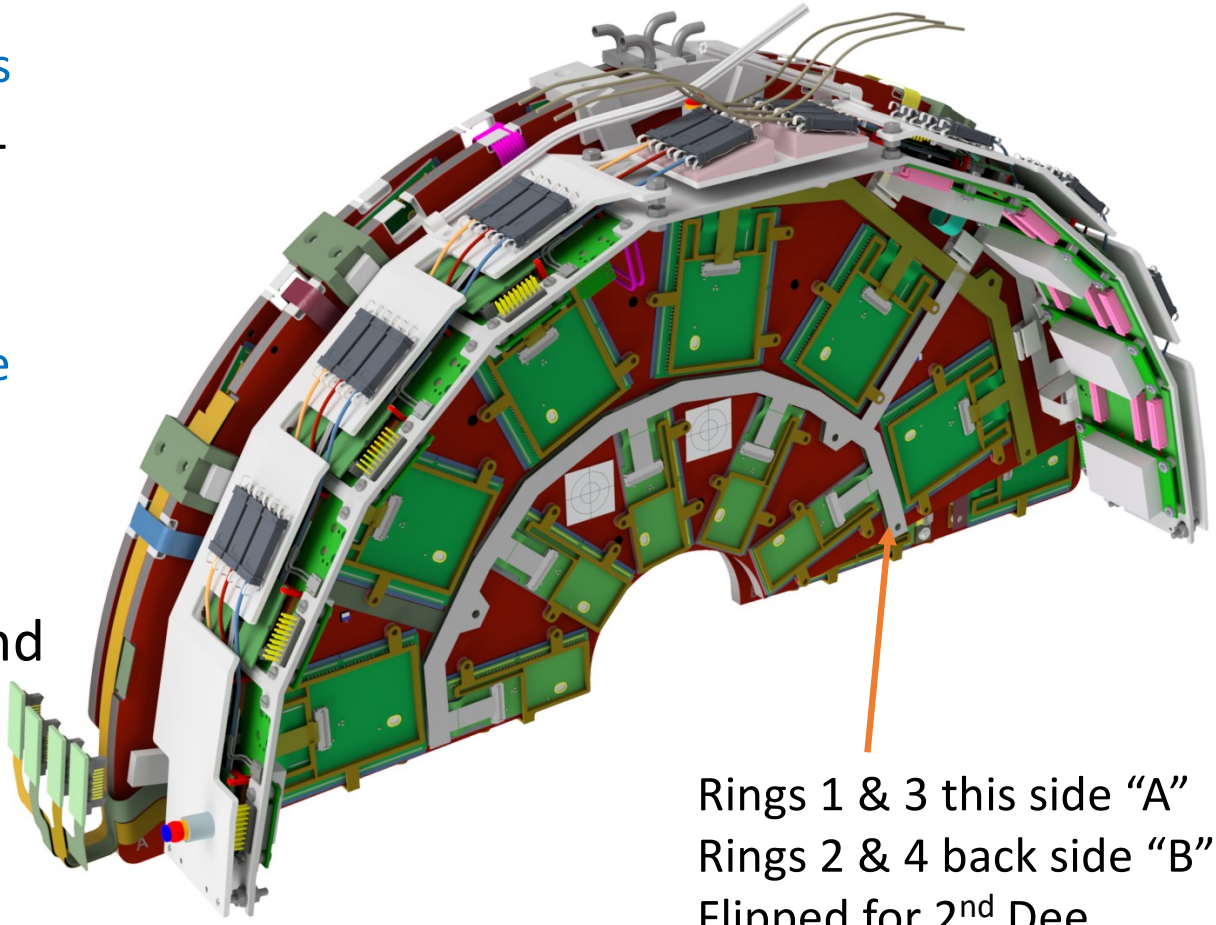
Progress Summary: Mechanics [402.7.6]

4a

Dee and cartridge design evolution has advanced well

- 2 Dees + port card frame = cartridge
  - Inserted into/removable from cylinder as a unit
  - Power, fibers, cooling connections at a few points
- Single design for all double-sided dees
  - Adjusted to meet tracking fiducials
  - Eliminates gaps in coverage
  - Simplified assembly
- Integrated port card frame
  - new optical fiber routing
- Streets defined for e-link and power cable routing
- Entry/exit for services to cylinder

Focus has moved to prototyping in 2021

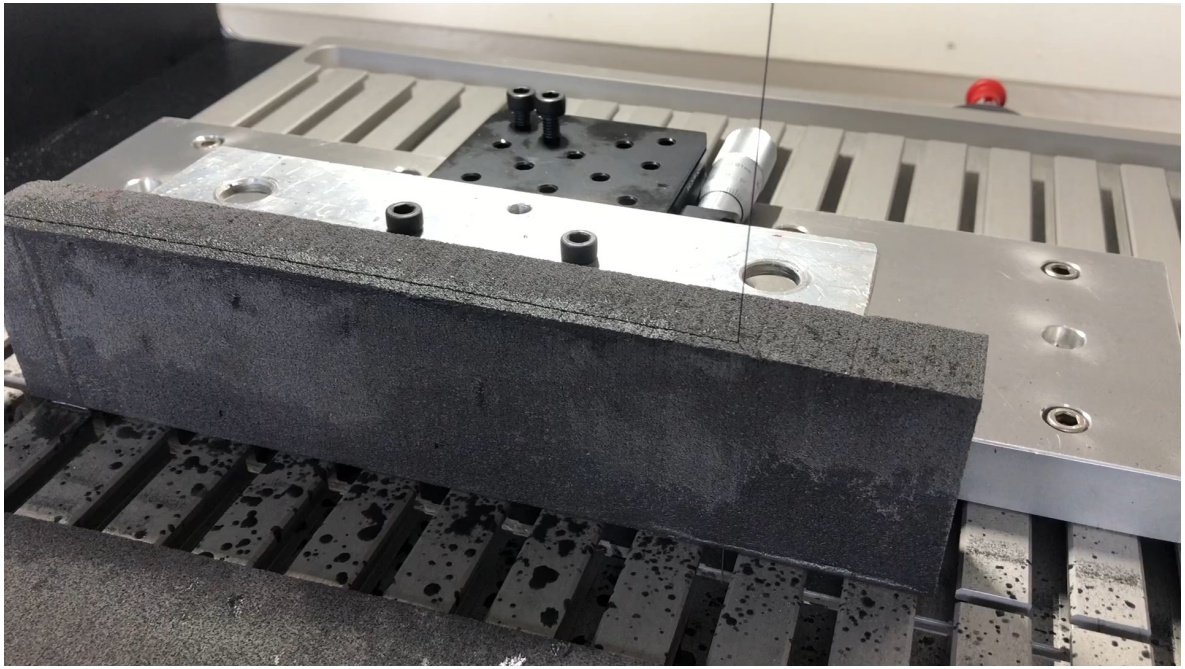


Rings 1 & 3 this side “A”
Rings 2 & 4 back side “B”
Flipped for 2nd Dee

Progress Summary: Mechanics [402.7.6]

4a

- Diamond Wire Saw in place at Cornell for cutting Carbon Foam
- First batches of Carbon Foam received from Allcomp (Lockheed-Martin)



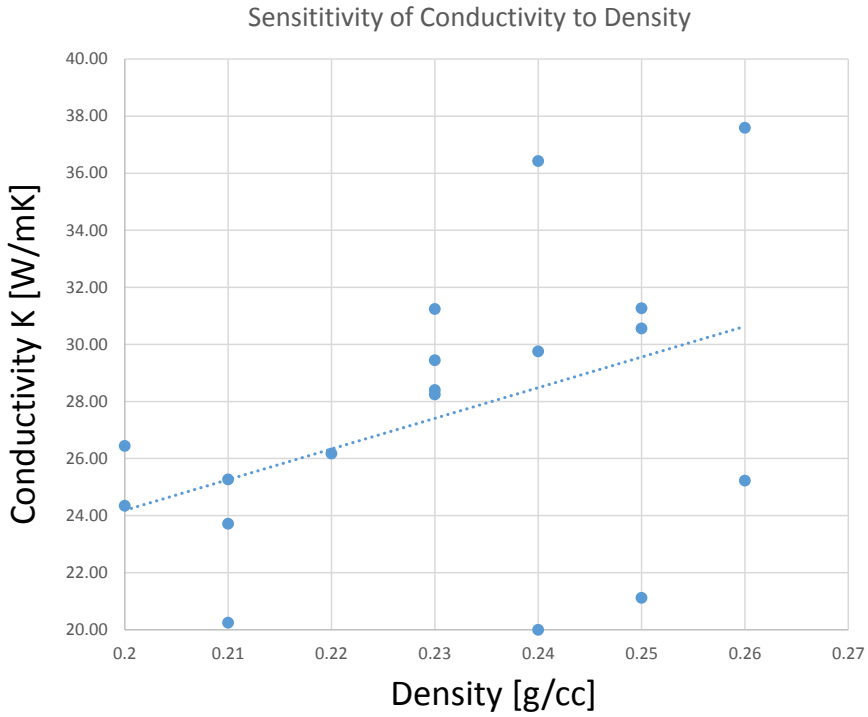
Slicing TFPX Dee Foam

Rough cuts and template for TPFX dee Carbon Foam Material

Corner removed for conductivity measurement

Allcomp Carbon Foam QC

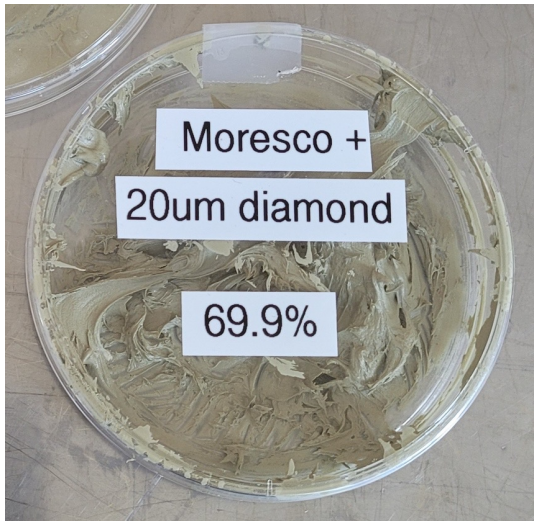
Date	Type	Lot No.	S/N	Density [g/cc]	K [Watt/mK]
2/11/2020	Allcomp K9	6	14	0.25	31.27
4/29/2021	Allcomp K9	13	1	0.23	28.40
4/29/2021	Allcomp K9	13	2	0.24	36.43
4/29/2021	Allcomp K9	13	20	0.21	23.72
4/29/2021	Allcomp K9	14	9	0.25	21.12
10/21/2020	Allcomp K9	12	16	0.24	20.00
10/21/2020	Allcomp K9	13	6	0.23	28.25
10/21/2020	Allcomp K9	13	7	0.23	31.24
10/21/2020	Allcomp K9	14	6	0.25	30.56
10/21/2020	Allcomp K9	14	15	0.22	26.18
6/2/2021	Allcomp K9	13	21	0.24	29.76
6/2/2021	Allcomp K9	15	5	0.26	37.59
6/2/2021	Allcomp K9	15	7	0.26	25.23
6/2/2021	Allcomp K9	15	9	0.2	24.35
6/8/2021	Allcomp K9	15	12	0.2	26.44
6/8/2021	Allcomp K9	15	13	0.21	20.25
6/8/2021	Allcomp K9	15	18	0.23	29.45
6/8/2021	Allcomp K9	15	19	0.21	25.27
	Average			**0.23**	**27.53**
	Mininum			**0.20**	**20.00**
	Maximum			**0.26**	**37.59**



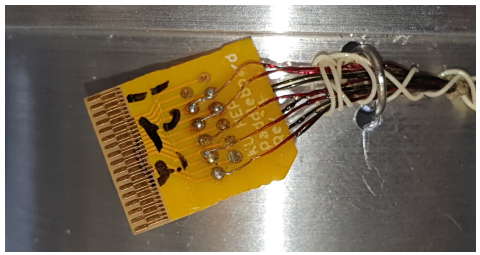
- Density and thermal conductivity measurements
  - Marked variation observed → may sort batches for use in critical places
  - Density – k : Correlation as expected

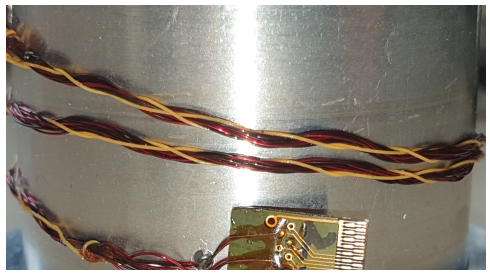
Progress Summary: Mechanics [402.7.6]

- Successful ^{60}Co Radiation tests of material samples
  - Thermal Interface Material tested for conductivity before/after irradiation
    - K = 1.2 W/m·K
    - Tested to 1.2 GRad
    - Still spreadable grease after irradiation
  - Module parts, adhesives, encapsulants, HDI electronics, e-links
- Big step towards MS: selection of materials



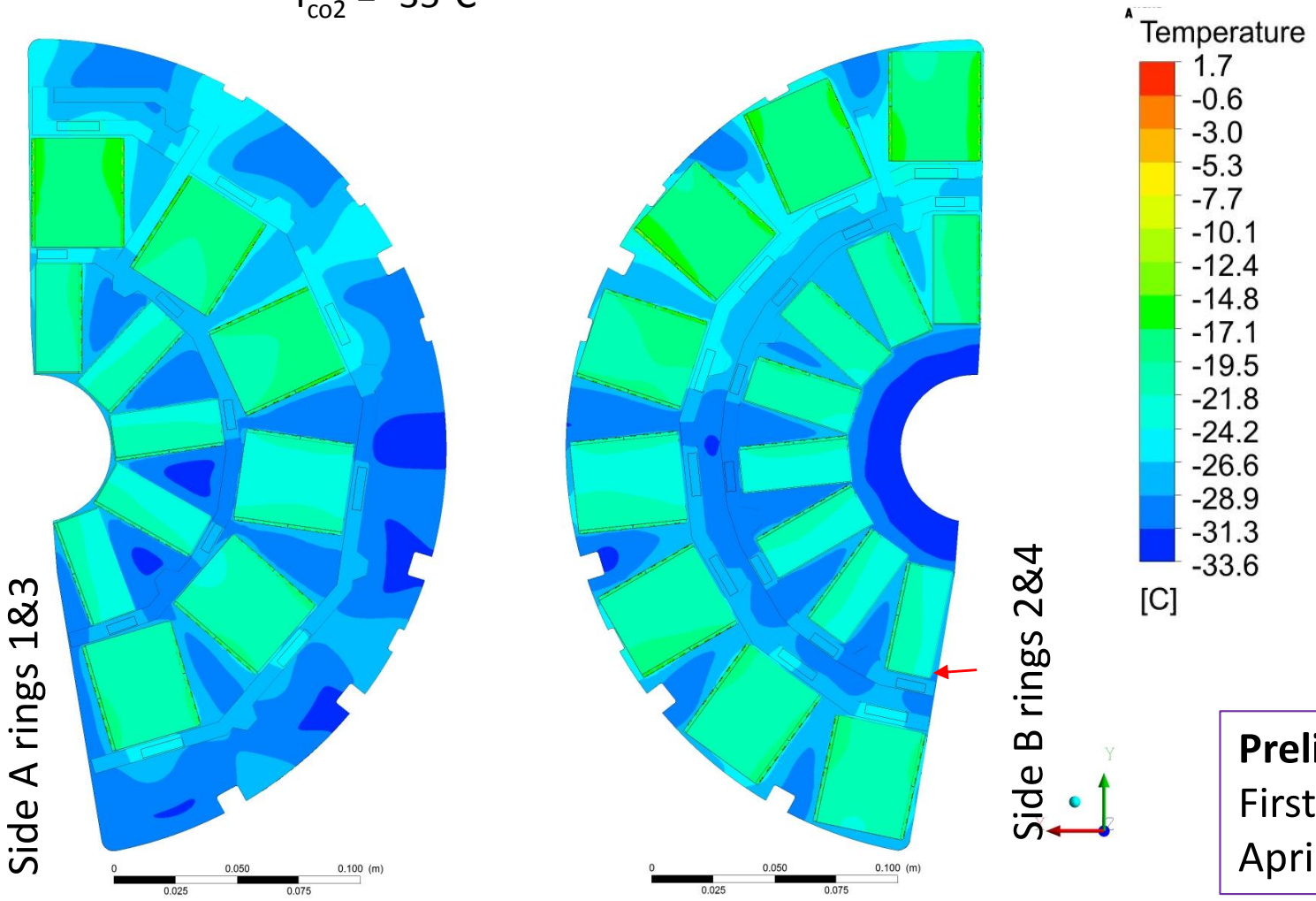
Moreseco
Rad-hard
Vacuum grease
Doped with diamond





Mechanics Thermal Simulation [402.7.6]

T_{co2} = -35°C



Detailed model
Includes thermal run away for Si

Preliminary:
First pass detailed study
April 2021

ANSYS FEA of TFPX Dees for study of thermal run away in collaboration with INFN Perugia
Expected heat load from C-ROC, power cabling, sensor leakage current at 2E16 & 800 V bias
→ Being updated for measured material parameters, TFPX design choices & optimization

Thermal Runaway Margin [402.7.6]

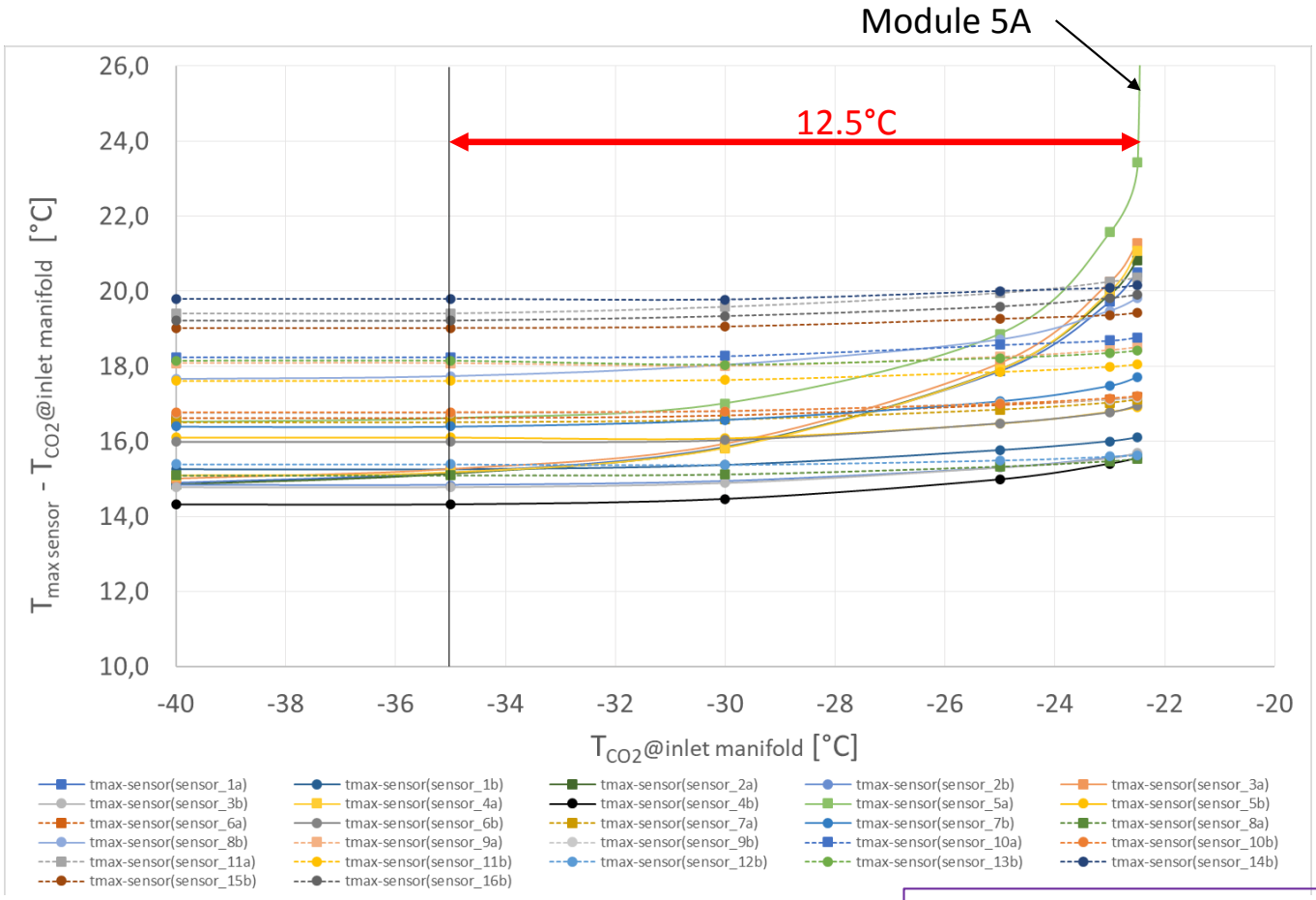
CMS Phase 2
INFN Perugia – UNIPG Department of Engineering

Thermal Runaway plot

Side A+Side B

Solid line – Double modules
Dash lines – Quad modules

Rectangular indicators – Side A
Circle indicators – Side B

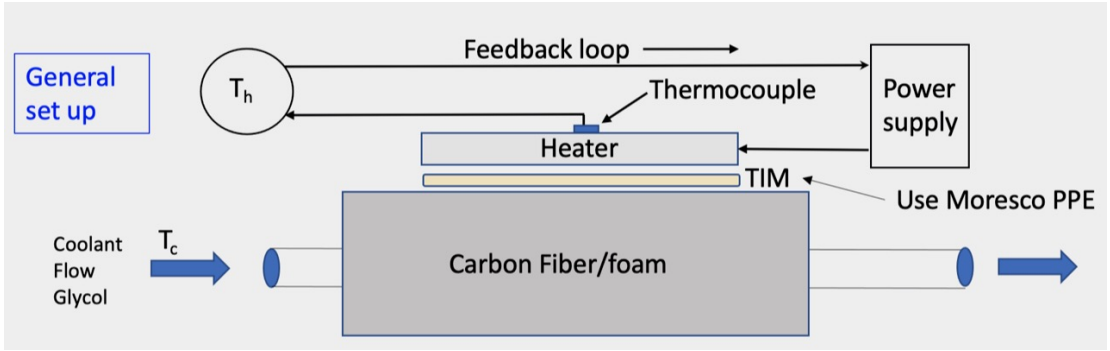


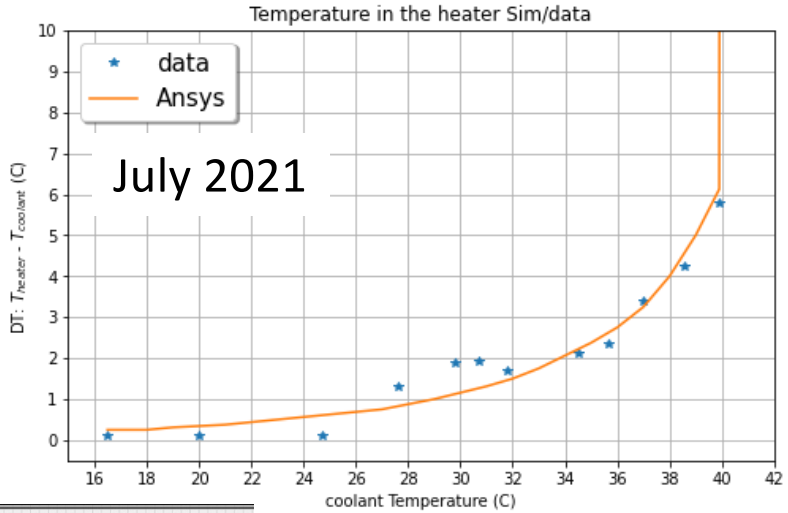
- TFPX has good thermal margin of > 10 °C
  - Module 5A on ring 1 corner is weakest ;
  - optimization possible

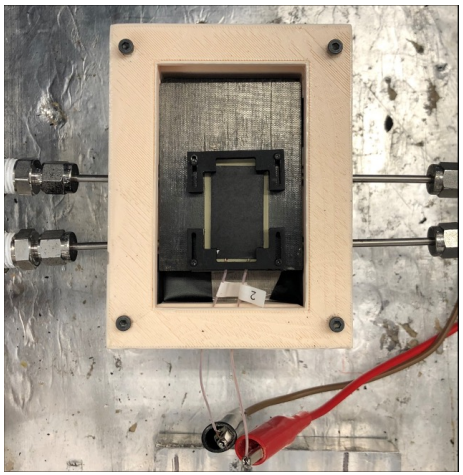
Preliminary:
First pass detailed study
April 2021

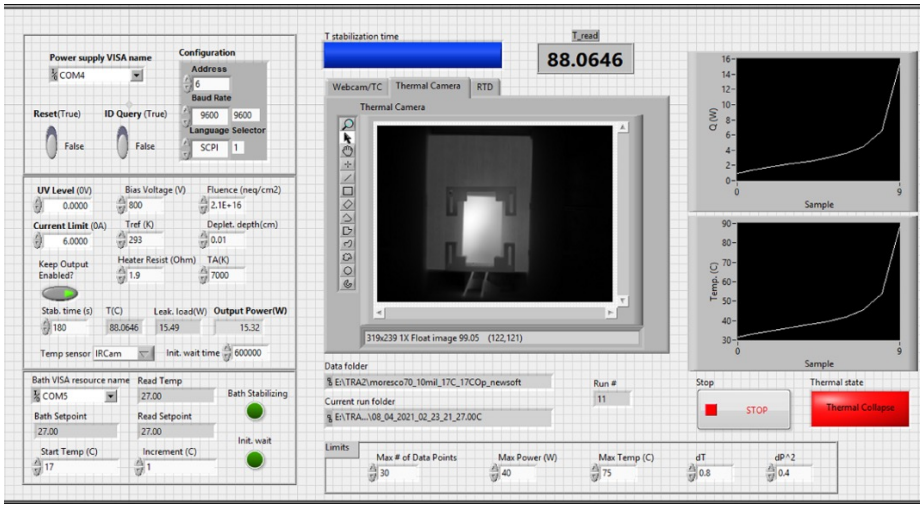
Mechanics Thermal Studies [402.7.6]

- Thermal run away emulator for single module “unit”
- Tests of design & verification of thermal modeling
  - Simulation of single module unit agrees after detailed comparison *









ANSYS FEA validated

Next steps

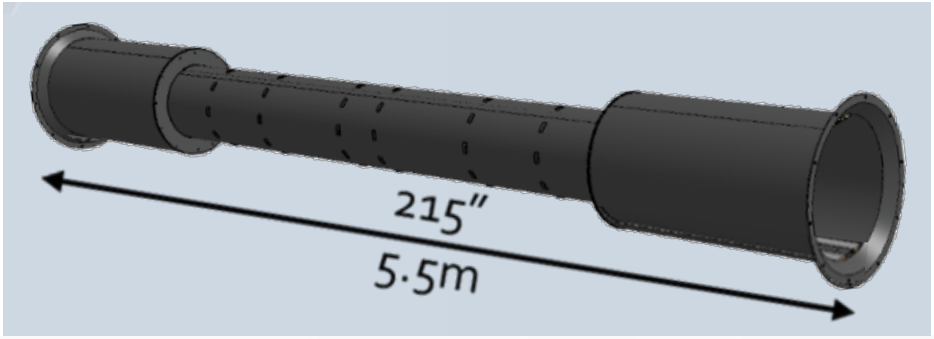
Update to match:

- latest TFPX design
- measured k’s for TIM, fiber/foam, …
- Sensor leakage currents, & V_{bias}

Progress Summary: Mechanics [402.7.6]

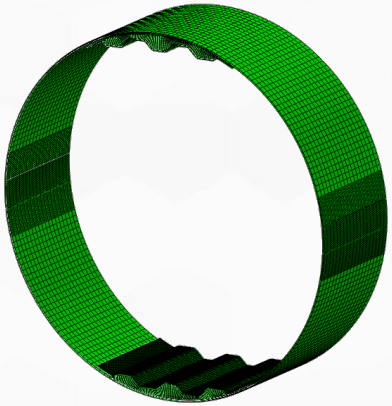
- Inner Tracker Support Tube Design & Prototyping
  - Carbon Fiber design, FEA studies, mold machining
  - Short section tests for shape compensation
  - Machining fixtures
  - Fabrication of Prototype started, 1m center section

c.f. Detailed Talk at Tracking Dectector Mechanics 2021

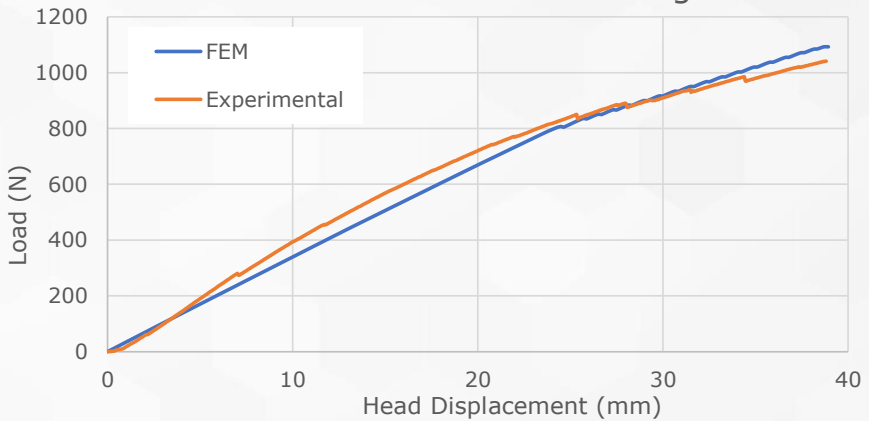


Test

Model



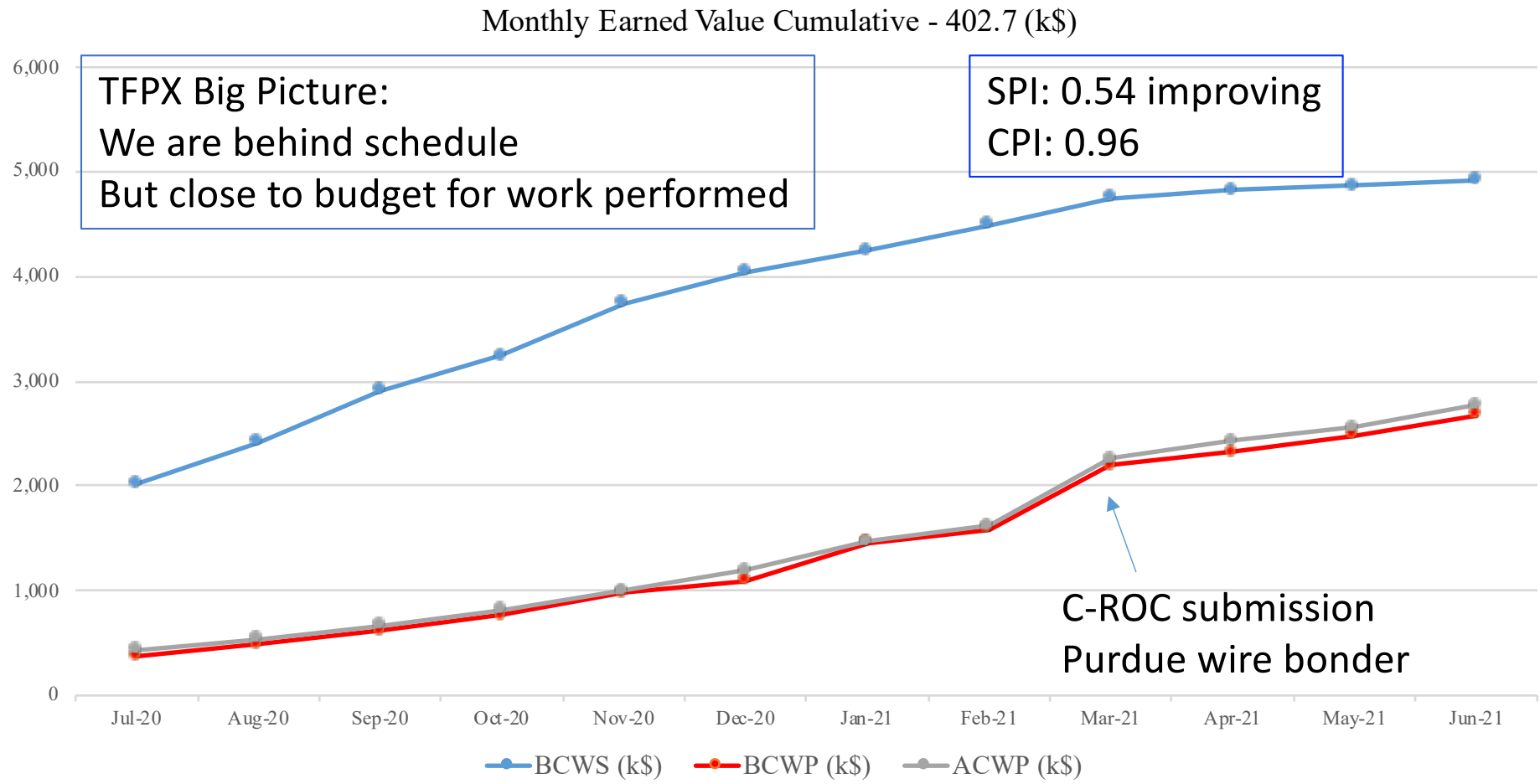
Validation: ITST - Including Tracks



TFPX Technical Review

- Recommendation at FDR
  - Concerns about remaining development, component choices / external deliverables (ASICs, sensors, optics)
- What is needed for this review
  - Sensor radiation qualification (irradiation, test beams)
    - Planar sensors are well in hand
    - Run 3 for 3D sensors in the US & with low-E protons in Europe
    - CMS sensor down select planned for mid Nov'21
  - ASIC and optical transceiver qualifications
    - C-ROC, lpGBT, bPOL12V, bPOL2V5 [all available by Oct'21]
    - VTRx+ [first production units available by end of 2021]
  - Prototype evaluations:
    - e-links, port card, modules (RD53A & C-ROC) → system testing
    - mechanical Dee/Cartridge, ITST
  - Mechanical evaluations: thermal & mechanical performance, assembly process
- Present schedule & planning (in RLS) indicate these items and evaluations should be available for a Summer 2022 review
  - Further delays from COVID could affect some items, but evaluations are well underway informing remaining work
  - Consistent with the planned CMS EDR later in Jan 2023
  - Expecting CMS inputs to CERN HL-LHC schedule evaluation for CERN LHCC P2UG meeting in late 2021; CMS replan for a change should follow in 1-2 mos.

EVM Summary



	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
BCWS (k$)	2,020	2,416	2,910	3,241	3,745	4,041	4,243	4,493	4,746	4,820	4,871	4,919
BCWP (k$)	374	488	612	766	981	1,093	1,456	1,588	2,194	2,330	2,490	2,673
ACWP (k$)	431	542	664	815	1,004	1,188	1,473	1,623	2,259	2,428	2,555	2,776

EVM Summary

- CAMs do status, do analysis & make reports monthly
  - We are following best practices & have established an EVM culture
  - Still on the learning curve
- Status analysis
  - Slow start during COVID
  - Large procurements are late but now launched
    - Wire bonders at factories, equipment for testing, assembly
    - Probe stations & testing equipment
  - Other early “production” equipment procurements have been slow for modules especially
  - Delayed order/delivery of carbon fiber that has limited shelf life (This was poorly modeled in RLS)
  - Delayed C-ROC submission affects modules, & delayed ASICs affect electronics downstream design
  - SPI improving as orders are filled and work is completed

EVM by institute

Institute	Budget	Earned	Actual	CPI	SPI
BU	306,566.07	151,229.56	112,869.43	1.34	0.49
CN	1,219,382.60	993,089.31	1,000,433.57	0.99	0.81
CO	213,109.88	76,016.11	60,738.25	1.25	0.36
CUA	389,847.75	21,392.94	41,483.28	0.52	0.05
KA	128,281.33	95,837.56	131,846.48	0.73	0.75
KS	361,656.61	257,219.99	198,026.14	1.30	0.71
NA	218,214.22	54,620.56	102,519.60	0.53	0.25
OS	32,904.65	17,796.90	31,972.40	0.56	0.54
PC	0.00	0.00	0.00	-	-
PD	1,488,308.14	702,659.32	819,207.99	0.86	0.47
PR	25,357.68	23,668.54	8,167.92	2.90	0.93
RI	239,406.95	156,256.83	187,605.37	0.83	0.65
UCD	64,880.77	27,205.70	16,806.41	1.62	0.42
UCR	0.00	0.00	0.00	-	-
UIC	102,798.62	2,397.78	23,106.44	0.10	0.02
UTK	102,027.15	69,979.95	41,062.63	1.70	0.69
VB	25,990.29	23,353.41	313.27	74.55	0.90
Total	**4,918,732.71**	**2,672,724.45**	**2,776,159.18**	**0.96**	**0.54**

N.B. No travel activities during COVID (esp. management institutions KS, PD, CN, RI, VB)
Outlier:
Module testing at UIC – slow start, delays in receiving modules, high early infrastructure costs

TFPX Milestones

2a

Tier - Milestone	Baseline	Previous Month	Forecast	Delta from baseline	Delta from previous month
T3 - FP - Pre-production C-ROC wafers received	2021-08-10	2021-09-10	2021-09-17	-38	-7
T3 - FP - Start ROC Procurement (production)	2022-01-14	2022-02-16	2022-02-23	-40	-7
T3 - FP - Ready for Technical Review	2022-01-19	2022-05-20	2022-06-22	-154	-33
T3 - FP - Start Sensor Procurement (Production)	2022-10-17	2022-10-17	2022-10-17	0	0
T3 - FP - Start Dee Fabrication	2022-11-21	2023-03-07	2023-03-06	-105	1
T3 - FP - Start Bump Bonding (Production)	2022-12-21	2022-12-21	2022-12-21	0	0
T3 - FP - Start DAQ/DTC Production	2023-03-15	2024-02-28	2024-03-25	-376	-26
T3 - FP - ITST Fabrication Complete	2024-03-05	2024-03-05	2024-03-05	0	0
T3 - FP - All Sensor-ROC Assembly shipped to Module Assembly	2024-07-11	2024-07-11	2024-07-11	0	0
T3 - FP - DAQ Complete	2025-01-31	2026-01-15	2026-02-11	-376	-27
T3 - FP - Modules Complete	2025-02-06	2025-02-06	2025-02-06	0	0
T3 - FP - First HC Completed at Cornell	2025-02-28	2025-02-28	2025-02-28	0	0
T3 - FP - First HC Received Reassembled and Tested at CERN	2025-07-28	2025-07-28	2025-07-28	0	0
T3 - FP - Mechanics and Assembly Complete	2026-06-29	2026-06-29	2026-06-29	0	0
T2 - FP - Forward Pixels UpGrades Complete	2026-06-29	2026-06-29	2026-06-29	0	0
T1 - PROJECT COMPLETE - TECHNICAL SCOPE	2026-06-29	2026-06-29	2026-06-29	0	0
T1 - PROJECT COMPLETE – ADMINISTRATION	2026-06-30	2026-06-30	2026-06-30	0	0
T1 - PROJECT COMPLETE	2026-06-30	2026-06-30	2026-06-30	0	0

June ‘21 monthly report

- High-level milestones are tracked monthly from P6
  - Recent realignment BCR so are forecast close to (new) schedule
- C-ROC submissions delayed 1-mo wrt new baseline
  - Chip wafers expected by September
- Ready for Technical Review
  - Slowed by access to sensor irradiation and test beam facilities
- DAQ delayed by design revisions but has sufficient float (BCR132 in July)

BCRs

- BCRs
  - 45 Mechanics optimization year 1
    - Added development & risk mitigation $352k
  - 53 LS3 and external constraints
    - One year shift of LS3 & TFPX need by date: -128d; $130k (esca.only)
  - 58 HL-LHC delay response
    - Added development & risk mitigation: $458k
  - 95 C-ROC schedule change: $1k
  - 107 Mechanics, CMSC scheduling: -3d, $29k
  - 117 Mechanics, add diamond wire saw: $41k
  - 120 Covid delays May'21: -55d, $86k (esca.only)
    - Coordinated with iCMS updates
  - 125 Schedule alignment for Covid: -193d, $149k (esca.only)
  - 121 Add UPRM test beam labor: $5k
  - 124 Covid Add UIC sensor irradiation labor: $0k
  - 132 Plan revision for modules, electronics: $192k
    - Response to iCMS schedule changes, risk mitigation: added prototypes & system tests; realized delay in DTC due to interface change

Added early MREFC Development activities Per FDR panel

External Deliverables

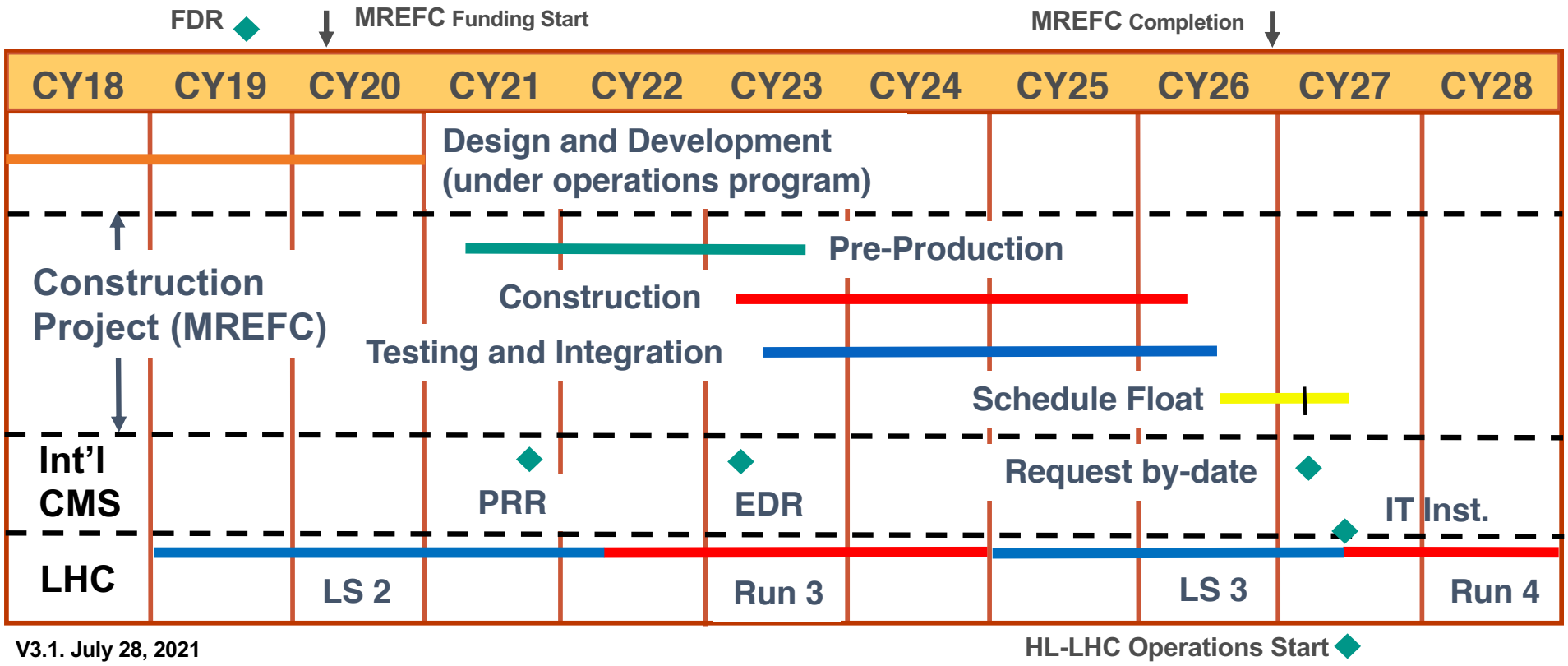
Plan evolution

COVID-19 Delays

Risk Mitigation

- We're using the change control process to manage the project, respond to realized delays or risks, and mitigate residual risks

TFPX Schedule Summary



- (150 working days) 7 months of Float from delivery to request date
- 16 additional weeks to install date (pre-install commissioning)
- Total contingency of 11 months, 16% of remaining time
- Risk analysis: 75% CL to finish by need-by date & 90% CL float of -3 mo
  - Can tighten with schedule re-optimization, after realized Covid delays
  - Consider speeding module production and/or staging disks if necessary to meet schedule

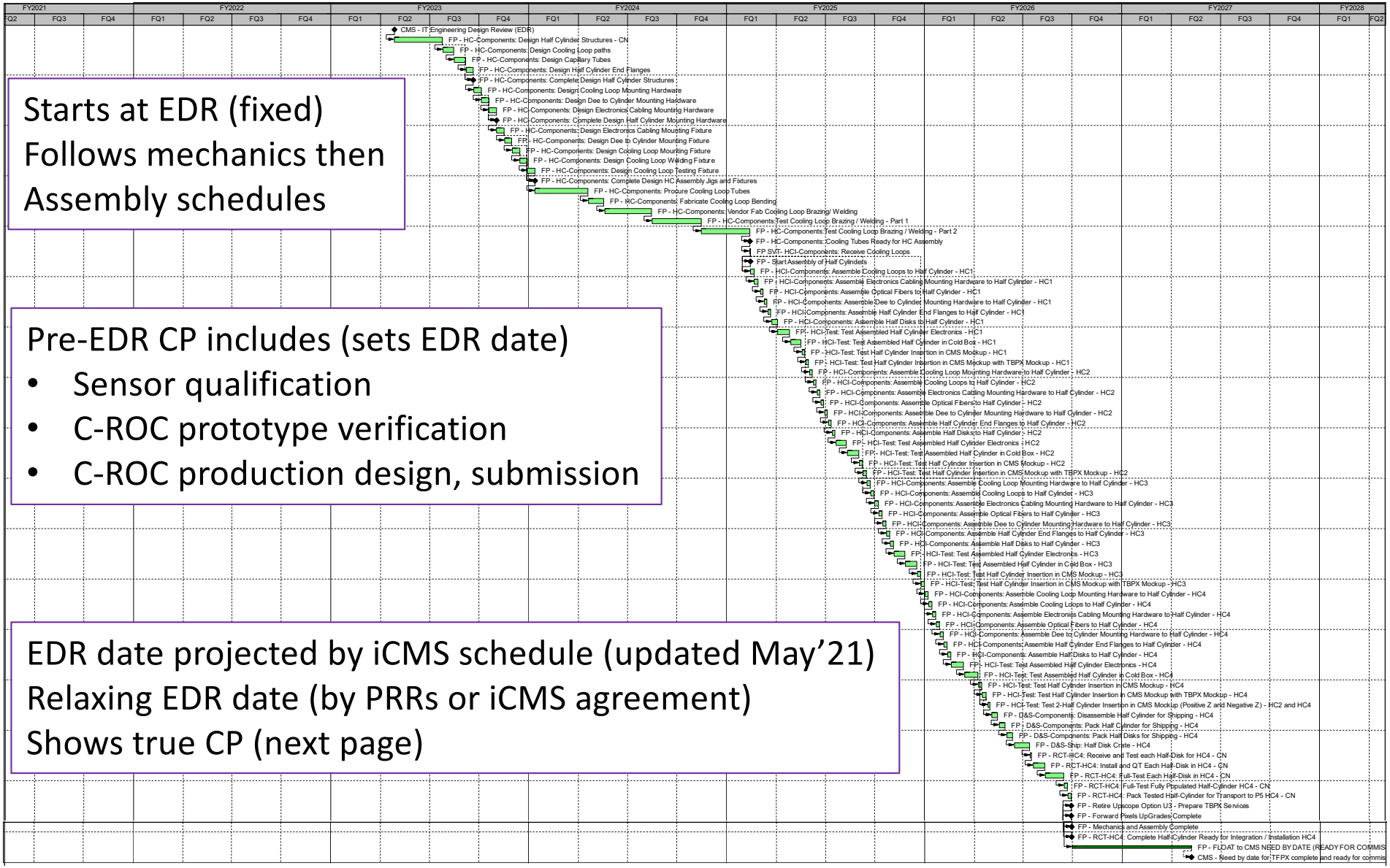
Critical Path

Starts at EDR (fixed)
Follows mechanics then
Assembly schedules

Pre-EDR CP includes (sets EDR date)

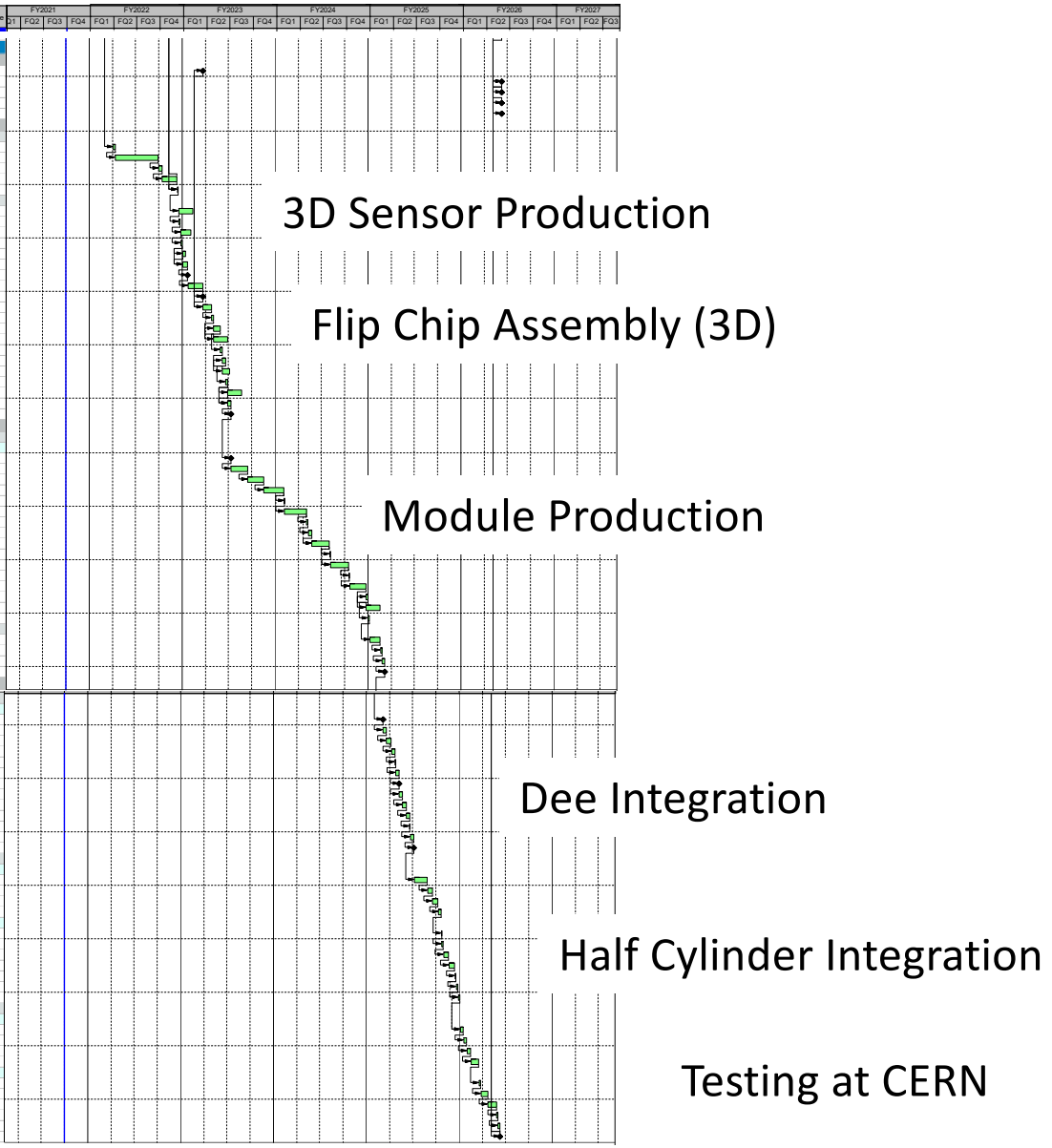
- Sensor qualification
- C-ROC prototype verification
- C-ROC production design, submission

EDR date projected by iCMS schedule (updated May'21)
Relaxing EDR date (by PRRs or iCMS agreement)
Shows true CP (next page)



Critical Path (EDR constraint removed)

Activity ID	Activity Name	PD	Start	Finish	TF	Control Account	Planned Labor HRs	Planned Total Burdened Cost	Estim Type	CTC Code	Control Account Manager	Funding Type	Cobra PMT Code
EVMS-Jun21-M402W-WI.7	**FP - Forward Pixels**	1050	04-Jan-22	11-Mar-26	329		18883	$1,410,046.35					
EVMS-Jun21-M402W-WI.7.1	**FP - Milestones**	805	21-Dec-22	11-Mar-26	329		0	$0.00					
FX331972	FP - Start Bump Bonding (Production)	0	21-Dec-22		227		0	$0.00					
FX16710	FP - Mechanics and Assembly Complete	0		10-Mar-26	227		0	$0.00					
FX16800	FP - Forward Pixels UpGrades Complete	0		10-Mar-26	227		0	$0.00					
FX60281	FP - Retire Upscope Option U3 - Prepare TBPX Services	0		10-Mar-26	227		0	$0.00					
FX99999	FP - RLS FINISH	0		11-Mar-26	329		0	$0.00					
EVMS-Jun21-M402W-WI.7.3	**FP - Sensors and Readout Chips**	350	04-Jan-22	23-May-23	227		1736	$827,181.59					
EVMS-Jun21-M402W-WI.7.3.1	**FP - Sensors**	180	04-Jan-22	16-Sep-22	227		126	$240,773.85					
FX310370	FP SVT - Issue PO for 3D Sensor Wafers 1x2 - PreProduction	5	04-Jan-22	10-Jan-22	227		0	$0.00					
FX310380	FP SVT - Vendor Fabricates 3D Sensor Wafers 1x2 - PreProduction	120	11-Jan-22	29-Jun-22	227		0	$0.00					
FX310400	FP - Vendor Delivers 3D Sensor Wafers 1x2 - PreProduction	10	30-Jun-22	14-Jul-22	227	07.03.01	0	$238,344.93	M4	73.400192	12214V	NSF.MREFC	C
FX310410	FP - Test 3D Sensor Wafers 1x2 - PreProduction	40	15-Jul-22	09-Sep-22	227	07.03.01	126	$2,027.39	L3	73.400191	12214V	NSF.MREFC	C
FX310430	FP - Ship to bump-bonder 3D Sensor Wafers 1x2 - PreProduction	5	12-Sep-22	16-Sep-22	227	07.03.01	0	$401.52	M2	73.400192	12214V	NSF.MREFC	C
EVMS-Jun21-M402W-WI.7.3.3	**FP - Sensor-ROC Assembly**	170	19-Sep-22	23-May-23	227		1610	$586,407.74					
FX33135	FP - Assemble (dicing and bump-bonding) - PreProduction	40	19-Sep-22	11-Nov-22	227	07.03.03	0	$236,889.06	M4	73.400392	12351V	NSF.MREFC	C
FX33145	FP SVT - Ship Sensor-ROC Assembly from bump-bonding - PreProduction	5	19-Sep-22	23-Sep-22	227		0	$0.00					
FX33155	FP - Apply parylene coatings - PreProduction	30	26-Sep-22	04-Nov-22	227	07.03.03	0	$37,988.32	M4	73.400392	12351V	NSF.MREFC	C
FX33165	FP SVT - Ship Sensor-ROC to Module Assembly and QA - PreProduction	5	26-Sep-22	30-Sep-22	227		0	$0.00					
FX33170	FP - Support for Assembly Testing - PreProduction	10	03-Oct-22	14-Oct-22	227	07.03.03	160	$0.00	L3	73.400391	12351V	NSF.MREFC	C
FX33175	FP - Test QA Sensor-ROC Assembly - PreProduction	15	03-Oct-22	21-Oct-22	227	07.03.03	500	$21,672.51	L4	73.400391	12351V	NSF.MREFC	C
FX33190	FP - AVAIL: Sensor-ROC Ready for Module Assembly - PreProduction (interfa			21-Oct-22	227		0	$0.00					
FX33197	FP - Prepare Procurement Readiness Review (PRR) - Sensor-ROC Assembly	40	24-Oct-22	20-Dec-22	227	07.03.03	320	$3,620.41	L3	73.400391	12351V	NSF.MREFC	C
FX331971	FP - AVAIL: Procurement Readiness Review (PRR) - Sensor-ROC Assembly	0		20-Dec-22	227		0	$0.00					
FX33200	FP - Prepare PO Document for bump bonding (dicing and bump-bonding and	20	21-Dec-22	24-Jan-23	227	07.03.03	44	$2,598.63	L3	73.400391	12351V	NSF.MREFC	C
FX33205	FP SVT - Issue PO for bump bonding (dicing and bump-bonding) - Production	5	25-Jan-23	31-Jan-23	227		0	$0.00					
FX33215	FP SVT - Wait time for assemble (dicing and bump-bonding) - Batch 1	20	01-Feb-23	28-Feb-23	227		0	$0.00					
FX33210	FP - Assemble (dicing and bump-bonding) - Batch 1	40	01-Feb-23	28-Mar-23	227	07.03.03	0	$238,059.04	M4	73.400392	12351V	NSF.MREFC	C
FX33220	FP SVT - Ship Sensor-ROC Assembly from bump-bonding - Batch 1	5	01-Mar-23	07-Mar-23	227		0	$0.00					
FX33235	FP SVT - Wait time for Partial parylene coating to Sensor-ROC Assembly - Ba	10	08-Mar-23	21-Mar-23	227		0	$0.00					
FX33225	FP - Apply parylene coating to Sensor-ROC Assembly - Batch 1	20	08-Mar-23	04-Apr-23	227	07.03.03	0	$38,113.20	M4	73.400392	12351V	NSF.MREFC	C
FX33240	FP SVT - Ship Sensor-ROC to Module Assembly and QA - Batch 1	5	22-Mar-23	28-Mar-23	227		0	$0.00					
FX33244	FP - Support for Production Assembly Testing	40	29-Mar-23	23-May-23	227	07.03.03	160	$0.00	L3	73.400391	12351V	NSF.MREFC	C
FX33245	FP - Test QA Sensor-ROC Assembly - Batch 1	10	29-Mar-23	11-Apr-23	227	07.03.03	426	$7,466.57	L3	73.400391	12351V	NSF.MREFC	C
FX33260	FP - AVAIL: Sensor-ROC Ready for Module Assembly - Batch 1 (interface MS	0		11-Apr-23	227		0	$0.00					
EVMS-Jun21-M402W-WI.7.4	**FP - Modules**	416	11-Apr-23	04-Dec-24	227		13224	$484,641.09					
EVMS-Jun21-M402W-WI.7.4.2	**FP - Module Assembly**	406	11-Apr-23	18-Nov-24	227		12620	$479,798.10					
EVMS-Jun21-M402W-WI.7.4.2.2	**FP - Purdue Assembly Site**	406	11-Apr-23	18-Nov-24	227		12620	$479,798.10					
FX422240	FP - NEED: HDI and Sensor-ROCs Assembly - Batch 1 - Purdue	0		11-Apr-23	227		0	$0.00					
FX422250	FP - SuperBatch 1 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	45	12-Apr-23	14-Jun-23	227	07.04.02	1575	$53,417.05	L3	74.400291	08525V	NSF.MREFC	C
FX422290	FP - SuperBatch 2 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	45	15-Jun-23	17-Aug-23	227	07.04.02	1575	$53,417.05	L3	74.400291	08525V	NSF.MREFC	C
FX422330	FP - SuperBatch 3 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	55	18-Aug-23	03-Nov-23	227	07.04.02	1575	$54,194.04	L3	74.400291	08525V	NSF.MREFC	C
FX422340	FP - Service Tech Visit for Wire Bonder - 2nd visit - Purdue	2	06-Nov-23	07-Nov-23	227	07.04.02	0	$11,374.32	M2	74.400292	08525V	NSF.MREFC	C
FX422380	FP - SuperBatch 4 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	55	08-Nov-23	01-Feb-24	227	07.04.02	1575	$55,126.42	L3	74.400291	08525V	NSF.MREFC	C
FX422385	FP - Prepare PO Document for Lab Supplies in FY22 - Purdue	5	02-Feb-24	08-Feb-24	227	07.04.02	20	$2,157.05	L3	74.400291	08525V	NSF.MREFC	C
FX422390	FP - Procure Lab Supplies in FY22 - Purdue	10	09-Feb-24	22-Feb-24	227	07.04.02	0	$8,565.00	M2	74.400292	08525V	NSF.MREFC	C
FX422420	FP - SuperBatch 5 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	50	23-Feb-24	02-May-24	227	07.04.02	1575	$55,126.42	L3	74.400291	08525V	NSF.MREFC	C
FX422430	FP - Service Tech Visit for Gantry - 2nd visit - Purdue	2	03-May-24	06-May-24	227	07.04.02	0	$7,922.63	M2	74.400292	08525V	NSF.MREFC	C
FX422470	FP - SuperBatch 6 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	50	07-May-24	17-Jul-24	227	07.04.02	1575	$55,126.42	L3	74.400291	08525V	NSF.MREFC	C
FX422480	FP - Service Tech Visit for Wire Bonder - 3rd visit - Purdue	2	18-Jul-24	19-Jul-24	227	07.04.02	0	$11,374.32	M2	74.400292	08525V	NSF.MREFC	C
FX422520	FP - SuperBatch 7 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	45	22-Jul-24	23-Sep-24	227	07.04.02	1575	$55,126.42	L3	74.400291	08525V	NSF.MREFC	C
FX422570	FP SVT - Wait time 8 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/	5	24-Sep-24	30-Sep-24	227		0	$0.00					
FX422560	FP - SuperBatch 8 (Inspect HDI and Hybrid; Measure IV Curve; Assemble/Wir	40	24-Sep-24	18-Nov-24	227	07.04.02	1575	$56,670.03	L3	74.400291	08525V	NSF.MREFC	C
FX422580	FP - Ship SuperBatch 8 for Testing and Calibration - Purdue	5	01-Oct-24	07-Oct-24	227	07.04.02	0	$200.94	M2	74.400292	08525V	NSF.MREFC	C
EVMS-Jun21-M402W-WI.7.4.3	**FP - Module Testing and Calibration**	40	08-Oct-24	04-Dec-24	227		604	$4,843.00					
FX43731	FP - Test and Calibrate Modules - Batch 8 (PU Northwest)	30	08-Oct-24	18-Nov-24	227	07.04.03	604	$4,664.03	L3	74.400391	08525V	NSF.MREFC	C
FX43740	FP SVT - Wait time Test and Calibrate Modules - Batch 8	5	19-Nov-24	25-Nov-24	227		0	$0.00					
FX43750	FP - Ship Modules from UIC to Cornell - Batch 8	5	26-Nov-24	04-Dec-24	227	07.04.03	0	$178.97	M2	74.400392	08525V	NSF.MREFC	C
FX43760	FP - AVAIL: Production Modules Ready for Modules Assembly - Batch 8 (interf	0		04-Dec-24	227		0	$0.00					
EVMS-Jun21-M402W-WI.7.6	**FP - Mechanics and Assembly**	314	04-Dec-24	10-Mar-26	227		3923	$98,223.67					
EVMS-Jun21-M402W-WI.7.6.1	**FP - Mechanics Components**	82	04-Dec-24	04-Apr-25	227		909	$23,140.62					
EVMS-Jun21-M402W-WI.7.6.1.2	**FP - Modules to Dees Integration (MDI)**	82	04-Dec-24	04-Apr-25	227		909	$23,140.62					
FX611110	FP - MDInteg-NEED: Modules - Batch 8 (Interface MS)	0		04-Dec-24	227		0	$0.00					
FX611140	FP - MDInteg-Fabricate: Mount Modules Top-Large - Batch 8	10	05-Dec-24	18-Dec-24	227	07.06	90	$3,445.39	L5	76.400091	40767V	NSF.MREFC	C
FX611150	FP - MDInteg-Fabricate: Mount Modules Bottom-Large - Batch 8	10	19-Dec-24	07-Jan-25	227	07.06	133	$2,633.00	L5	76.400091	40767V	NSF.MREFC	C
FX611160	FP - MDInteg-Fabricate: Connect e-Links - Batch 8	10	08-Jan-25	22-Jan-25	227	07.06	147	$3,648.19	L5	76.400091	40767V	NSF.MREFC	C
FX611170	FP - MDInteg-Fabricate: Attach RTDs - Batch 8	1	23-Jan-25	23-Jan-25	227	07.06	14	$508.23	L5	76.400091	40767V	NSF.MREFC	C
FX611180	FP - MDInteg-QC & Fix: QuickTest Mounted Modules - Batch 8	10	24-Jan-25	06-Feb-25	227	07.06	121	$2,111.79	L5	76.400091	40767V	NSF.MREFC	C
FX611190	FP - MDInteg-Modules to Dees Integration Complete - Batch 8	0		06-Feb-25	227		0	$0.00					
FX611240	FP - MDInteg-Fabricate: Mount Modules Top-Large - Batch 9	10	07-Feb-25	20-Feb-25	227	07.06	90	$3,445.39	L5	76.400091	40767V	NSF.MREFC	C
FX611250	FP - MDInteg-Fabricate: Mount Modules Bottom-Large - Batch 9 - CN	10	21-Feb-25	06-Mar-25	227	07.06	32	$1,080.42	L5	76.400091	40767V	NSF.MREFC	C
FX611260	FP - MDInteg-Fabricate: Connect e-Links - Batch 9	10	07-Mar-25	20-Mar-25	227	07.06	147	$3,648.19	L5	76.400091	40767V	NSF.MREFC	C
FX611270	FP - MDInteg-Fabricate: Attach RTDs - Batch 9	1	21-Mar-25	21-Mar-25	227	07.06	14	$508.23	L5	76.400091	40767V	NSF.MREFC	C
FX611280	FP - MDInteg-QC & Fix: Quick Test Mounted Modules - Batch 9	10	24-Mar-25	04-Apr-25	227	07.06	121	$2,111.79	L5	76.400091	40767V	NSF.MREFC	C
FX611290	FP - MDInteg-Modules to Dees Integration Complete - Batch 9	0		04-Apr-25	227		0	$0.00					
EVMS-Jun21-M402W-WI.7.6.3	**FP - Assembly and Testing**	127	07-Apr-25	03-Oct-25	227		1320	$33,942.19					
EVMS-Jun21-M402W-WI.7.6.3.1	**FP - Half Disks Integration (HDI)**	76	07-Apr-25	23-Jul-25	227		258	$6,412.98					
FX653251	FP - HDIngeg-Assembly: Mate Two Dees into halfdisk - HC4 (MDI Batch 8 & 9	38	07-Apr-25	29-May-25	227	07.06	38	$1,583.42	L4	76.400091	40767V	NSF.MREFC	C
FX653261	FP - HDIngeg-Assembly: Attach Portcard Structures - HC4	13	30-May-25	17-Jun-25	227	07.06	25	$1,346.09	L4	76.400091	40767V	NSF.MREFC	C
FX653281	FP - HDIngeg-Assembly: Connect e-Links to Portcard - HC4	16	18-Jun-25	10-Jul-25	227	07.06	32	$1,776.08	L4	76.400091	40767V	NSF.MREFC	C
FX653291	FP - HDIngeg-QC and Fix: Test Vertical Slice Test halfdisk - HC4 (Batch 8&9)	9	11-Jul-25	23-Jul-25	227	07.06	163	$1,707.38	L5	76.400091	40767V	NSF.MREFC	C
EVMS-Jun21-M402W-WI.7.6.3.2	**FP - Half Cylinder Integration**	51	24-Jul-25	03-Oct-25	227		1062	$27,529.20					
FX6702704	FP SVT- HCI-Components: Receive Half Disks - HC4	1	24-Jul-25	24-Jul-25	227		0	$0.00					
FX6702804	FP - HCI-Components: Assemble Half Disks to Half Cylinder - HC4	5	25-Jul-25	31-Jul-25	227	07.06	169	$8,686.01	L4	76.400091	40767V	NSF.MREFC	C
FX670680	FP - HCI-Test: Test Assembled Half Cylinder Electronics - HC4	15	01-Aug-25	21-Aug-25	227	07.06	363	$3,887.42	L4	76.400091	40767V	NSF.MREFC	C
FX670690	FP - HCI-Test: Test Assembled Half Cylinder in Cold Box - HC4	15	22-Aug-25	12-Sep-25	227	07.06	363	$3,887.42	L5	76.400091	40767V	NSF.MREFC	C
FX670700	FP - HCI-Test: Test Half Cylinder Insertion in CMS Mockup - HC4	5	15-Sep-25	19-Sep-25	227	07.06	42	$2,771.49	L5	76.400091	40767V	NSF.MREFC	C
FX6705504	FP - HCI-Test: Test Half Cylinder Insertion in CMS Mockup with TBPX Mockup	5	22-Sep-25	26-Sep-25	227	07.06	42	$2,771.49	L5	76.400091	40767V	NSF.MREFC	C
FX670720	FP - HCI-Test: Test 2-Half Cylinder Insertion in CMS Mockup (Positive Z and N	5	29-Sep-25	03-Oct-25	227	07.06	83	$5,523.37	L5	76.400091	40767V	NSF.MREFC	C
EVMS-Jun21-M402W-WI.7.6.4	**FP - Shipping to CERN and Reassembly**	105	06-Oct-25	10-Mar-26	227		1694	$41,140.86					
EVMS-Jun21-M402W-WI.7.6.4.2	**FP - Disassemble and Ship**	51	06-Oct-25	17-Dec-25	227		266	$15,265.85					
FX680440	FP - D&S-Components: Disassemble Half Cylinder for Shipping - HC4	10	06-Oct-25	17-Oct-25	227	07.06	56	$2,129.34	L3	76.400091	40767V	NSF.MREFC	C
FX680450	FP - D&S-Components: Pack Half Cylinder for Shipping - HC4	10	20-Oct-25	31-Oct-25	227	07.06	105	$5,418.46	L3	76.400091	40767V	NSF.MREFC	C
FX680470	FP - D&S-Components: Pack Half Disks for Shipping - HC4	10	03-Nov-25	14-Nov-25	227	07.06	105	$5,418.46	L3	76.400091	40767V	NSF.MREFC	C
FX680480	FP - D&S-Ship: Half Disk Crate - HC4	21	17-Nov-25	17-Dec-25	227	07.06	0	$2,299.60	M3	76.400092	40767V	NSF.MREFC	C
EVMS-Jun21-M402W-WI.7.6.4.3	**FP - Reassemble and CERN Test**	54	18-Dec-25	10-Mar-26	227		1428	$25,875.01					
FX685700	FP - RCT-HC4: Receive and Test each Half-Disk for HC4 - CN	4	18-Dec-25	23-Dec-25	227	07.06	142	$4,674.63	L4	76.400091	40767V	NSF.MREFC	C
FX685710	FP - RCT-HC4: Install and QT Each Half-Disk in HC4 - CN	16	26-Dec-25	21-Jan-26	227	07.06	391	$6,569.74	L4	76.400091	40767V	NSF.MREFC	C
FX685730	FP - RCT-HC4: Full-Test Each Half-Disk in HC4 - CN	24	22-Jan-26	24-Feb-26	227	07.06	502	$4,662.76	L4	76.400091	40767V	NSF.MREFC	C
FX685740	FP - RCT-HC4: Full-Test Fully Populated Half-Cylinder HC4 - CN	5	25-Feb-26	03-Mar-26	227	07.06	156	$4,208.92	L5	76.400091	40767V	NSF.MREFC	C
FX685750	FP - RCT-HC4: Pack Tested Half-Cylinder for Transport to P5 HC4 - CN	5	04-Mar-26	10-Mar-26	227	07.06	237	$5,758.96	L3	76.400091	40767V	NSF.MREFC	C
FX685760	FP - RCT-HC4: Complete Half-Cylinder Ready for Integration / Installation HC	0		10-Mar-26	227		0	$0.00					



Completion ~4 months earlier. We continue to revise and streamline our schedule and in iCMS

COVID Impacts

- COVID impacts
  - Delayed access to radiation facilities & test beams had a very significant impact on sensor radiation qualification
  - External ASICs are delayed and affect prototyping
    - C-ROC delay partly due to verification personnel & slow testing for ATLAS ITkPixv1 (1st RD53B design)
    - lpGBTv1 delayed due to radiation qualification & CERN procurement strategy during pandemic
  - Slowed progress due to efficiencies, lab access, delayed technical specs and availability of parts
  - BCR125 incorporated external & internal realized COVID delays
    - Reduced float by 6 months (7 months remaining) from *present* LS3 date
    - Cost change from escalation $149k
- Covid efficiencies for labor were ~80% but now improving
  - Estimated from technical progress vs. planned
  - Causes:
    - Work from home, lack of access to labs & prototyping
    - Delays in procurement, longer lead times
    - Some standing army effects early on, requiring agile rescheduling for personnel
    - Delays in ext. deliverables led to inefficiency in design work (lacking final specs)
  - Still today – loss of travel for efficient collaborative activities, test beam…

Plans for FY2022 and iCMS Updates

3b

- Overview of 2022 Plans
  - Sensors:
    - Complete radiation qualification, selection for R1 sensor (Nov'21)
    - Launch of procurement of sensors (Jan'22 for contract, pre-prod. orders Fall '22)
  - C-ROC:
    - Evaluation of prototype (Sep'21 – Mar'22), wafer testing, radiation qualification, SEU testing
    - Design modifications (Nov'21 – May'22) & Production submission (June'22)
  - SRA:
    - Flip chip assembly for C-ROC demo modules
    - Launch procurement at CERN (Spring'22 contract, pre-production orders Fall'22)
  - Module:
    - Build RD53A demo modules (Aug – Sep'21)
    - Build C-ROC demo modules (Oct'21 – May'22)
    - Test & Evaluate demo modules (Sep'21 – Aug'22)
    - Prepare factories for preproduction
  - Electronics:
    - Signal chain tests with prototypes:
      SCC/module – e-link – port card – uDTC (Apr'21 – Aug'22)
    - DTC & Power system prototype design & testing
  - Mechanics:
    - Dee prototype assembly and evaluations (Apr'21 – May'22)
    - ITST prototype fabrication (Jun'21 – Dec'21)
- Technical review in summer of 2022 prior to Jan'23 EDR

QA/QC Implementation

2d

Reqs. docdb-13304
QAQC docdb-13093

- TFPX documentation
  - Requirements, QA/QC plan – no significant changes required
  - ICD – updated contacts
- QA/QC procedures under development
  - Sensor: process QC plan development at Cornell & QA source testing at Colorado
  - Sensor ROC Assembly: QA test station assembled at UTK
  - Modules: procedures, code development at OSU, x-ray testing at UIC
  - Electrical: e-link eye measurements, BERT at Kansas; port card test development at Rice; DTC prototype tests; rad qualification of e-links, PCB materials, connectors
  - Mechanical – thermal test procedures & simulations at Cornell; material radiation qualifications for Cfiber, glues, encapsulants, underway
  - From all above developments, draft procedures & documentation will be prepared

Summary

- TFPX has addressed FDR recommendations
  - Added / updated risks after FDR for external deliverables & tracking their compliance
  - Added early MREFC design activities to mitigate risks and prepare for a technical review
- Technical progress is proceeding well, though slower than planned due to COVID
  - Parts & prototypes will be available and evaluated before Summer 2022
    - Port cards, e-link prototypes already under test
    - targeted period for technical review – in advance of CMS IT EDR
  - Latest arrivals are irradiated silicon sensors and C-ROC prototypes
  - Sensor radiation qualification is nearing completion
    - Access to irradiation facilities in fall remains critical
  - C-ROC prototype chips are due in Sept opening remaining developments
    - C-ROC module assembly and signal chain system tests
    - C-ROC design validation, radiation qualification
  - FY22 plan includes preparations for technical review and preparations for pre-production
- TFPX management is performing EVM
  - Behind schedule, on budget. SPI 0.54, CPI 0.96
  - COVID impacts tracked, substantial component of schedule variance
  - BCRs used to revise planning and manage the project
- QA/QC is integrated into RLS
  - QA on first articles, prototypes, material
  - Process QC for sensors, SRA, modules, electronics in development

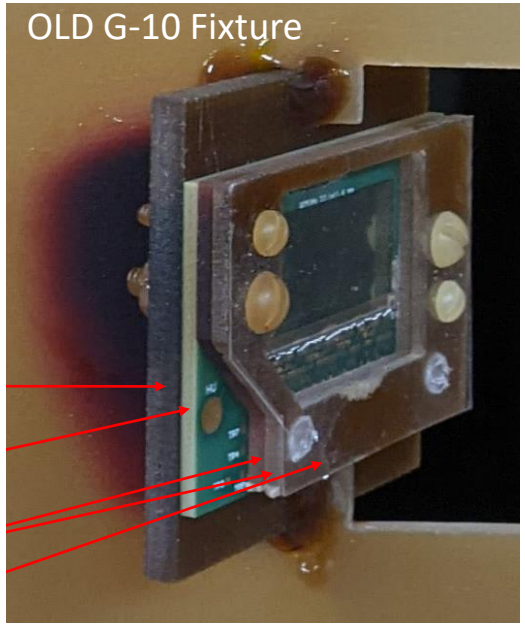
Additional Material

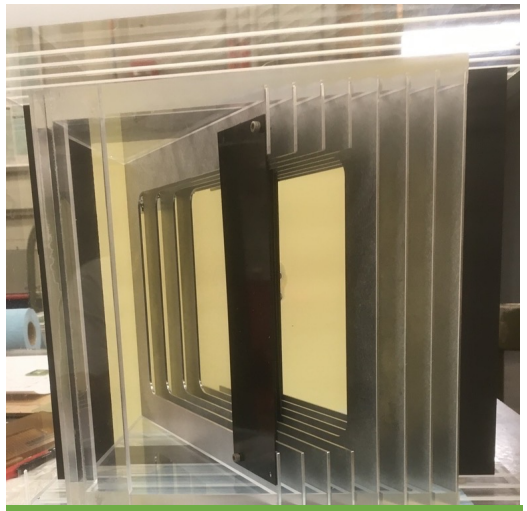
- Backup slides

TFPX Sensor Irradiation/Test Beam

- Highest fluences (1~3E16 n/cm^2) with high-energy protons unique to US
  - FNAL Irradiation Test Area (K=400 MeV)
  - Essential for evaluation of TFPX sensors
  - Decision date Nov'21
- Status of Irradiations at ITA
  - Run 0 to test procedures (goal 0.5E16 n/cm^2) ended Jan 28
  - Run 1 (goal 1.5E16 n/cm^2) ended Feb 21 for beamline work
  - Run 1 resumed Apr 10 – May 2 ; reached goal at 1.4E16 n/cm^2 for 8 sensors
  - Safety Stop on May 4 due to presence of radioactive contamination
    - Likely due to use of G-10 (fiberglass/epoxy), wet saw cutting & high dose damage
    - Samples removed from fixtures and successfully decontaminated
    - Procedures established for ITA ; resumed irradiation runs in past weeks
  - Requested run 1 sensors be released for test beam & tuning
  - Run 2 for next group of 9 sensors with goal of 2.0E16 n/cm^2
    - Took place June 18 – 21 with fresh samples on new fixtures (no G-10)
    - Higher flux now possible from TLG update from 1 pulse / min → 10 pulses/min
- FNAL TFPX test beam continues to run successfully
  - Ran Dec 23 – Jan 12 & Feb 3–16 for pre-irradiation tests of baseline sensors
  - Ran Apr 28 – May 18 for full scans of pre-irradiated Run 2 sensors
  - Running June 16 – 26 for evaluation of irradiated Run 1 sensors
  - Run 2 samples (ended June 21) to be moved when safe
    - Evaluation on test bench and test beam asap
    - Further test beam possible in October before sensor decisions
- Again, ongoing efforts at FNAL make our program possible

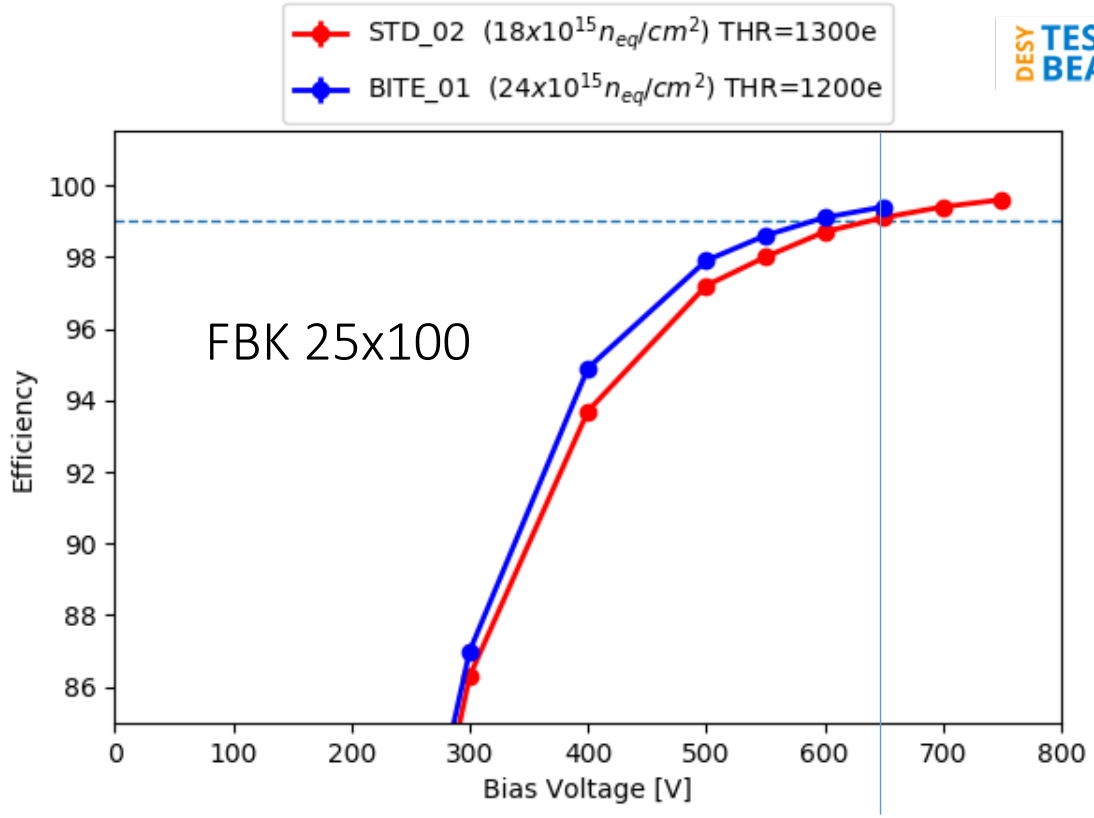
Thanks again to AD, PPD, and Radiation Safety personnel at FNAL





New Al Frame & Kapton Strip

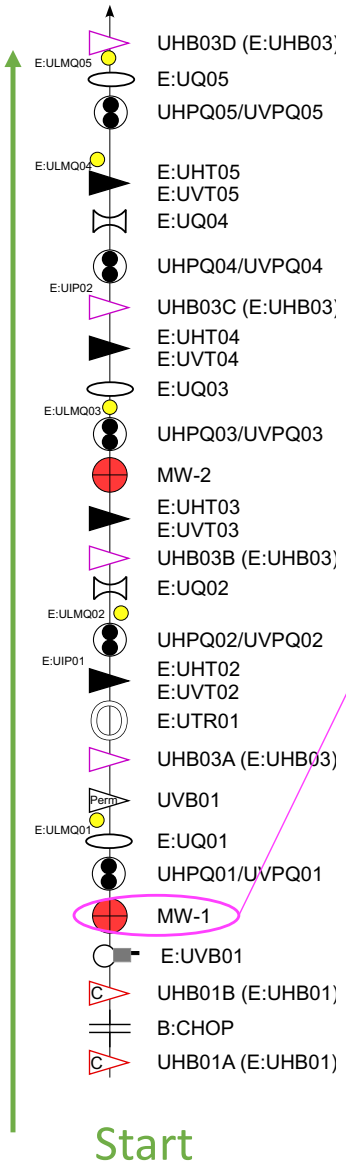
Progress Summary : Sensors (FBK) [402.7.3]

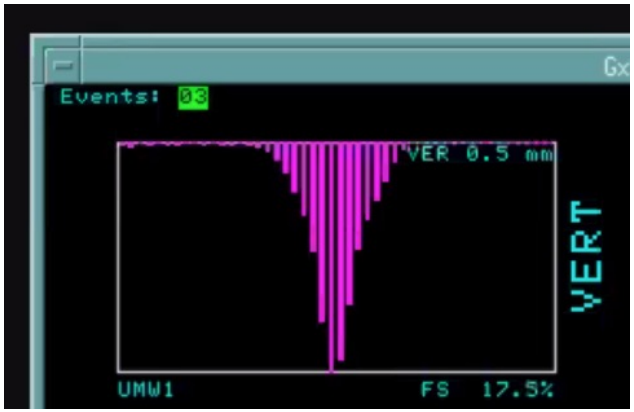


- Planar Sensor Candidate radiation qualification
  - FBK 150um active thickness sensors with two cell designs
    - "Bite" similar to HPK "bitten"
  - KIT cyclotron irradiation & DESY test beam
  - Tested to 1.8~2.4E16 n_{eq}/cm^2
  - >99% efficiency for V_{bias}>650

ITA Sensor Irradiation commissioning

- Run 1 paused Feb 21
  - Beam too narrow and offset
  - Magnet trip
- Past six wks spent commissioning ITA
  - Repairs to multi wire chambers for x,y beam profiles
  - Improved PIN diode array for beam profile in front of our samples
  - Tuned beam position and width
  - "Burned" a few foil cards to check targeting and width
  - Last adjustments this week; foil card analysis to confirm beam center and sigma
  - Test of TLG to add pulses → higher flux, shorter runs
- Resumed irradiation "Run 1" April 9
  - 1.5 E16 $n_{eq.}cm^{-2}$
  - Baseline design Planar and 3D sensors
- Run 2 for 2E16 in June
  - Increased 1→10 pulses per cycle

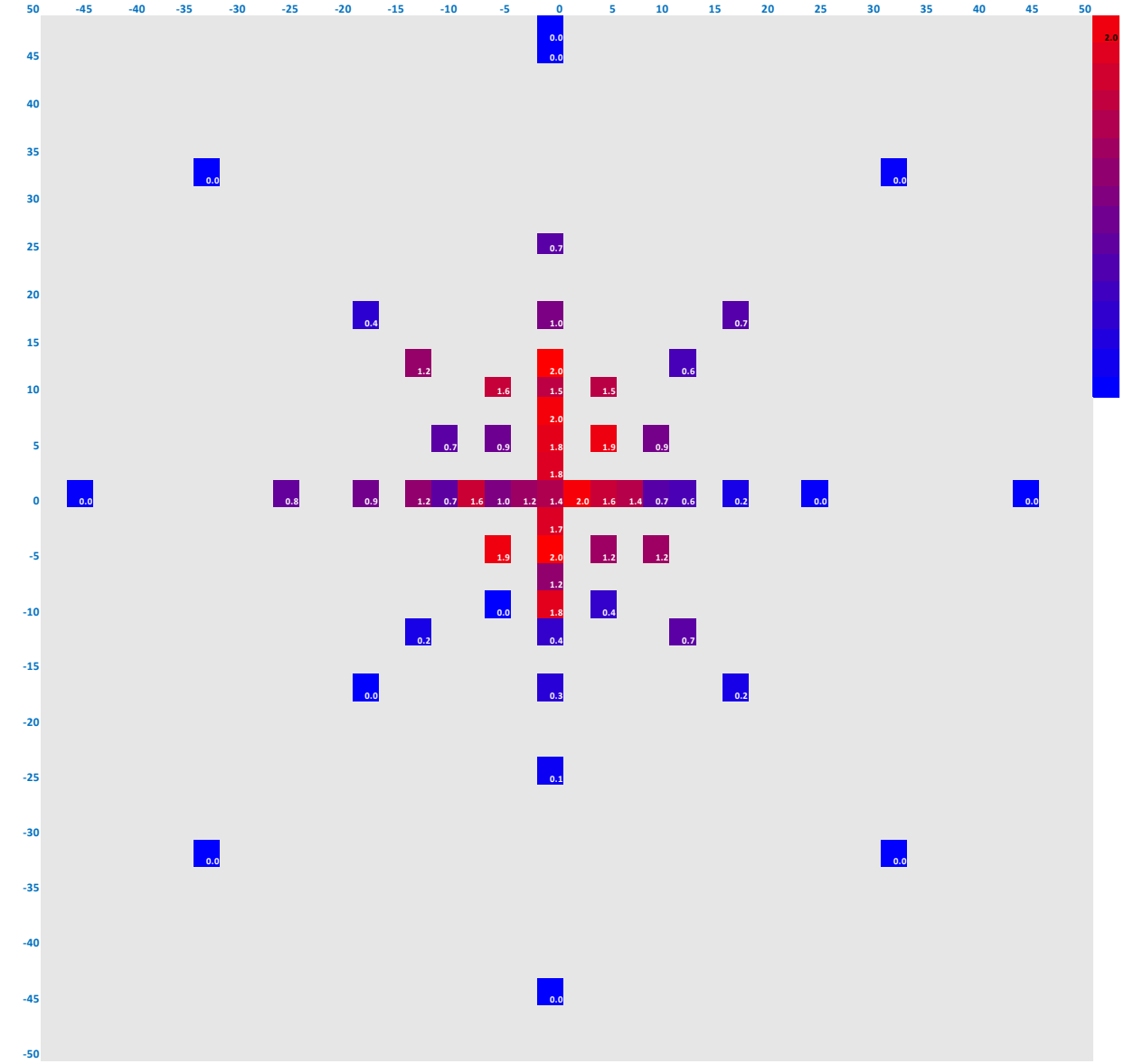




Multi-wire 1
Vertical (y) profile
Near start of beamline

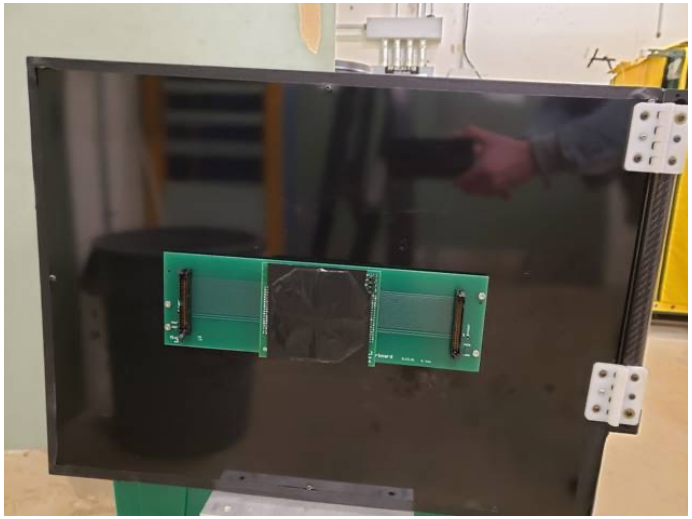
US CMS TFPX ITA Run PI's (Mills, Wagner) heavily involved during ITA commissioning

ITA PIN Diode Array



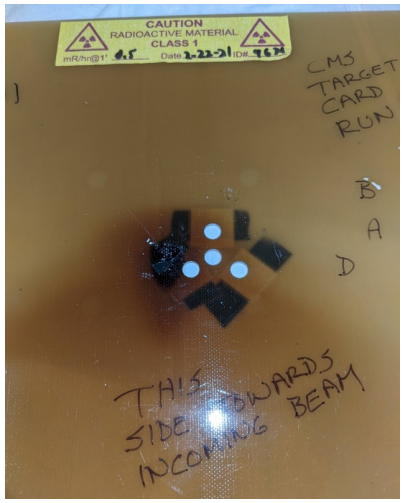
ITA PIN Diode Array
100 x 100 mm
1 mm^2 diodes on 2.5mm grid

- Leakage current → Fluence
- "Quick" feedback
- Beam spot at sample "crate"



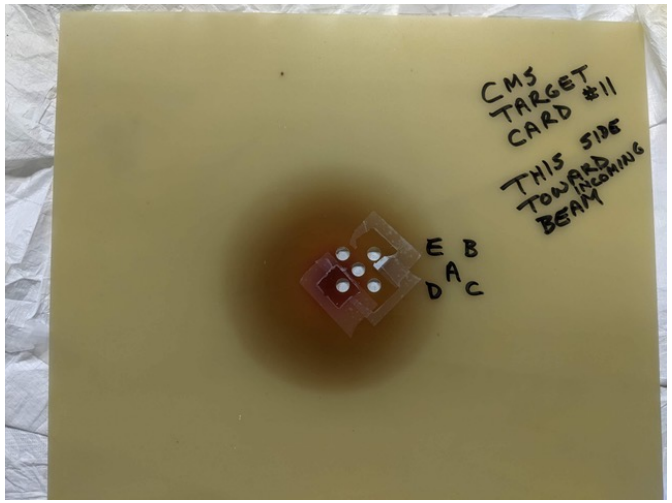
Instrumentation requested/suggested by TFPX from LANL experience

ITA Mid-Run1 Tuning

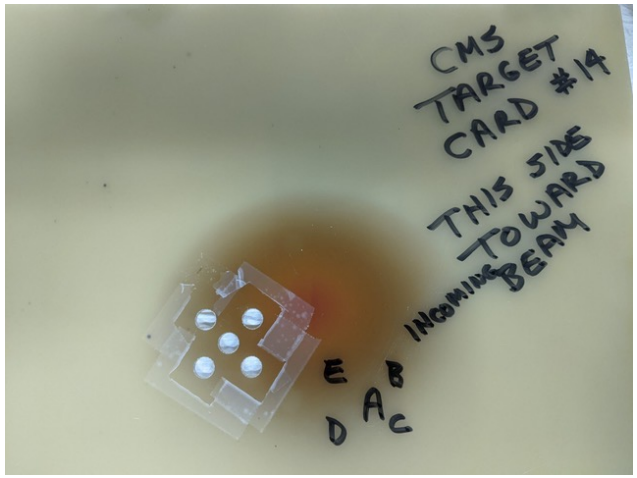


Run 1a Dosimetry foil card

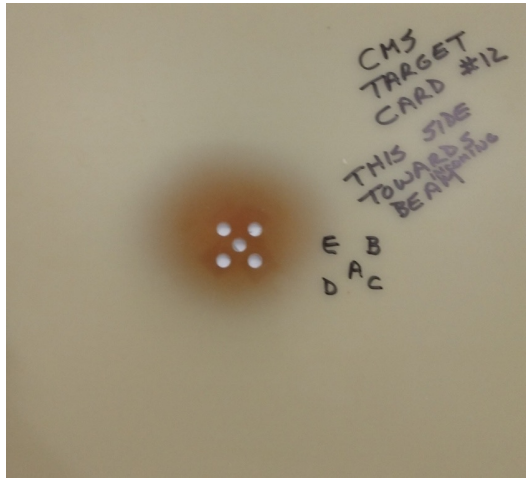
Pause for repairs



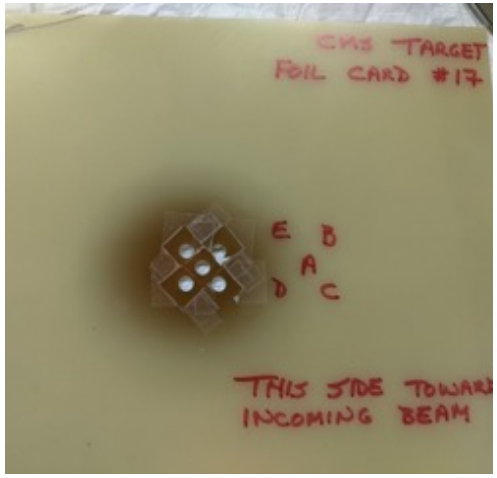
Restart 1 – width improved



Restart 2 – shifted too far



Restart 3 – brought back



Restart 4 – final adjustments

April 9 foils confirm beam tuning :

x_{beam} = -0.376 cm ± 0.114 cm

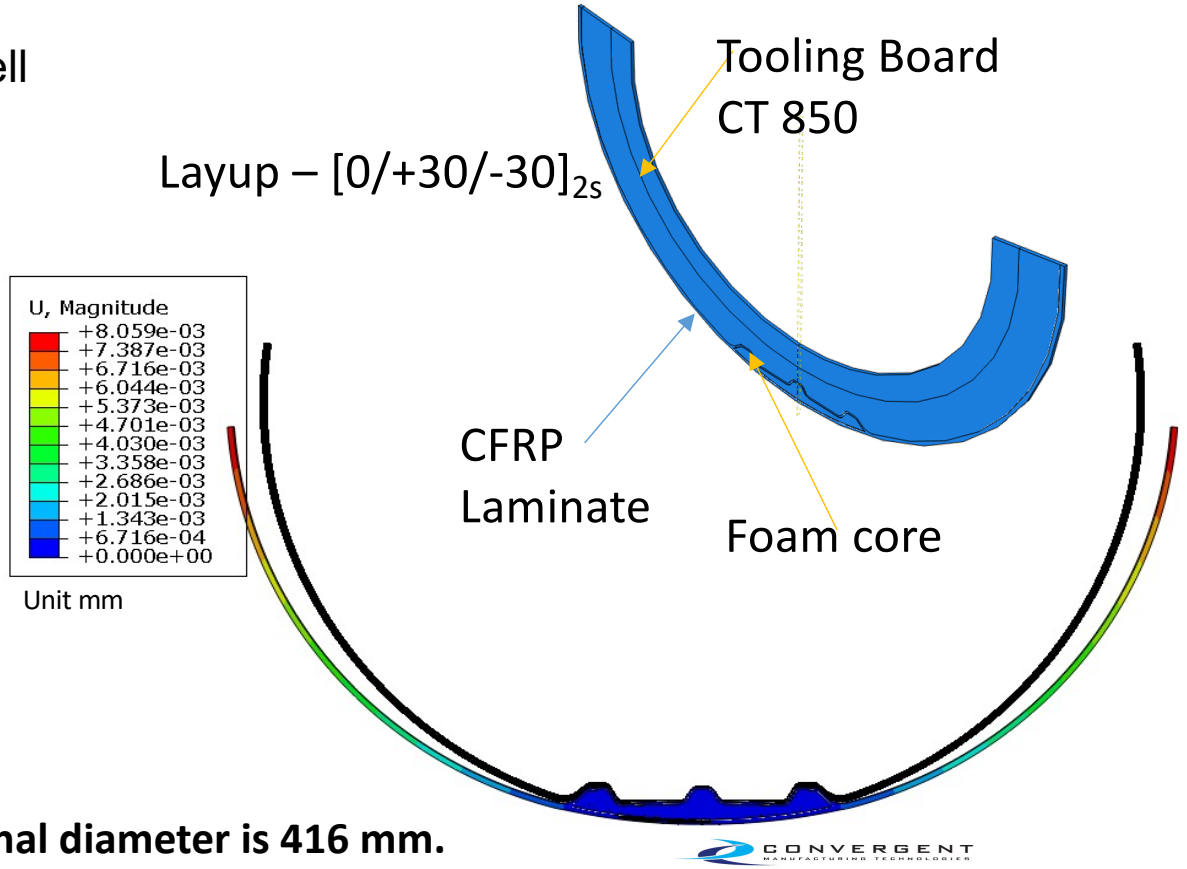
y_{beam} = +0.037 cm ± 0.114 cm

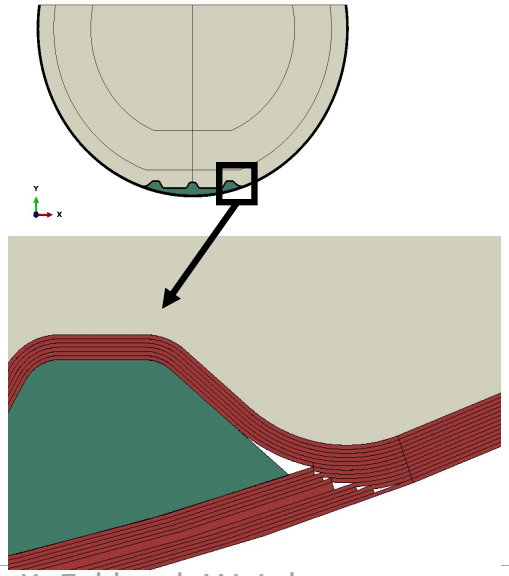
σ = 0.990 cm ± 0.074 cm

Colorado fluence ‘foil’ cards used for beam adjustments

ITST Prototype Status

- ITST is a solid 3mm carbon fiber shell with an integrated track support
- Design Cycle: laminate property determination, predicted tool compensation, tool manufacturing, part layup & curing, part metrology
- Challenging simulations, due to splicing
  - Initial FEA not detailed enough
  - Fixed by refined FEA to model: individual plies, mesh sensitivity, initial and boundary conditions





Target nominal diameter is 416 mm.
<u>Diameter measured is 415.9 mm</u>
with cylindricity of +/- 0.8 mm.
Detailed metrology of the part to follow.

→ Clear need for detailed FEA in manufacturing process!

→ Mid section prototype done by 09/2021 + End section 10/2021

Initial metrology results: