Interface Documentation

ePIC Barrel ECAL Project

Abstract

This document will cover technical details on the Astropix Modules, AstroPix wafer quality control, End-of-Sector Board (EOSB), and Global Design interfaces.

Prepared by	*Checked by*	*Approved by*
Manoj Jadhav, Please add your name here (title.tex)		

Distribution List
title.tex to edit

History of Changes

Rev. No.	*Date*	*Pages*	*Description of changes*
Draft	11 April 2024	All	Draft
v0.1	11 April 2024	All	created the draft
v0.2	26 April 2024	6-7	Added calculations for Staves

Edit file history.tex to update this information

Contents

1 Introduction

The document will provide details on different interfaces for Barrel Imaging Electromagnetic Calorimeter (BIC) at electron-Proton/Ion Collider (ePIC) experiment at the Electron-Ion Collider (EIC). This document will cover technical details on the Astropix Modules, AstroPix wafer quality control, End-of-Sector Board (EOSB), and Global Design interfaces.

Part I

Global Design Interfaces

2 Global Design

Part II

AstroPix Module Interfaces

3 AstroPix Module

The Barrel Electromagnetic Calorimeter comprises two detector technologies: AstroPix, an HV-CMOS MAPS sensor, and Pb/SciFi. The AstroPix sensors are integrated into 4 barrel layers, sandwich between Pb/SciFi layers to construct an imaging part of the barrel ECAL.

The document will provide details on the AstroPix chip, Module design, Module electric schematic, Stave assembly, and interfacing with the end-of-stave FPGA card.

4 AstroPix Chip Specification

AstroPix is a low-power HV-CMOS monolithic active pixel sensor designed with 180 nm CMOS process technology. The AstroPix baseline performance requirements are listed in table 1, comprising effective area, angular resolution, and energy resolution.

Pixel size	500×500 μm^2
Chip size	2×2 cm^2
Power usage	1.5 mW/cm^2
Dynamic range	20keV -700 keV
Energy resolution	5 keV σ @ 122 keV
Time resolution	25 ns
Noise Floor	5 keV
Signal threshold	20 keV

Table 1: The expected specifications of AstroPix readouts.

4.1 AstroPix Version 5

Currently testing AstroPix versions 3 and 4. The specifications of versions 3 and 4 will be added later. Version 5 is under design process and will be available at the beginning of FY2025. The specifications of AstroPix version 5 are listed in table 2.

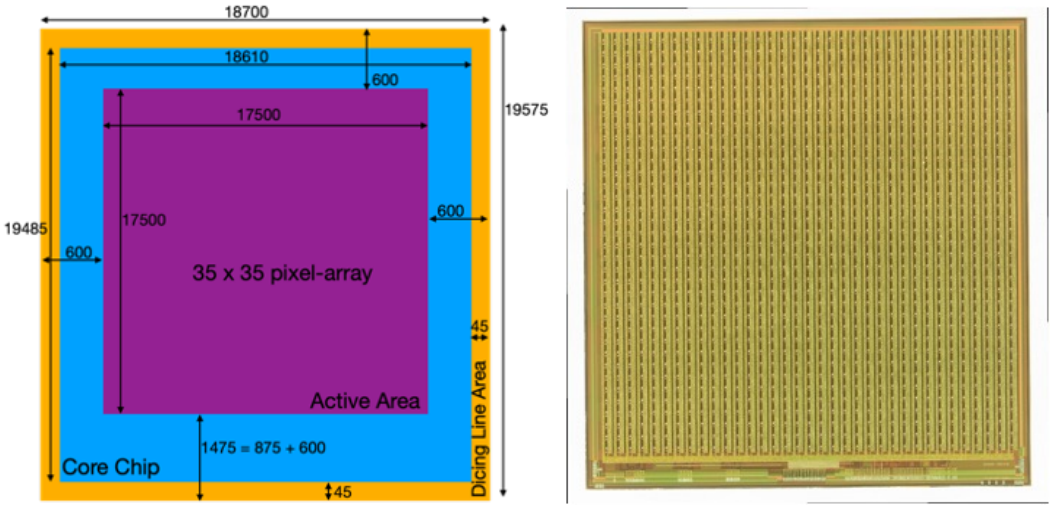


Figure 1: The AstroPix version 3 dimensions (left) and chip image (right). Version 5 dimensions match to the dimensions of version 3.

Pixel Pitch	500 μm (pixel size 300 μm)
Chip size	1.87 $\times$ 1.96 cm^2
Pixel matrix	35 $\times$ 33
Sensor thickness	525 μm
Power usage	1.63 mW/cm^2
Dynamic range	20keV -700 keV
Energy resolution	5 keV σ @ 122 keV
Time resolution	3.25 ns (25 ns without TDC)
Noise Floor	5 keV
Signal threshold	20 keV
Operating temperature (not tested)	-40 °C/+150 °C

Table 2: The specifications of AstroPix version 5.

Analog VDDA	1.8V
Analog VSSA	1.2V
Digital VDDD	1.8V
Analog Ground	GNDA
Digital Ground	GNDD
Sensor Reverse Bias Voltage	0 to 400V

Table 3: External supply voltage required of AstroPix version 5.

4.2 Digital Interface

AstroPix version 5 has pixel-by-pixel readout with 1 Hitbuffer assigned per pixel. Each column has an end-of-column buffer. There are 3 timestamp clocks: 15-bit course TimeStamp at 2.5 MHz, 3-bit fine TimeStamp at 20 MHz, and 16-bit flash TDC, which provides time

response and Time-Over-Threshold resolution of 3.125 ns. The comparator output is con-

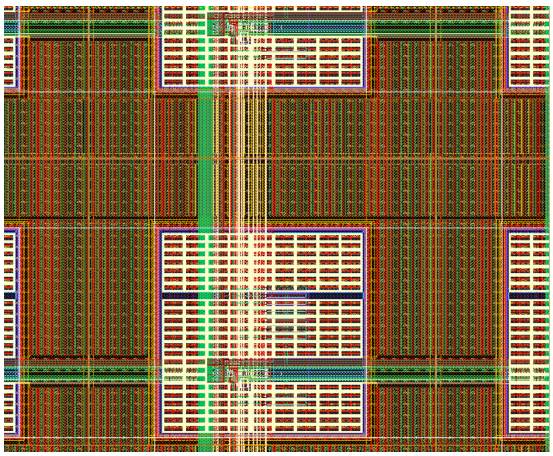


Figure 2: The pixel matrix structure for AstroPix with a pixel pitch of 500 μm and pixel nwell/implant size of 300 μm.

nected to Hitbuffer in the periphery. At the signal's first (falling) edge, coarse and fine TS are saved, and the Flash TDC is started. The TDC measures the exact difference from the falling edge to the next rising edge of the FineTS clk.

DaisyChain Protocol

The data streaming from End-of-tray-card (EOTC) to AstroPix and AstroPix to EOTC features a Header and Data format. The formats are different in two directions: EOTC to the chip (Module) configures AstroPix chips by writing data and AstroPix chip (Module) to EOTC only defines frames of data passing through the daisy chain with length. The command set is framed by the chip selection, some of the commands can be chained.

EOTC to Chip protocol:

bits

7	6	5	4	3	2	1	0
Command			Chip Address				

BIT	FIELD	DESCRIPTION
[4:0]	Address	Requires 20 single addresses - 0x00 - 0x14 : Single addresses - 0x15 - 0x1F : Reserved - 0x1D: Invalid - 0x1E: Broadcast
[7:5]	Command	8 Commands: - 0x01 - NOCMD / IDLE - 0x02 - Routing: dispatch addresses - 0x03 - Shift Register Config

IDLE Byte represents no specific command and an invalid address: 0x1D for address and 0x1 for IDLE -> **0x3D**

Figure 3: Hyder Bytes.

COMMAND	NAME	LENGTH	DESCRIPTION
0x01	NOCMD	1 Byte	Nothing to do
0x02	Address Config	1 Byte	Header Address represents the new address of the Chip Chip forwards command to the next chip with Address = Address + 1 To configure Addresses with first Chip “00”, send 0x40 to the first Chip, then send some IDLE bytes so that the Clock stays active and the addressing byte gets passed down the chain
0x03	Shift Register Config	N Bytes	Once this command is send, the whole SPI Frame is used - SPI Chip Select must be deasserted and reasserted to send a new command

Figure 4: Commands to AstroPix Chip.

Chip to EOTC protocol:

bits

7	6	5	4	3	2	1	0
Chip Address					Payload Length		

- Chip Address is the Configured Chip ID using the routing byte
- The PayloadLength is the number of bytes trailing the header

Hit Packet Type

At the moment we only need 1 Packet type:

bytes

0	1	2	3	4	5	6	7
Header	Row<0:5>,Col<0:1>	Col<2:5>,TSFromDet<0:3>	TSFromDet<4:11>	TSFromDet<12:14>,TSFromDet2<0:4>	TSFromDet2<5:12>	TSFromDet2<13::14>,TSFine<0:2>,TSFine<0:2>	TSTDC1<0:3>, TSTDC2<0:3>

Figure 5: Data Format from the Chip.

AstroPix version 5 will have 1x8 Bytes. Right now, they can be reduced by on-chip subtraction. As shown in figure 5 the data bytes can be decoded as,
8b Header,
6b Row,
6b Col,
15b TS,
15b + 2x(4b + 3b) ToT.

4.3 Digitization Data Rate

The whole Chip triggers at 10Hz. Only one counter per row/column with 8 Bytes. With Chip array of 36 × 36 and 500 μm Pixels there are around 1300 Pixels.
1300 * 8 Bytes Data = 10400 Bytes
Protocol including daisy chain etc.. = 50% overhead i.e. +5200 Bytes
Total = 15600 Bytes /s / chip
Pixelator: 1 Chip, Full Module with 9 chips = 9 * Pixelator = 9 Chips
For one Module: 9 × 15600 = 140 kByte/s

The maximum expected rate for Barrel Ecal using the following table 4:
Avg hit rate/pixel [1/s] is 5.68E-02, so for a chip it is 70 hits and for a Module it is 840
Considering double the hits per module, it is 1680
The expected data rate for a Module is 1680*8 bytes = 13.44 kBytes/s.

Data rate for Barrel ECAL

Integration time [s]	6.00E-06
Nb of pixels	5.28E+08
Total rate [1/s]	3.00E+07
Avg hit rate/pixel [1/s]	5.68E-02
Propablility of getting hit twice	1.94E-08
Propablility of getting hit twice for entire detector	1.02E+01
Drop rate for the entire detector	3.41E-07
Nb of hits with one drop	2.93E+06

Table 4: Data hit rate

The expected hit rate for all imaging layers together Low rates is well below $<$ 30 MHz
This translates to a maximum hit rate per tracker stave (1 x 108) $<$ 36 kHz

This draft will also add more information about module design, electrical interface and power numbers. This information can temporarily be accessed at link here

4.4 AstroPix Chip Final Dimensions

Final size of the AstroPix chip reticle will be 2 cm $\times$ 2 cm. It will have pixel-by-pixel flash-TDC to provide fast time response with individual tune-DAC for the pixel tuning. Table 5 provide details of physical dimensions of AstroPix chip considered for the imaging layers of Barrel Electromagnetic Calorimeter at the ePIC.

Final chip size	2 cm $\times$ 2 cm^2
Pixel Pitch	500 μm (pixel size 300 μm)
Pixel matrix	39 $\times$ 37
Sensor thickness	525 μm
Dicing line clearance	45 μm
Pixel to chip edge distance	205 μm

Table 5: Physical dimensions of final AstroPix chip.

This dimension provides full coverage along the stave length spanning the length of 218.16 using 12 modules with 9 chips each. The current AstroPix dimension is shorter than final dimensions and hence requires a design respin after version 5 has been tested.

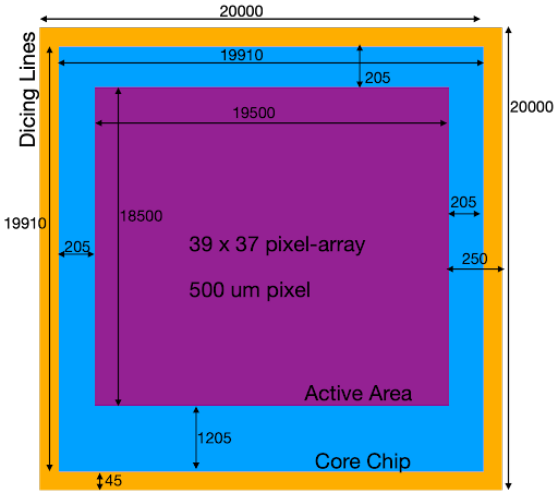


Figure 6: The AstroPix final dimensions.

Each module will have 9 chips with intermediate gap of 200 μm. The module length is 18.11 cm with full stave length is 218.16 cm. The number of chips and modules are calculated by following consideration,

Total BIC length = 440 cm
Length to cover with single stave = 220 cm
AstroPix size + gap = 2.02 cm
Number of chips required = 220/2.02 = 108.91
Round of number for required chips = 108 chips/stave
Which leads to 9 chips and 12 modules

The next section will describe Mechanical considerations of the module and stave designs.

5 Mechanical Structure Design

The imaging part of calorimetry has 4 layers of low-power HV-CMOS MAPS sensors, AstroPix. Layer numbers 1, 3, 4, and 6 will be integrated with AstroPix chips.

5.1 Total Active Area Calculations

This section calculates the active area on the Tray (along with the length and width).

5.1.1 Along the Tray length

Along the stave, we have a 20 mm AstroPix chip with an in-between gap of 0.2 mm (0.1 mm to stay within 435 cm). The active length on the chip is 19.5 mm (39 pixels).

0.2 mm gap between adjacent chips -
Length of the Stave = 20.2*108 = 2181.6 mm = 218.16 cm
Length of the Calorimeter = 2*2181.6 mm = 4363.2 mm = 436.32 cm
Active chip array length = 19.5 mm
Inactive area on chip = 0.5 mm
Inactive area in-between two chips = 0.2 mm
Active area percentage = Active area / Total detector area = 19.5/20.2 = **96.53**%
Inactive area percentage = 0.7/20.2 = 3.47%.

0.1 mm gap between adjacent chips -
Length of the Stave = 20.1*108 = 2170.8 mm = 217.08 cm
Length of the Calorimeter = 2*2170.8 mm = 4341.6 mm = 434.16 cm
Active chip array length = 19.5 mm
Inactive area on chip = 0.5 mm
Inactive area in-between two chips = 0.1 mm
Active area percentage = Active area / Total detector area = 19.5/20.1 = **97.01**%
Inactive area percentage = 0.6/20.2 = 2.97%.

5.1.2 Along the Tray width

In this direction, the chip and module will have considerable inactive areas. The calculation below provides numbers to minimize the dead area in this direction.

Active chip array length = 18.5 mm
Inactive area on top side = 0.25 mm
The inactive area on the bottom side (digital periphery) = 1.25 mm
Total inactive area on chip = 1.5 mm
The inactive area on the Module at the top of the chip = 0 mm
The inactive area on the Module at the bottom of the chip = 0 cm
Module flex will carry the bus bar (data and power lines) as well as power regulation circuitry.

Unavoidable dead area at top = Dead area on the (Chip + Module) = 0.25 + 0.0 mm.
Total unavoidable dead area = 0.5 mm. (Keeping top side outward on each sidewall)

There will be 4 Imaging layers in the Barrel Electromagnetic Calorimeter (BIC). Appendix xx provides design geometry for the BIC Sector.

Available space for imaging layers is,
Layer 1: 107.257 mm
Layer 3: 117.411 mm
Layer 4: 122.488 mm
Layer 6: 132.642 mm

Targeting minimum dead space in the detector acceptance region, the stave at one end of the Tray will be flipped to align the minimum inactive area edge of the chip with the side wall.
The calculation shows the number of staves required to cover Tray with the minimum inactive area possible.

The AstroPix detector Staves are arranged to provide maximum active area along the beam direction and in a barrel region.

Layer 1: 107.257 mm
Number of Staves = (107.257-0.5)/18.5 = 106.757/18.5 = 5.77 → **6 Staves**
Total active length available = 18.5*6 = 111 mm
Additional **overlap** needed to fit 6 Chips (in addition to 1.25 mm at the bottom and 0.25 at the top) = 111 - 106.757 = 4.243 mm
Additional overlap per Stave = 4.243/6 = 0.707 mm

Total dead area percentage = 0.5/107.257 = 0.47%

Layer 3: 117.411 mm
Number of Staves = (117.411-0.5)/18.5 = 116.911/18.5 = 6.3195→ **6 Staves or 7 Staves?**

- 6 Staves:
Total active length available = 18.5*6 = 111 mm
Additional **dead** space = 116.911 - 111 = 5.911 mm
Additional dead area per Stave = 5.911/6 = 0.9852 mm

Total dead area percentage = (5.911+0.5)/117.411 = 5.46%

- 7 Staves:

Total active length can be available = 18.5*7 = 129.5 mm

Additional **overlap** needed to fit 7 Chips = 129.5 - 116.911 = 12.589 mm

Additional overlap per Stave = 12.589/7 = 1.7984 mm

Total dead area percentage = 0.5/117.411 = 0.43%

Layer 4: 122.488 cm

Number of Staves = (122.488-0.5)/18.5 = 121.988/18.5 = 6.5939 → **6 or 7 Staves?**

- 6 Staves:

Total active length can be available = 18.5*6 = 111 mm

Additional **dead** space = 121.988 - 111 = 10.988 mm

Additional dead area per Stave = 10.988/6 = 1.831 mm

Total dead area percentage = (10.988+0.5)/122.488 = 9.38%

- 7 Staves:

Total active length can be available = 18.5*7 = 129.5 mm

Additional **overlap** needed to fit 7 Chips = 129.5 - 121.988 = 7.512 mm

Additional overlap per Stave = 7.512/7 = 1.073 mm

Total dead area percentage = 0.5/12.2488 = 0.41%

Layer 6: 132.642 mm

Number of Staves = (132.642-0.5)/18.5 = 132.142/18.5 = 7.1428 → **7 Staves or 8 Staves?**

- 7 Staves:

Total active length available = 18.5*7 = 129.5 mm

Additional **dead** space = 132.142 - 129.5 = 2.642 mm

Additional dead area per Stave = 2.642/7 = 0.3774 mm

Total dead area percentage = (2.642+0.5)/132.642 = 2.37%

- 8 Staves:

Total active length can be available = 18.5*8 = 148 mm

Additional **overlap** needed to fit 8 Chips = 148 - 132.142 = 15.858 mm

Additional overlap per Stave = 15.858/8 = 1.982 mm

Total dead area percentage = 0.5/132.642 = 0.38%

Table 6: Summary of AstroPix coverage (layer 6 - 7 Staves).

Layer#	Length (mm)	# Staves	Overlap or Inactive (mm)	Overlap/Inactive per Stave (mm)	Overlap/Inactive per Gap (mm)	Inactive (%)
1	107.257	6	4.243	0.707	0.8486	0.47
3	117.411	7	12.589	1.7984	2.0982	0.43
4	122.488	7	7.512	1.073	1.252	0.41
6	132.642	7	2.642	0.3774	0.4403	2.37

Table 7: Summary of AstroPix coverage (layer 6 - 8 Staves).

Layer#	Length (mm)	# Staves	Overlap or Inactive (mm)	Overlap/Inactive per Stave (mm)	Overlap/Inactive per Gap (mm)	Inactive (%)
1	107.257	6	4.243	0.707	0.8486	0.47
3	117.411	7	12.589	1.7984	2.0982	0.43
4	122.488	7	7.512	1.073	1.252	0.41
6	132.642	8	15.858	1.982	2.2654	0.38

Table 8: Summary of AstroPix all coverage calculations.

Layer#	Length (mm)	No. of Staves	Inactive (mm)	Overlap (mm)	Overlap or Inactive per Stave (mm)	Total Inactive (%)
1	107.257	6	-	4.243	0.707	0.47
3	117.411	6	5.911	-	0.9852	5.46
		7	-	12.589	1.7984	0.43
4	122.488	6	10.988	-	1.831	9.38
		7	-	7.512	1.073	0.41
6	132.642	7	2.642	-	0.3774	2.37
		8	-	15.858	1.982	0.38

5.2 Stave integration in imaging layers

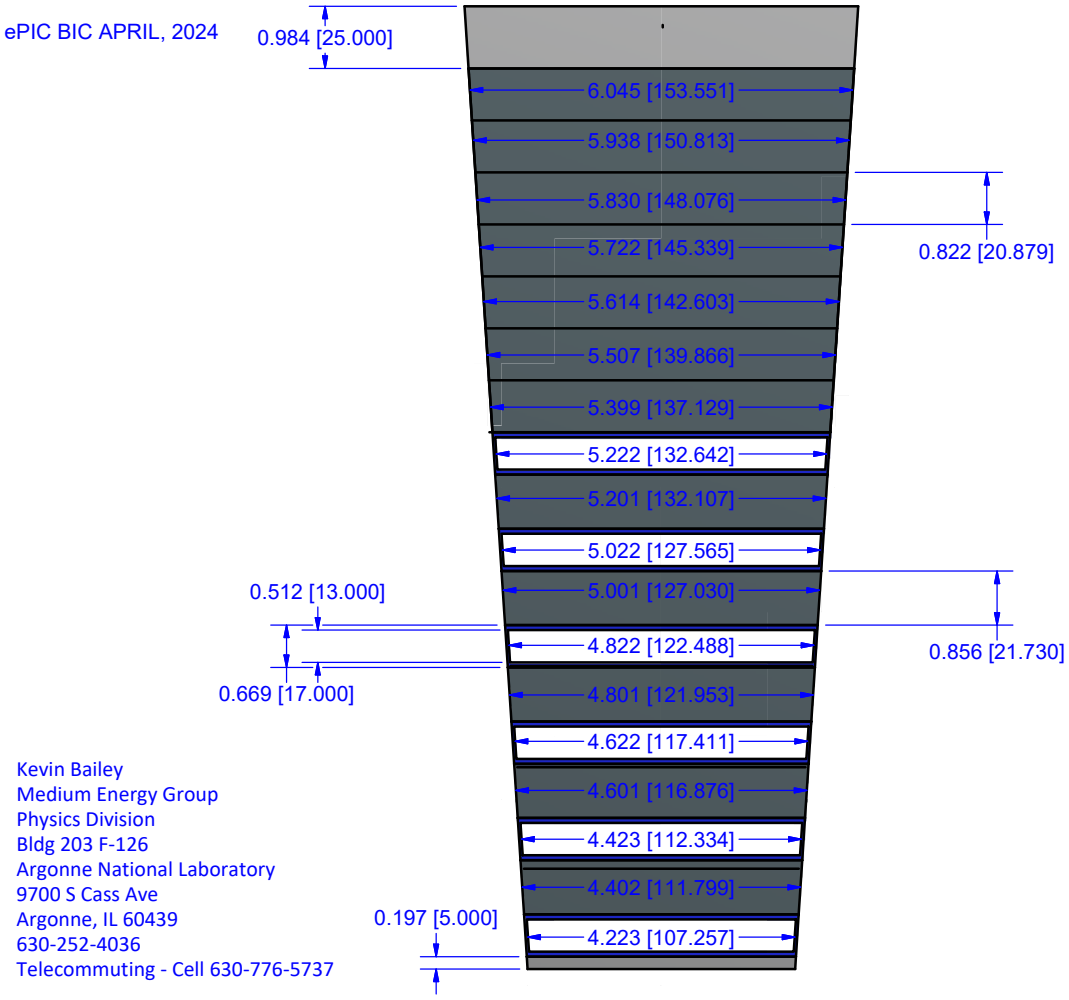
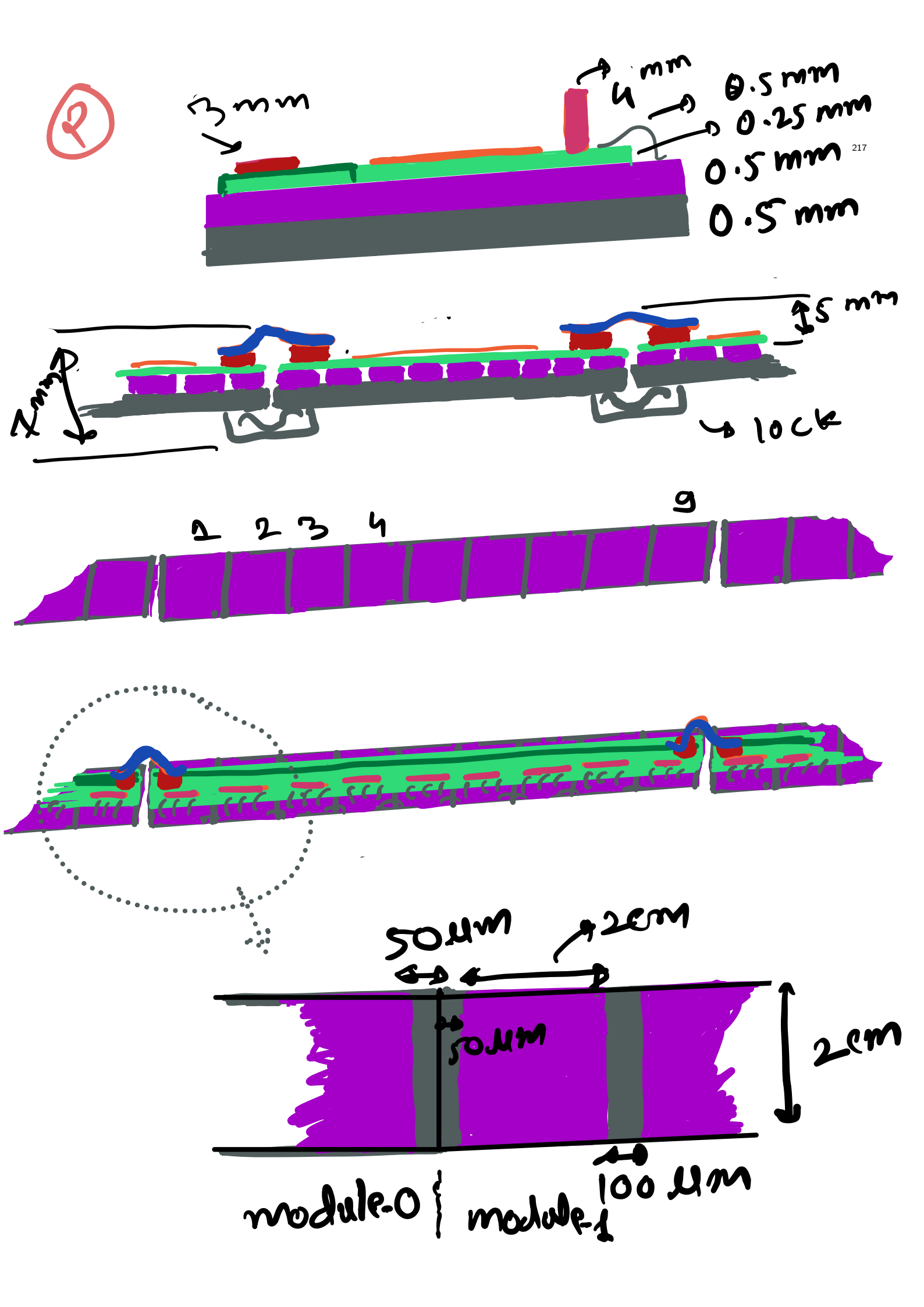


Figure 7: AstroPix Tray envelope for BIC layers.

5.3 Module Mechanical Design


3 mm
4 mm
0.5 mm
0.25 mm
0.5 mm
0.5 mm
5 mm
2 mm
10 cm
1 2 3 4 9
50 μm
2 cm
50 μm
2 cm
100 μm
module-0
module-1

AstroPix chip - 2cm x 2 cm (0.5 mm)

Al module Carrier (0.5 mm)

width → 2cm

length 2.01 * 9 = 18.09 cm

{ will have some locking systems on back — 1mm height }

Flex Bus bar / PCB (0.25 mm)

width → 18.5 mm

length → 18.09 cm

→ Bus Bar / Power-data lines

width → 8.5 mm

→ Bus Bar PCB

Power regulation (LDO)

4 traces to wirebond

width → 10 mm

→ module-to-module connector (3 mm)

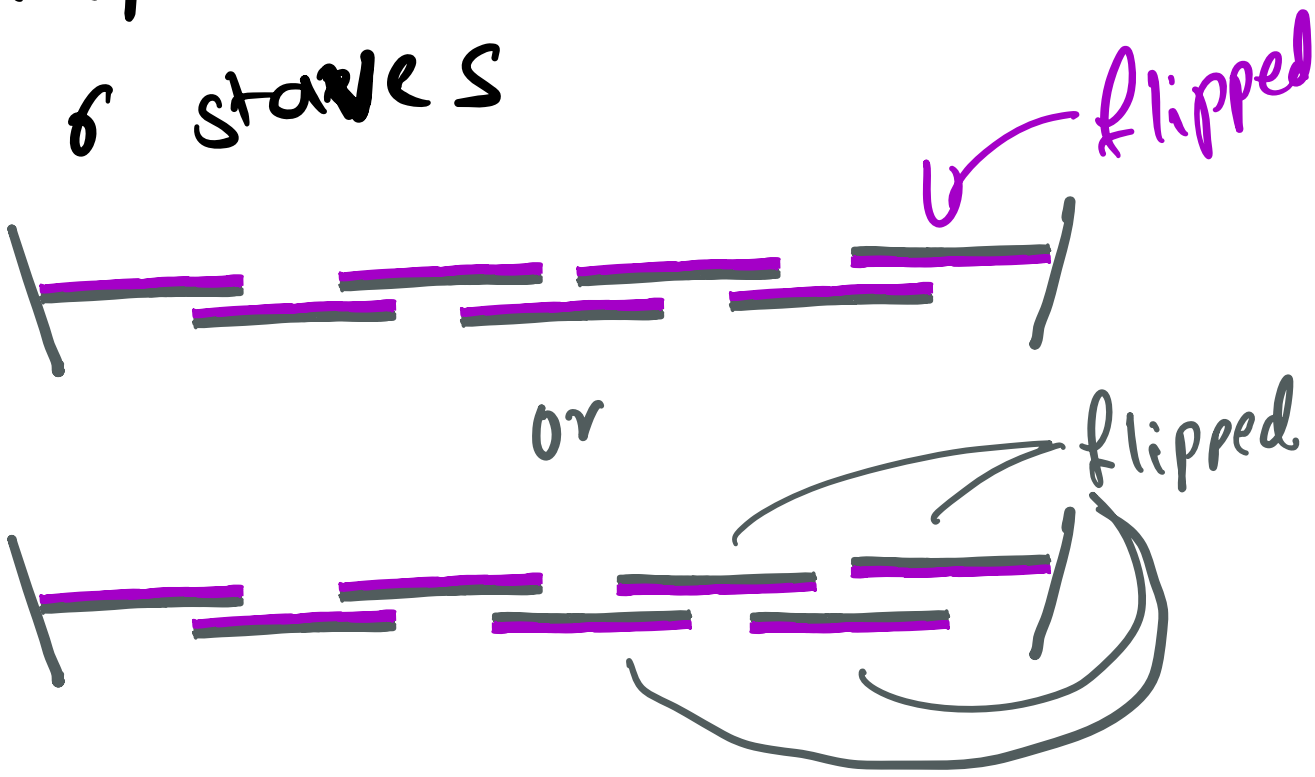
– module to module Pigtail (1.75 mm)

→ wirebond protector (4 mm)

---

layer-1 (107.257 mm)

6 staves



AstroPix Module Interfaces

220

Module Mechanical Design:

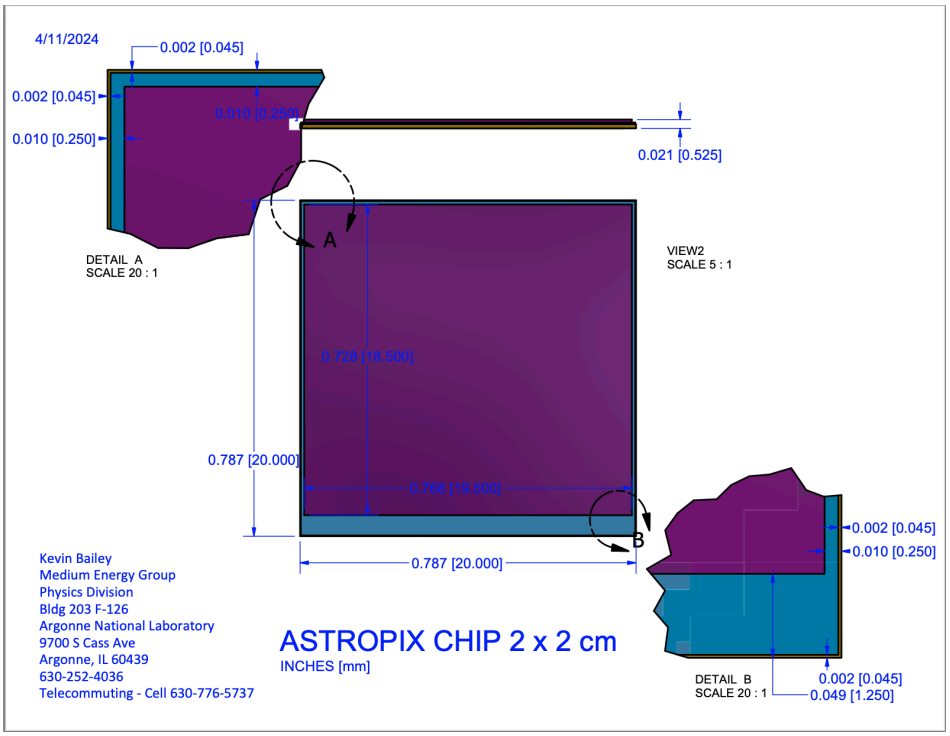
The imaging part of calorimetry has 4 layers of low-power HV-CMOS MAPS sensors, AstroPix. Layer numbers 1, 3, 4, and 6 will be integrated with AstroPix chips

- ~ 2 cm x 2 cm chip area
- 100 um gap between two chips
- 9 chips per module
- 12 modules per stave
- 6 or 7 staves per tray
- 12 or 14 staves per layer (first 3 layers have 12 staves and 4th have 14 staves)
- 54 staves per sector
- Total 48 sectors

- Total number of AstroPix chips = 9*12*54*48 = 279936

BaseLine Detector Coverage

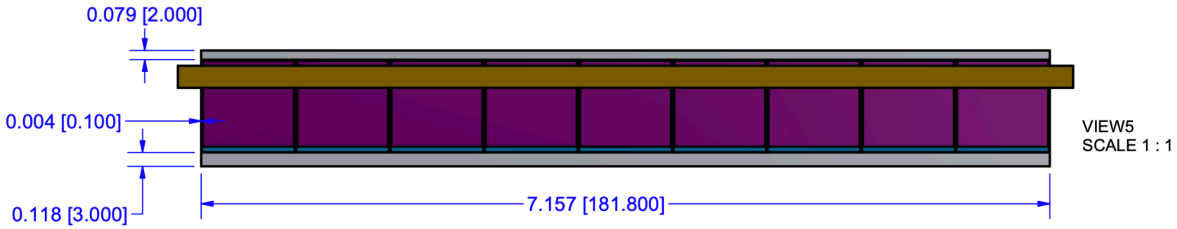
- New baseline module layout: 12 modules of 9 chips
- Length assuming 100 μm gap and 2cm chips: 2.01 cm x 12 x 9 x 2 = 434.16 cm
- Sector length:
    - 434.16 cm (no longer than 440 cm as the upper limit)
- End-of-sector box length:
    - 15 cm (keep at least 2 cm reserved for connectors)

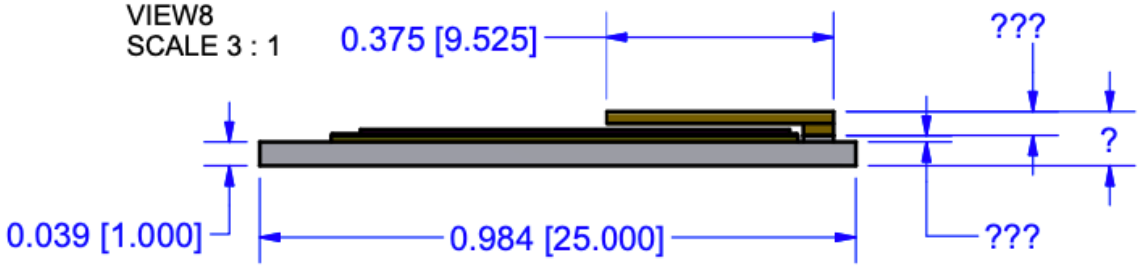


AstroPix Module Interfaces

221

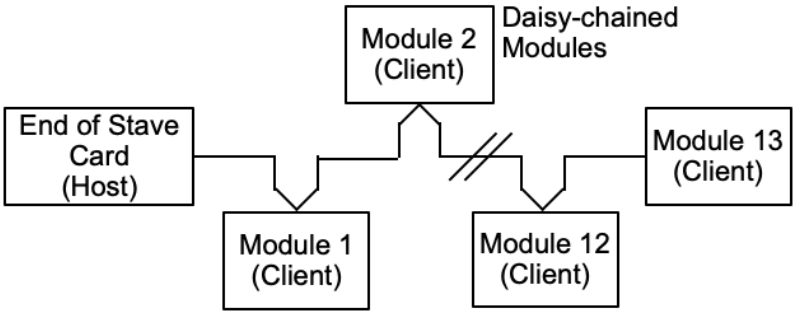
Initial Module Design





Stave length

Electrical Interfaces:



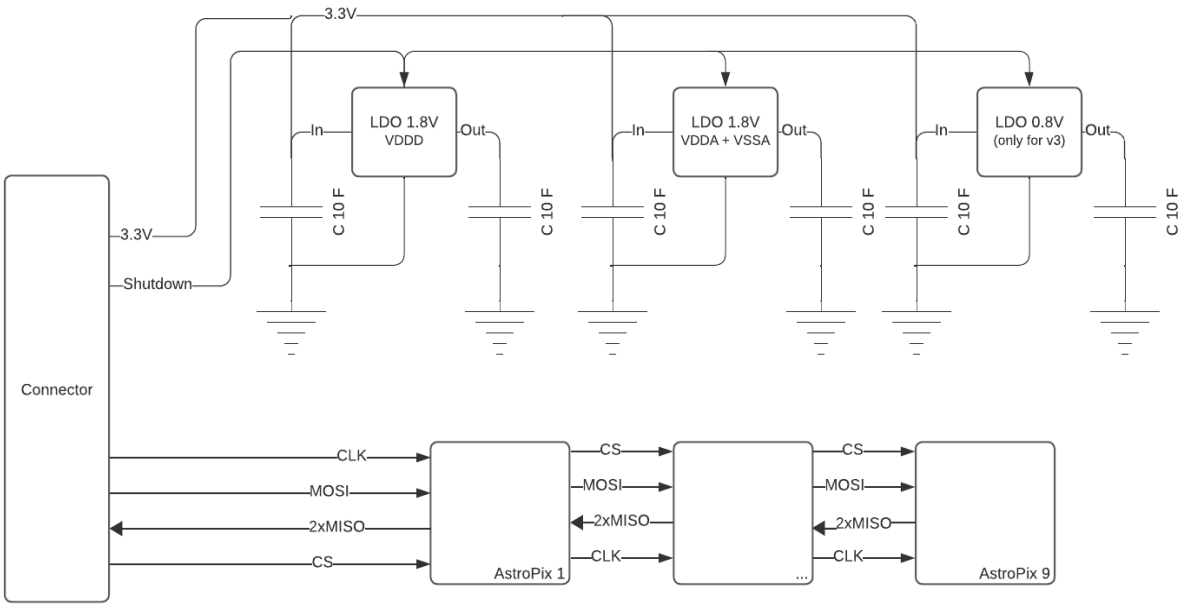
- Daisy Chain on the Module and Module will directly take command and stream data to EOSC
- What are our options?
    - Differential SPI (KIT confirmed - ePIC meeting)
    - Multi-drop data transmission using flex bus

AstroPix Module Interfaces

- Power distribution on bus bar or cable harness
- Daisy-chained chips on the module will be parallel to chips on other modules.
- Host End-of-Stave will connect to Client Modules through a daisy-chain (LVDS on Modules)

- Module enable control
  - Allows to control Module operation individually
  - This will allow to save stave by switching off bad Module

Electric Block Diagram for Module



LDOs

LT3041, LT3097, or LT3045

Connectors

Right angle connectors:
the Samtec connector series Edgerate (ERM8), Razor Beam(LSHM), or the TigerEye series

Vertical Connectors:
- Need inputs

🗀 AstroPixModule datasheets of LDOs and Connectors.

AstroPix Module Interfaces

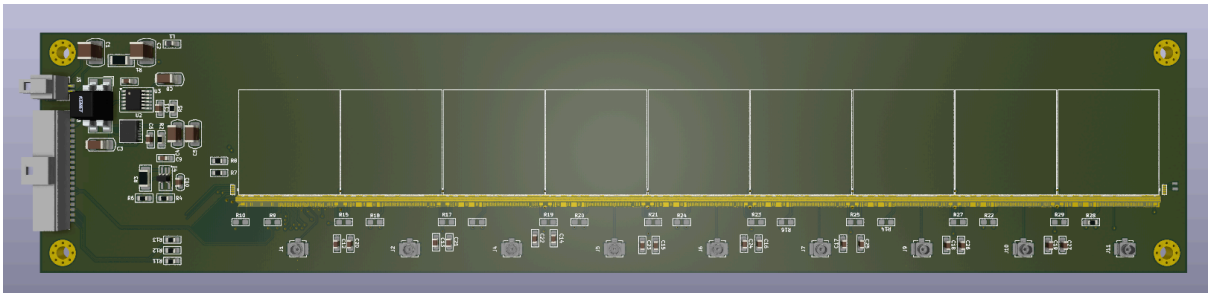
Bus Bar and Cable Harness:

- Pending

223

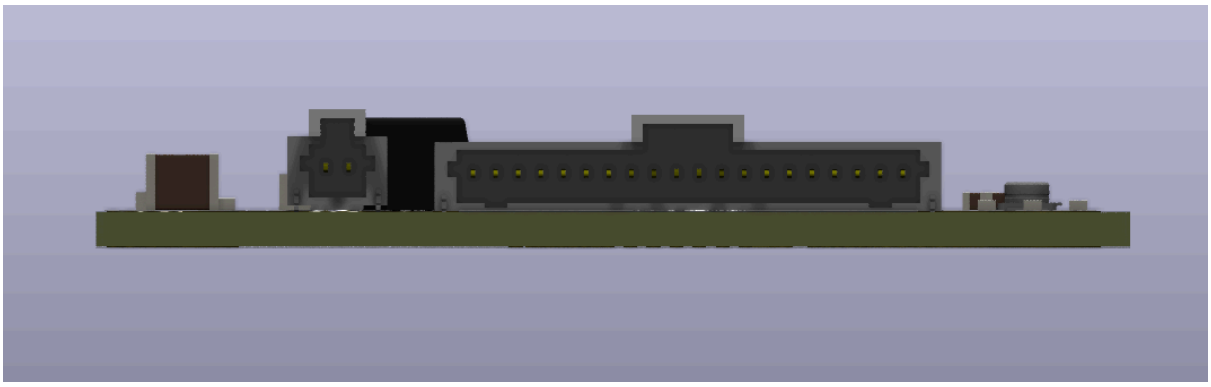
PCB board design:

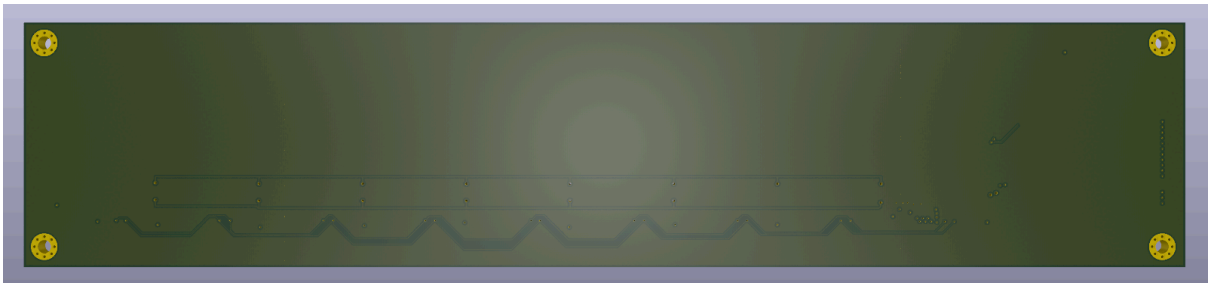
Module PCB Test Board -



AstroPix Module Interfaces

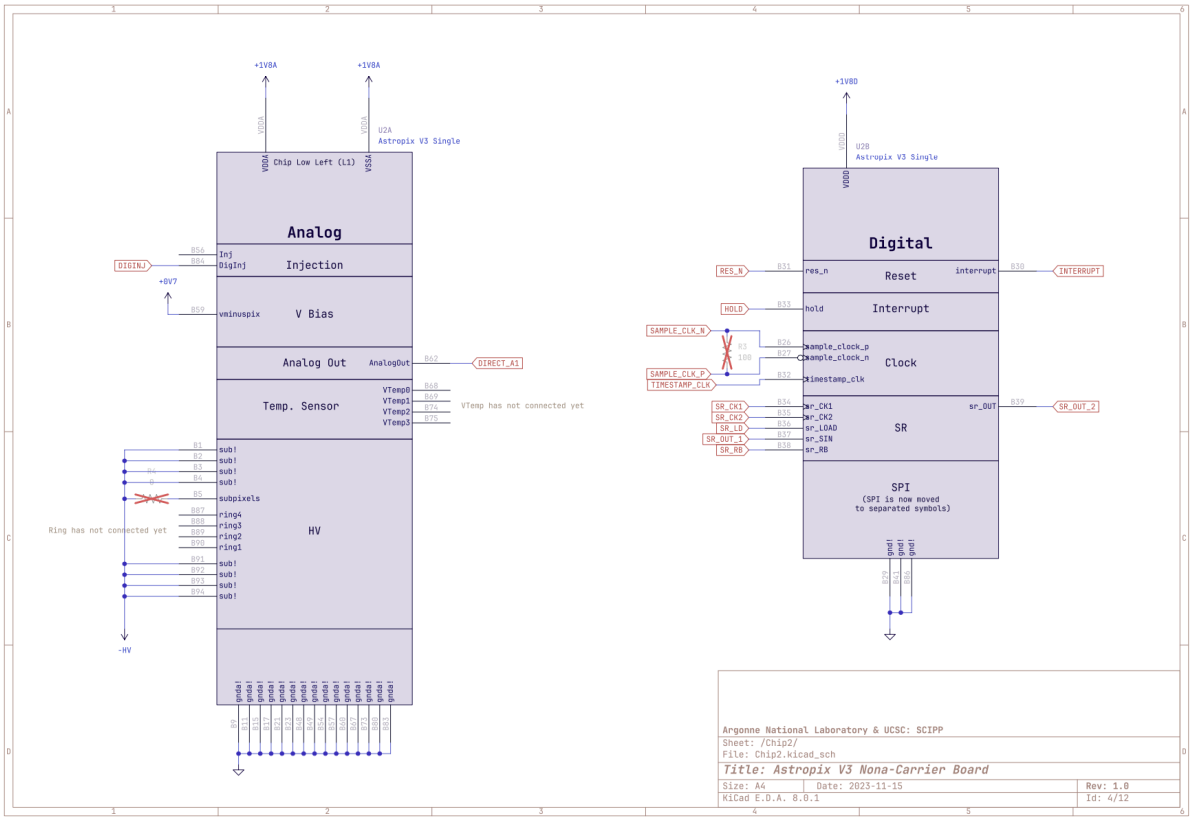
224





AstroPix Module Interfaces

Module PCB Schematic

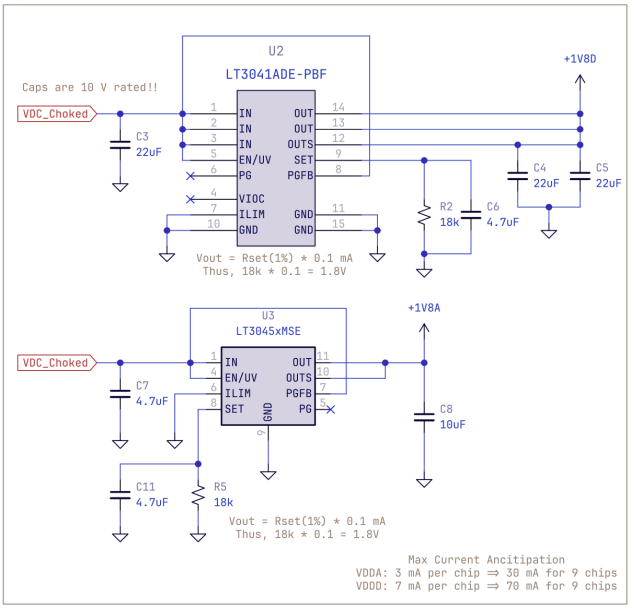


AstroPix Module Interfaces

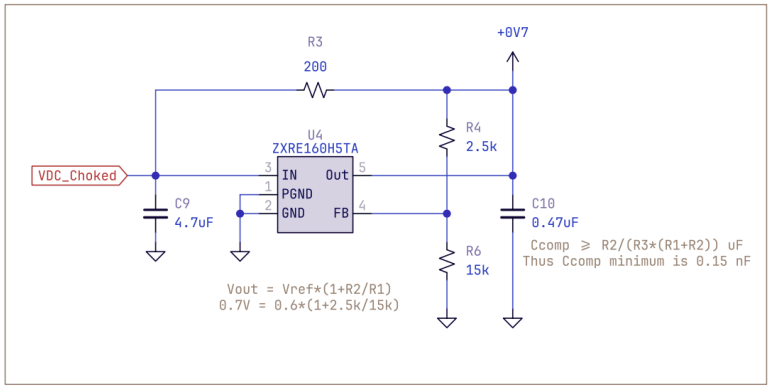
226

Voltage regulators for VDDD and VDDA

- LT3041ADE and LT3045xMSE



Voltage Regulator for Vminuspix 0.7V - will be removed in next iteration



Pin Outs

AstroPix Module Interfaces

Usage	V3	V-final
Power	HVin	HVin
	GND	GND
	VDCIN	VDCIN
SPI	MISO0	MISO0
	MISO1	MISO1
	CSN	CSN
	CLK	CLK
	MOSI	MOSI
Sample Clk	SAMPLE_CLK_P	SAMPLE_CLK_P
	SAMPLE_CLK_N	SAMPLE_CLK_N
Shift Register	SR_Ck1	
	SR_Ck2	
	SR_LD	
	SR_SIN	
	SR_RB	
	SR_OUT	
Other	DIGINJ	
	INTERRUPT	
	TIMESTAMP_CLK	TIMESTAMP_CLK
	Hold	
	RES_N	

227

AstroPix Power Consumption:

AstroPix v3	1.87cm x	3.66	cm2			

AstroPix Module Interfaces

	1.95cm					
	Per Chip					
Supply	Voltage (V)	Current (mA)	Power (mW)	Power (mW/cm2)	Power per Module (mW)	Power per Stave (mW)
VDDA Analog	1.8	1.47	2.65	0.72	23.85	286.2
VSSA Analog	1.2	1.33	1.6	0.44	14.4	172.8
VDDD Digital	1.8	6.88	12.24	3.34	110.16	1321.92
		Total	16.49	4.51	148.41	1780.92
AstroPix v final	2cm x 2cm	4	cm2			
(expected)	Per Chip					
Supply	Voltage (V)	Current (mA)	Power (mW)	Power (mW/cm2)	Power per Module (mW)	Power per Stave (mW)
VDDA Analog	1.8	2.4	4.32	1.08	38.88	466.56
VSSA Analog	1.2	0	0	0	0	0
VDDD Digital	1.8	1.67	3	0.75	27	324
		Total	7.32	<1.83	65.88	790.56

Part III

End-Of-Sector Board (EOSB) Interfaces

7 EOSB

Part IV

AstroPix Wafer Quality Control

8 AstroPix Wafers

Part V

Appendices

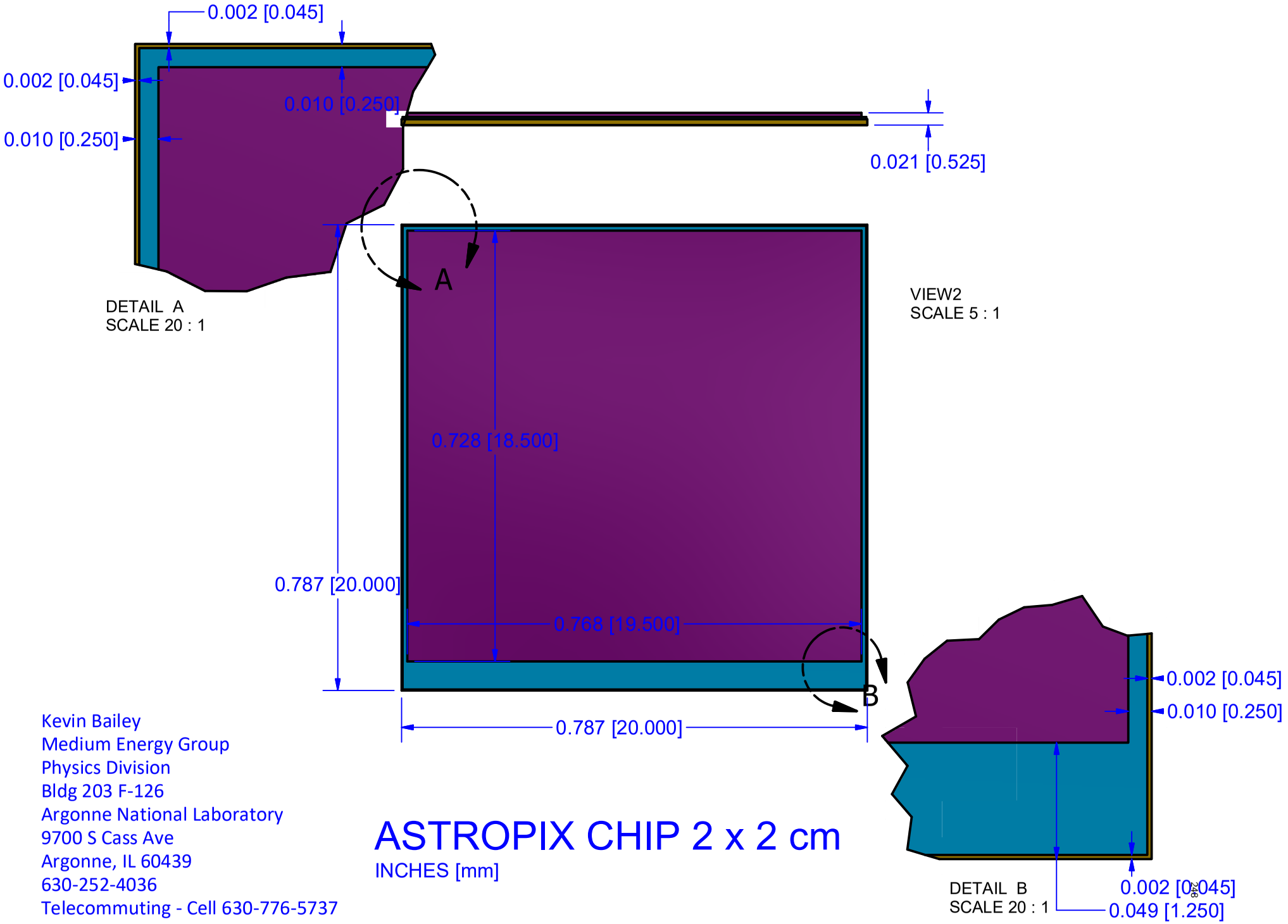
A Global Design Interfaces

A.1 Starts with subsection

B AstroPix Module Interfaces

B.1 AstroPix Module Design CAD Drawings

APRIL 23 2024

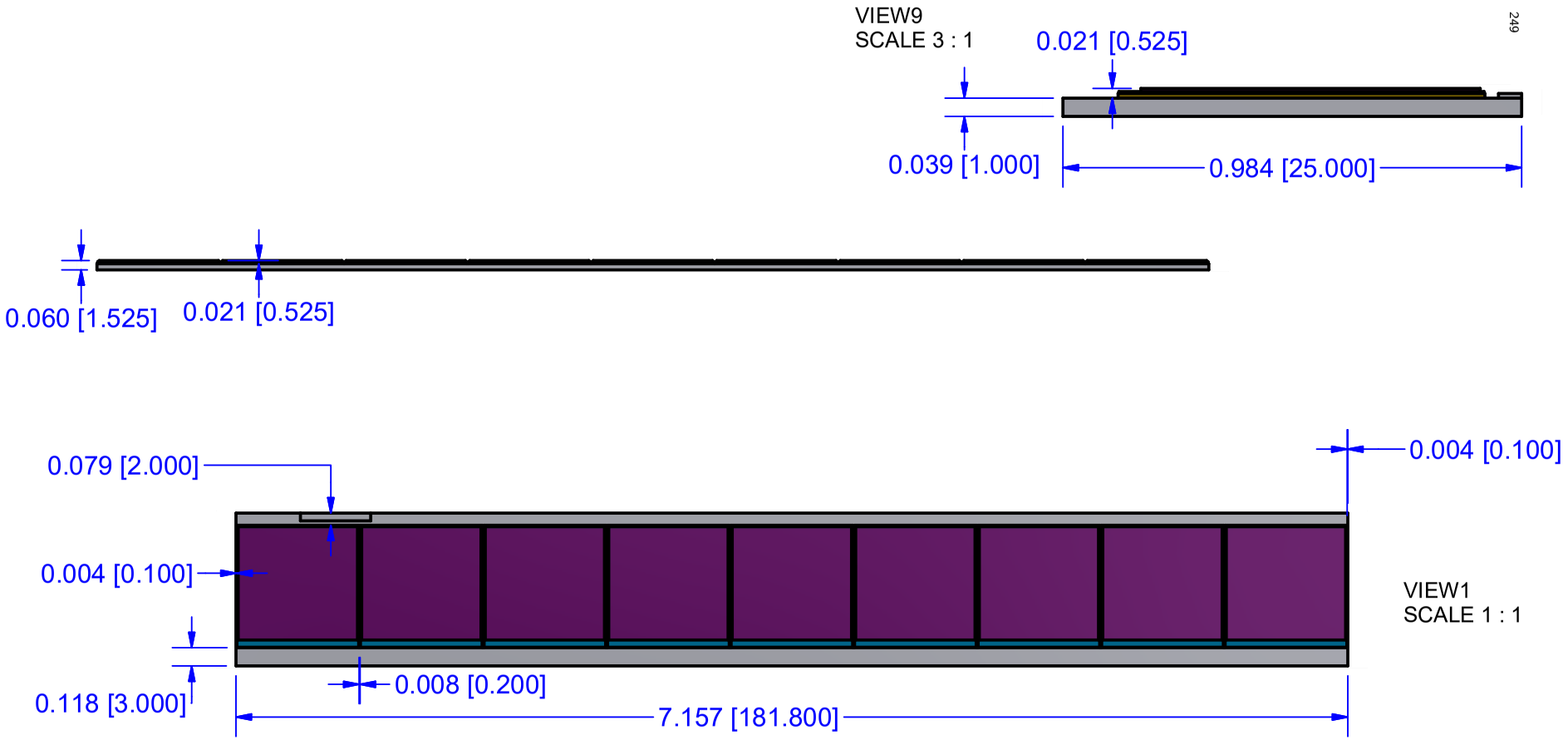


Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

ASTROPIX CHIP 2 x 2 cm

INCHES [mm]

APRIL 23 2024

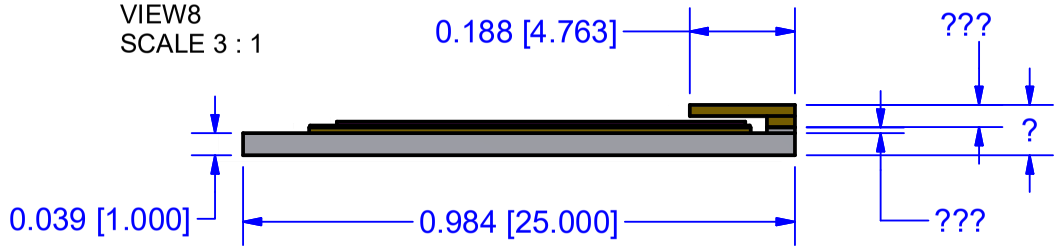


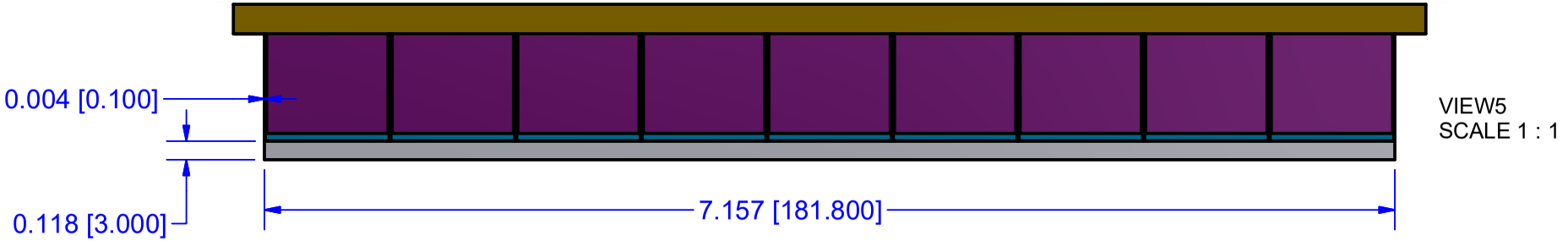
Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

ASTROPIX 2 x 2 cm W/O BUS TAPE

INCHES [mm]

APRIL 23 2024



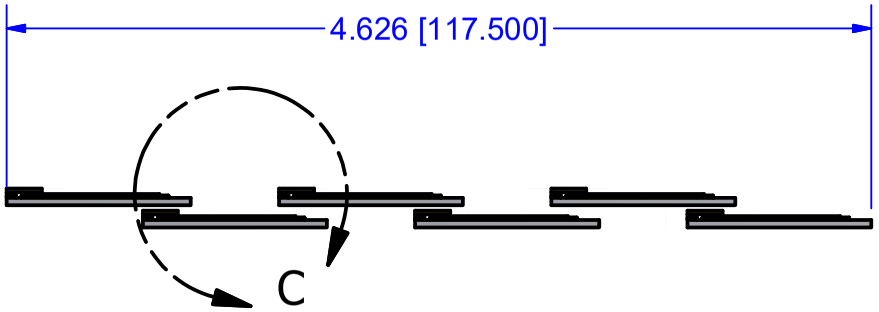


Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

ASTROPIX 2 x 2cm W/ BUS TAPE

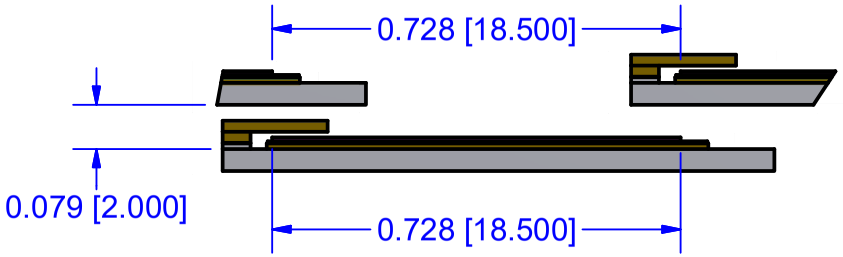
INCHES [mm]

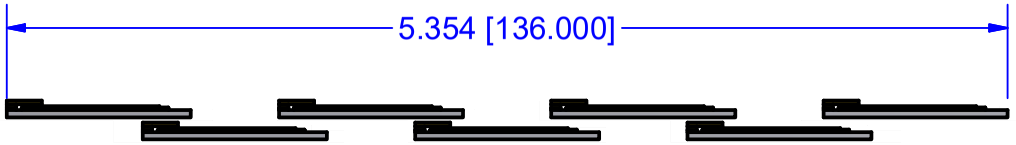
APRIL 23 2024



SIX MODULES WIDE

DETAIL C
SCALE 3 : 1





SEVEN MODULES WIDE

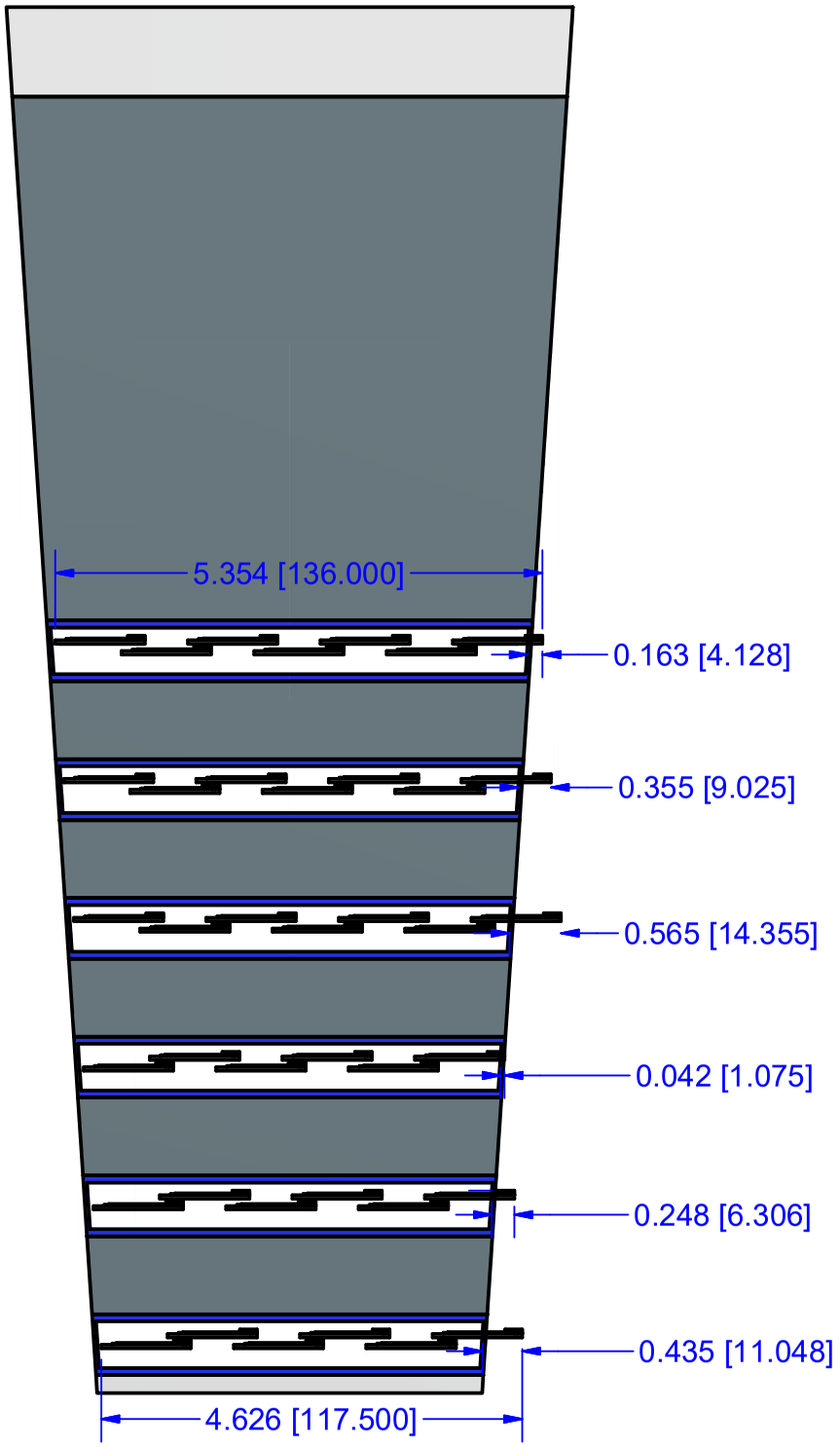
Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

APRIL 23 2024

Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

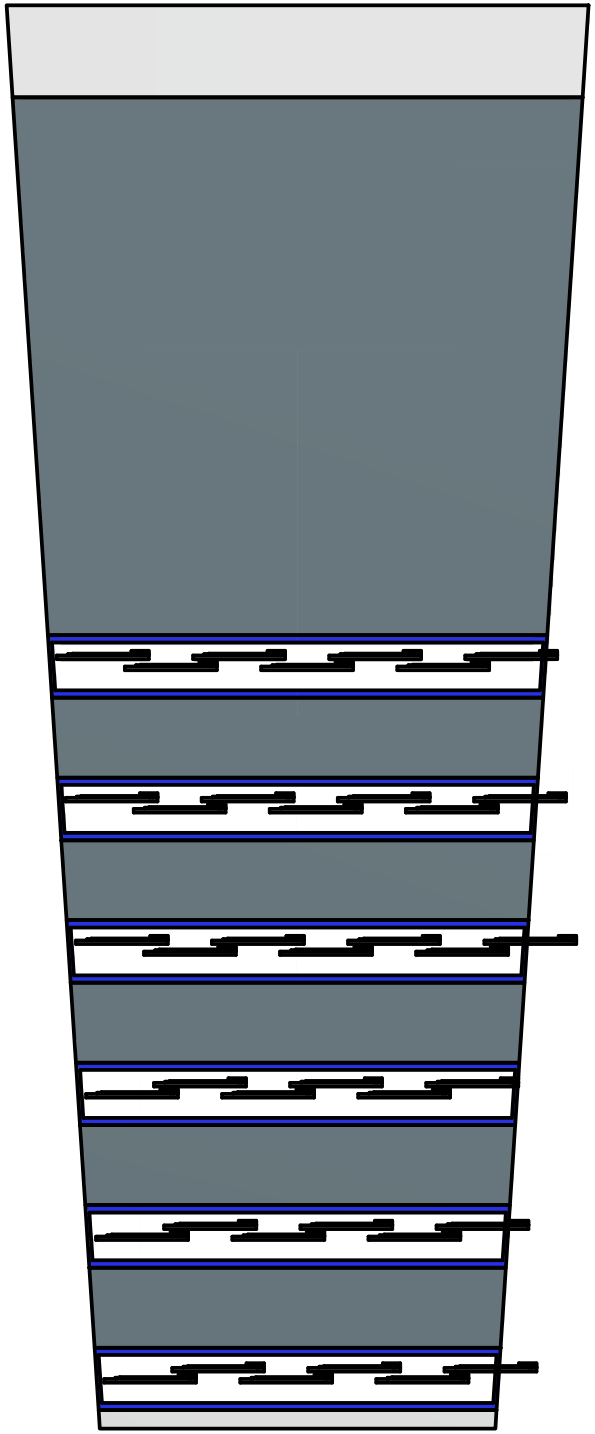
ASTROPIX 2 x 2cm STAVE -13 MODULES

13 MODULES ARRAY
INCHES [mm]



Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

APRIL 23 2024



Kevin Bailey
Medium Energy Group
Physics Division
Bldg 203 F-126
Argonne National Laboratory
9700 S Cass Ave
Argonne, IL 60439
630-252-4036
Telecommuting - Cell 630-776-5737

C End-Of-Sector Board (EOSB) Interfaces

C.1 Starts with subsection

D AstroPix Wafer Quality Control

D.1 Starts with subsection