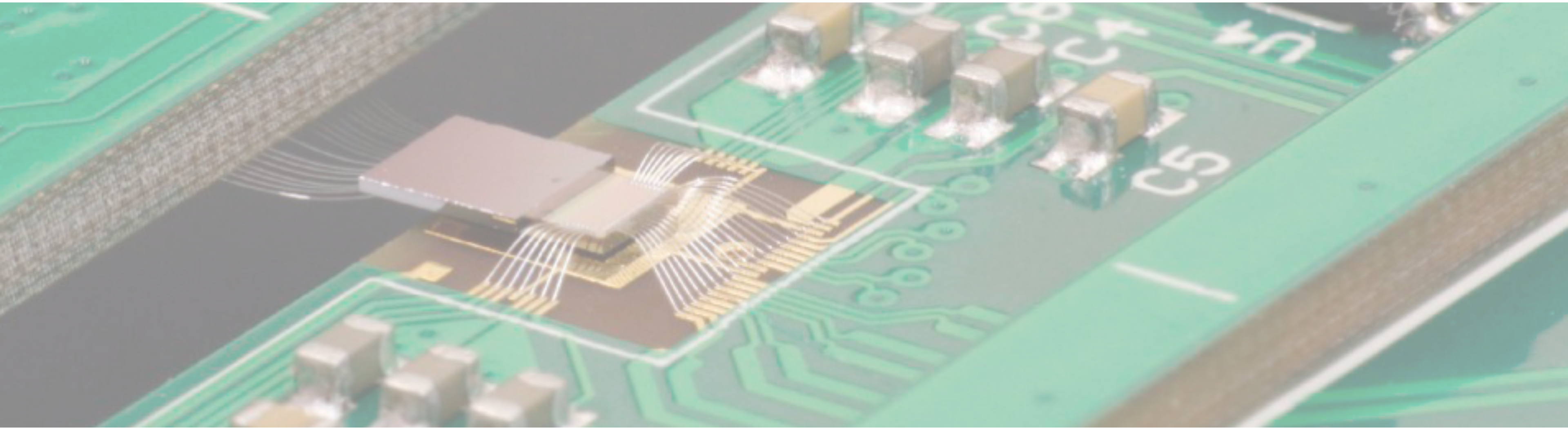
HV-CMOS Coupling Simulation*

* Updated on Sept 27th



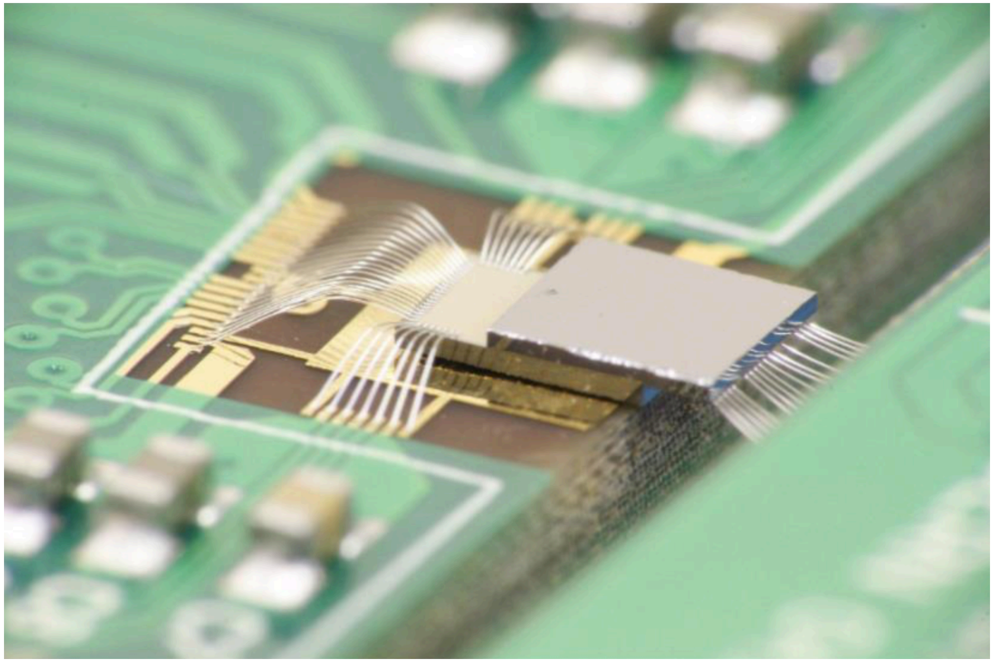
CLICpix + CCPDv3. Szymon Kulis - http://skulis.web.cern.ch/skulis/clicpix/

CLICdp Workshop
31/08/2016

Mateus Vicente

Outline

- Introduction to Capacitive Coupling
  - Detector assembly
- Objective
  - Find coupling between pixels
    - Maxwell Capacitance Matrix
  - Simulate existing chips
    - Understand observed performance
  - Simulate new chips
    - Optimize design
- Simulation
  - Physics model
  - COMSOL Multiphysics
  - Geometry
- Results
  - and discussion
- Conclusions

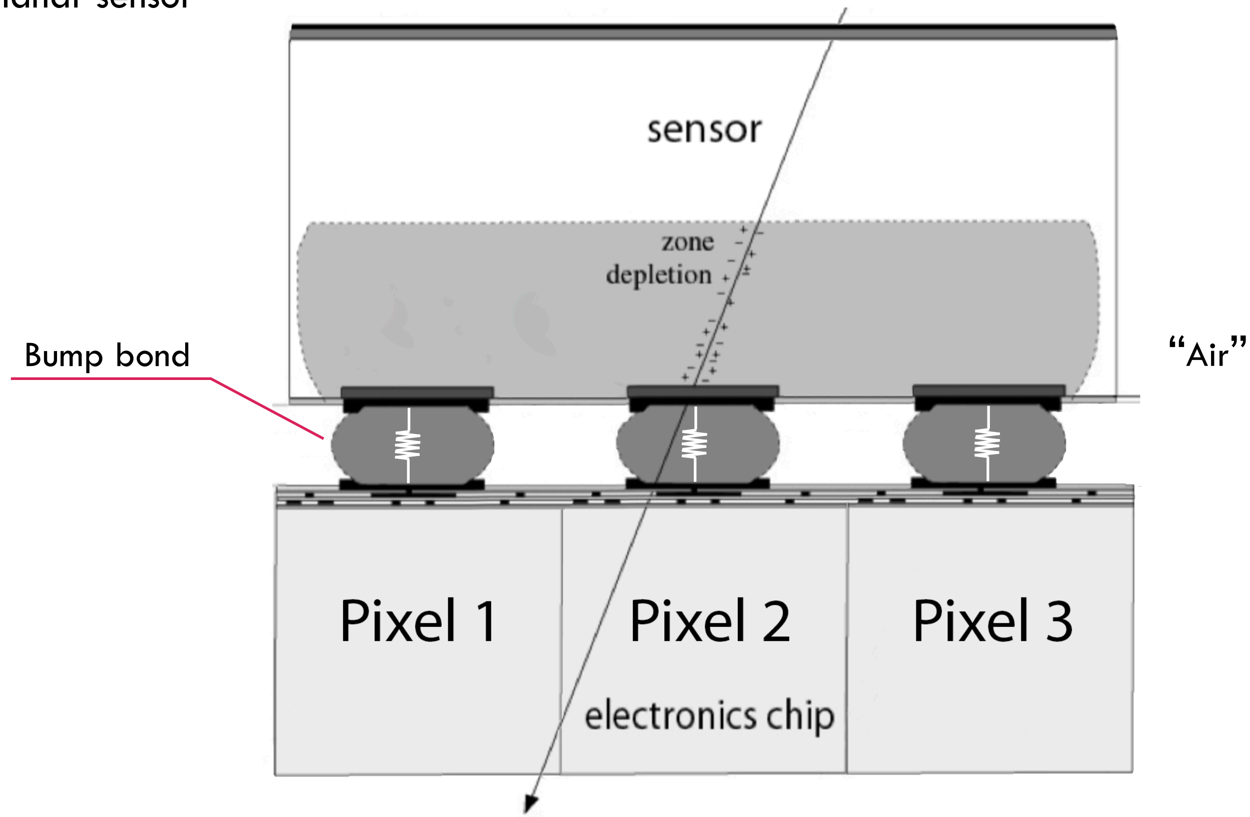


CLICpix Coupled to CCPDv3. Szymon Kulis - http://skulis.web.cern.ch/skulis/clicpix/

Detector Assembly

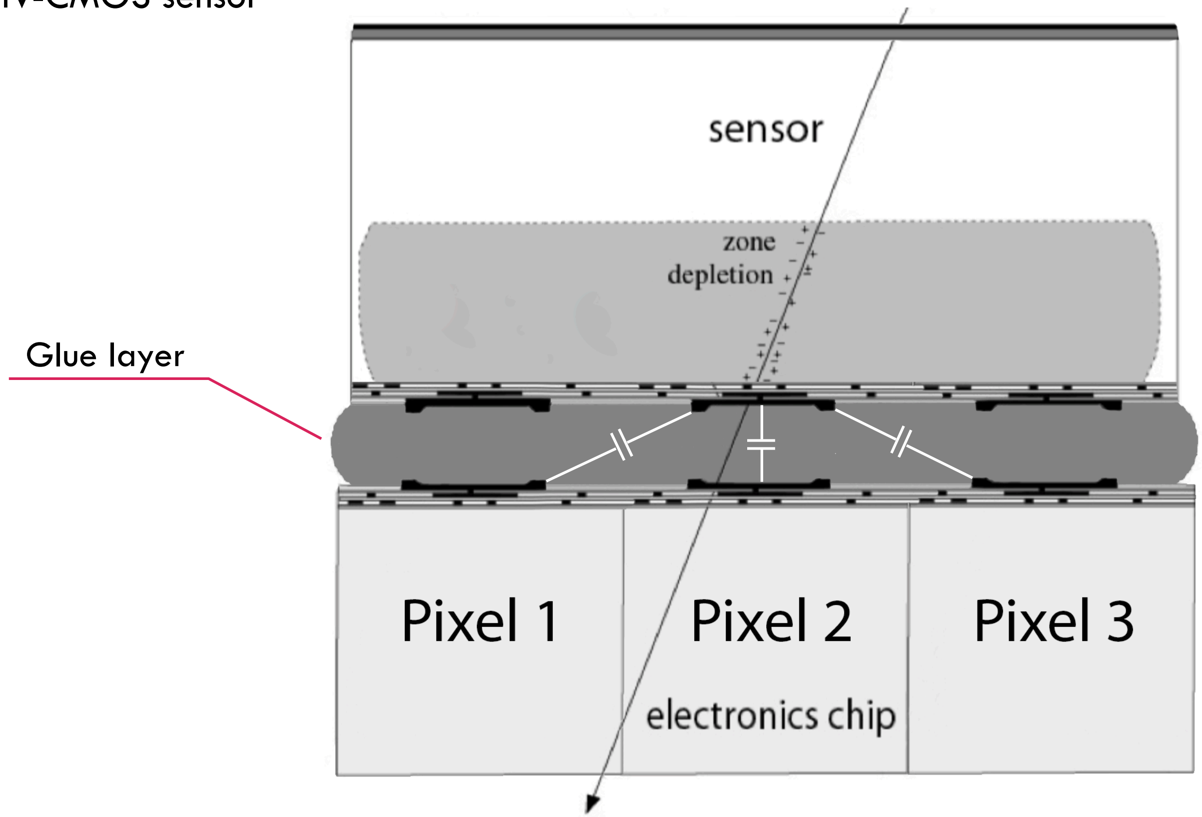
Hybrid detector bump-bonded (DC Coupled)

- Signal transmitted form sensor pixel to read-out pixel by a metalic connection (bump bond)
  - Planar sensor



Detector Assembly
Hybrid detector glued (AC Coupled)

- Signal capacitively transmitted form sensor pixel to read-out pixel through a dielectric glue layer*
  - HV-CMOS sensor

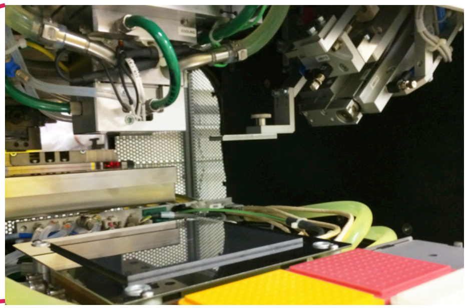


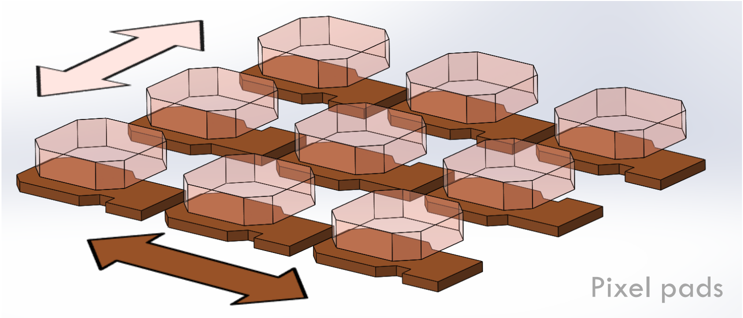
* Araldite 2011 Epoxy

Chips Bonding

Flip-Chip with the Accμra 100 machine*

- Heating up to **400C** and force applied by bonding arm up to **100 kg**
- XY Alignment stage with resolution of **0.015 um**
- Post bonding accuracy **< 0.5 um****
  - ** Not straightforward. Special software created to help on chip alignment (*PixelShop*)

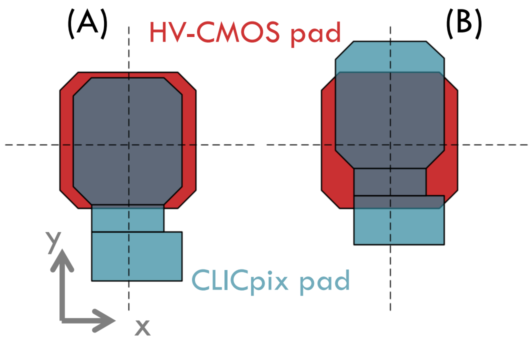


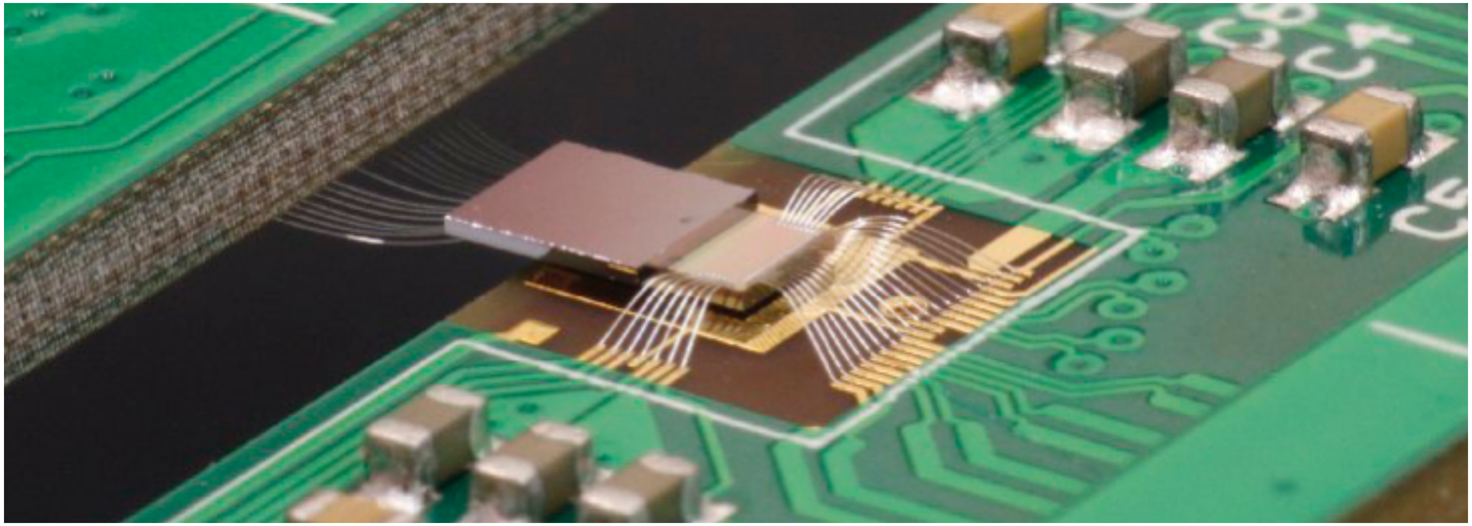


*At Geneva University

Chips Assembly
CLICpix + CCPDv3

- CLICpix + CCPDv3 assemblies produced
  - Assemblies studied in Test Beam
    - Early measurements: Assemblies with pad alignment (A)
    - Later measurements: Assemblies with "ideal alignment" (B) and with offset in x-direction by 1/4 pixel or 1/2 pixel.
  - Assemblies for cross-section measurements were produced with pad alignment (A).



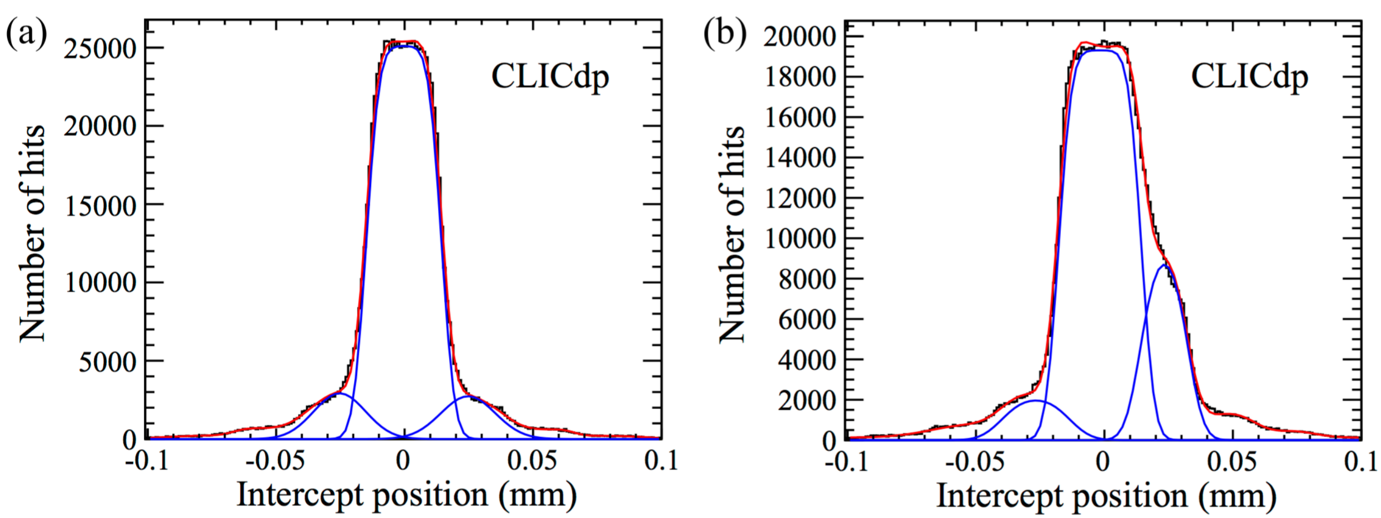


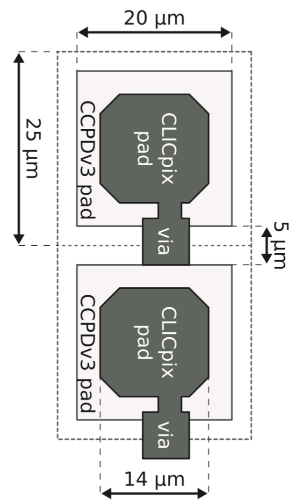
CLICpix + CCPDv3. Szymon Kulis - http://skulis.web.cern.ch/skulis/clicpix/

Chips (Mis)Alignment?

Asymmetric pixel response in Test Beam data

- Pixel response function
  - Ideal function should be smeared rectangular function with width described by the lateral charge diffusion
- Difference response in row and column directions
  - Possible misalignment in the Col (a) and/or Row (b) direction



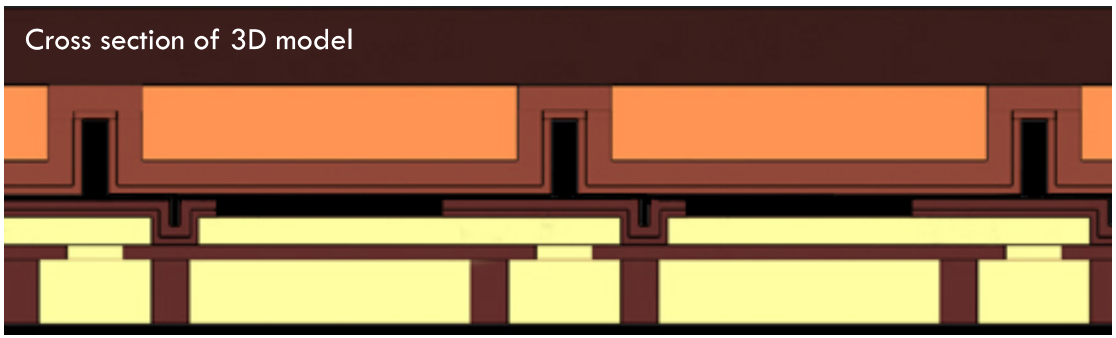


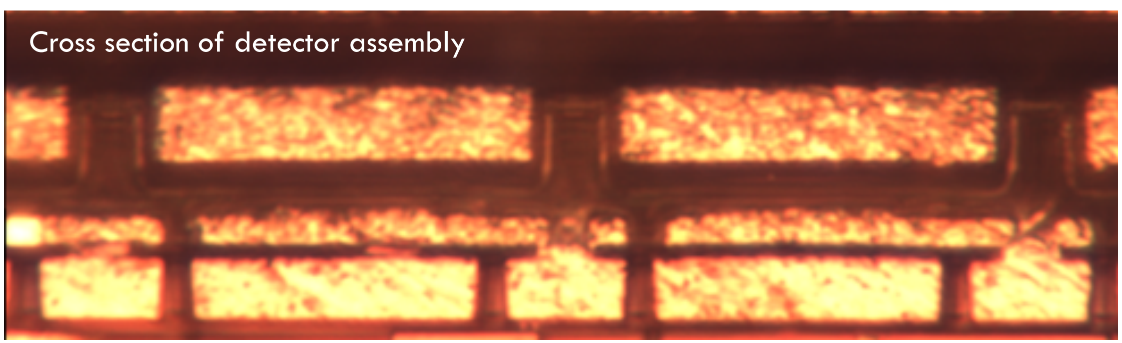
Nucl. Instrum. Meth. A823 (2016) 1

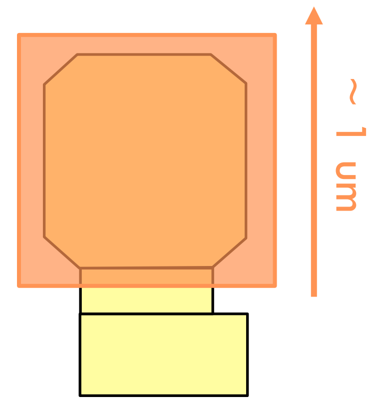
Assembly Measurement

Cross Section after Flip-Chip

- Measurement of SET29 sample (CLICpix + CCPDv3) with an optical microscope
  - Bump pads misaligned (with respect to **A**) by ~ 1.1um (after bonding process)







CLICpix (yellow) and CCPDv3 (orange) pads

SET29 measurement thanks to Florian Pipper

Physics model

- Relationship between the charge and electric potential of different terminals
- Purely Geometric (+ material dependency)!!!
  - Quantitatively
    - Maxwell *Coefficients of Capacitance* in the backup

$$C_{ij} \equiv -\varepsilon_0 \oint_{S_i} \nabla f_j \cdot \mathbf{n}_i \, dS$$

  - Qualitatively

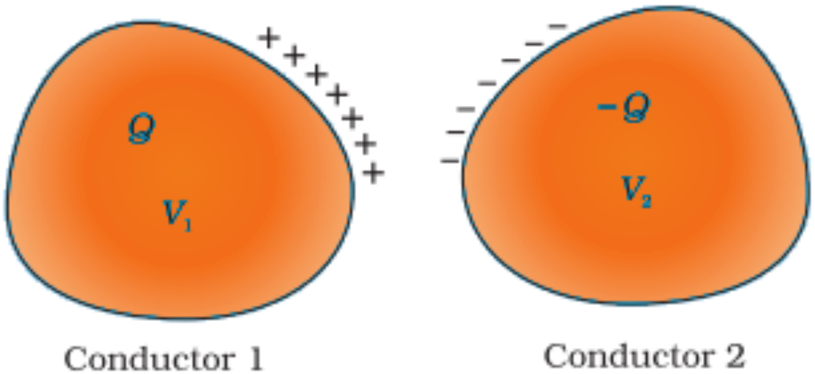
Scott Hughes - Lecture 6: Capacitance – MIT 2005

$$V \equiv \phi_2 - \phi_1 = -\int_1^2 \vec{E} \cdot d\vec{s}$$

Independent of the integration path

Potential difference V must be proportional to the geometry

$$V = \underbrace{(\text{Horribly messy constant depending on geometry})}_{\text{Capacitance}} \times Q$$



  - Materials
    - Glue + 4 passivation layers (2 from sensor + 2 from the read-out chip)
    - Glue Dielectric Coefficient: 1 Hz = 3.4 | 100 Hz = 3.2 | 1000 Hz = 3.2 | >1000 Hz = <3.2 ? (To be measured)

Physics model

- Capacitance between pixels in the CLICpix2 and C3PD chips
- Purely Geometric (+ material dependency)!!!
  - Quantitatively
    - Maxwell *Coefficients of Capacitance* in the backup

$$C_{ij} \equiv -\varepsilon_0 \oint_{S_i} \nabla f_j \cdot \mathbf{n}_i \, dS$$

  - Qualitatively

    Scott Hughes - Lecture 6: Capacitance – MIT 2005

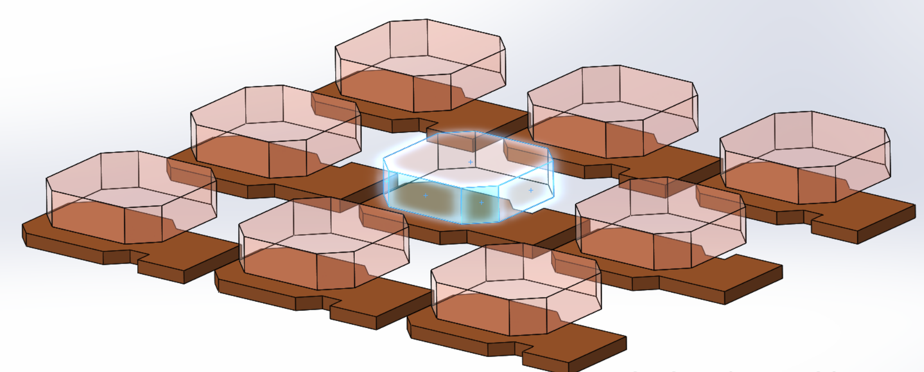
$$V \equiv \phi_2 - \phi_1 = -\int_1^2 \vec{E} \cdot d\vec{s}$$

    Independent of the integration path

    Potential difference V must be proportional to the geometry

$$V = \underbrace{(\text{Horribly messy constant depending on geometry})}_{\text{Capacitance}} \times Q$$

  - Materials
    - Glue + 4 passivation layers (2 from sensor + 2 from the read-out chip)
    - Glue Dielectric Coefficient: 1 Hz = 3.4 | 100 Hz = 3.2 | 1000 Hz = 3.2 | >1000 Hz = <3.2 ? (To be measured)

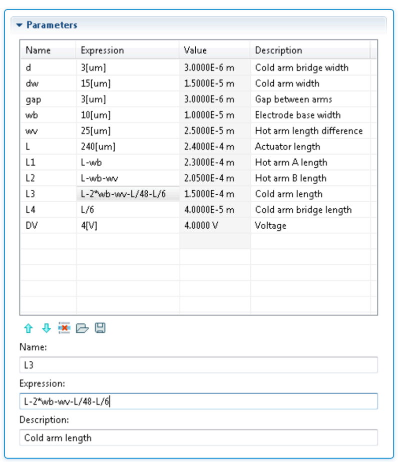


CLICpix2 and C3PD pads

Simulation

COMSOL Multiphysics®

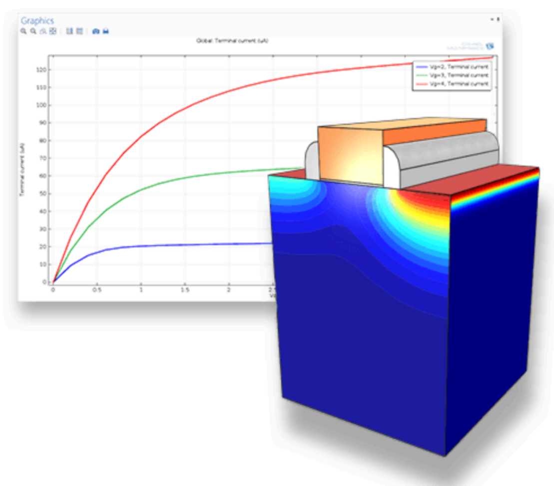
- Key Features @ https://www.comsol.com/comsol-multiphysics#specs
  - **Finite Element Analysis**
  - Several different templates for general second-order systems of nonlinear partial differential equations
    - Electric currents
    - Heat transfer in solids and fluids
  - Free tetrahedral meshing
  - Nonlinear material properties as a function of any physical quantity



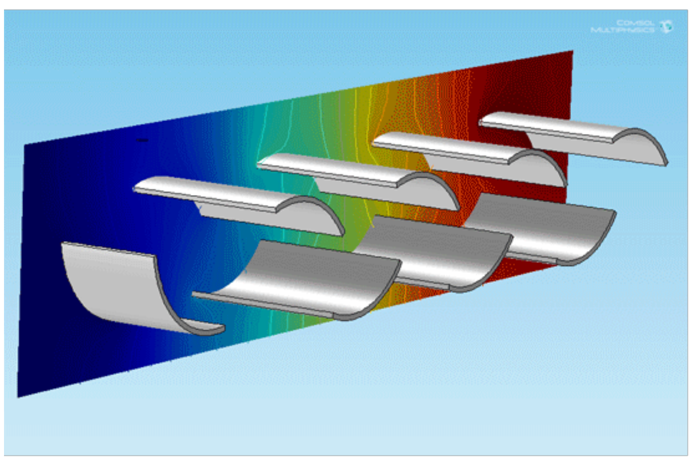
Parameters

Name	Expression	Value	Description
d	3[um]	3.0000E-6 m	Cold arm bridge width
dw	15[um]	1.5000E-5 m	Cold arm width
gap	3[um]	3.0000E-6 m	Gap between arms
wb	10[um]	1.0000E-5 m	Electrode base width
wv	25[um]	2.5000E-5 m	Hot arm length difference
L	240[um]	2.4000E-4 m	Actuator length
L1	L-wb	2.3000E-4 m	Hot arm A length
L2	L-wb-wv	2.0500E-4 m	Hot arm B length
L3	L-2*wb-wv-L/48-L/6	1.5000E-4 m	Cold arm length
L4	L/6	4.0000E-5 m	Cold arm bridge length
DV	4[V]	4.0000 V	Voltage

Name:
L3
Expression:
L-2*wb-wv-L/48-L/6
Description:
Cold arm length

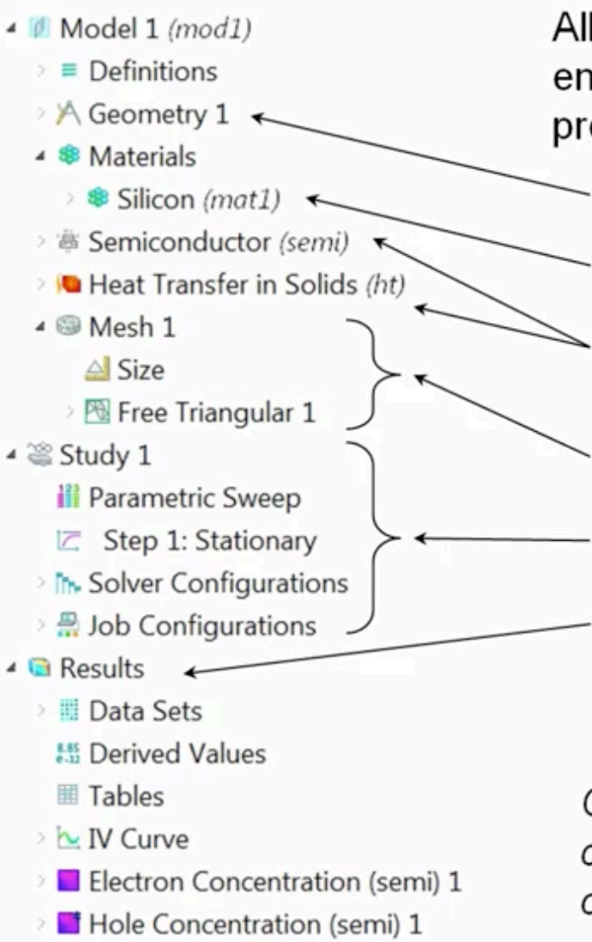


Transistor operation where an applied gate voltage turns the device on and then determines the drain saturation current.



Simulation

Fully Integrated Software Suite



All modeling steps are available from a single unified environment. The model tree (shown on the left) provides quick and easy access to all the settings:

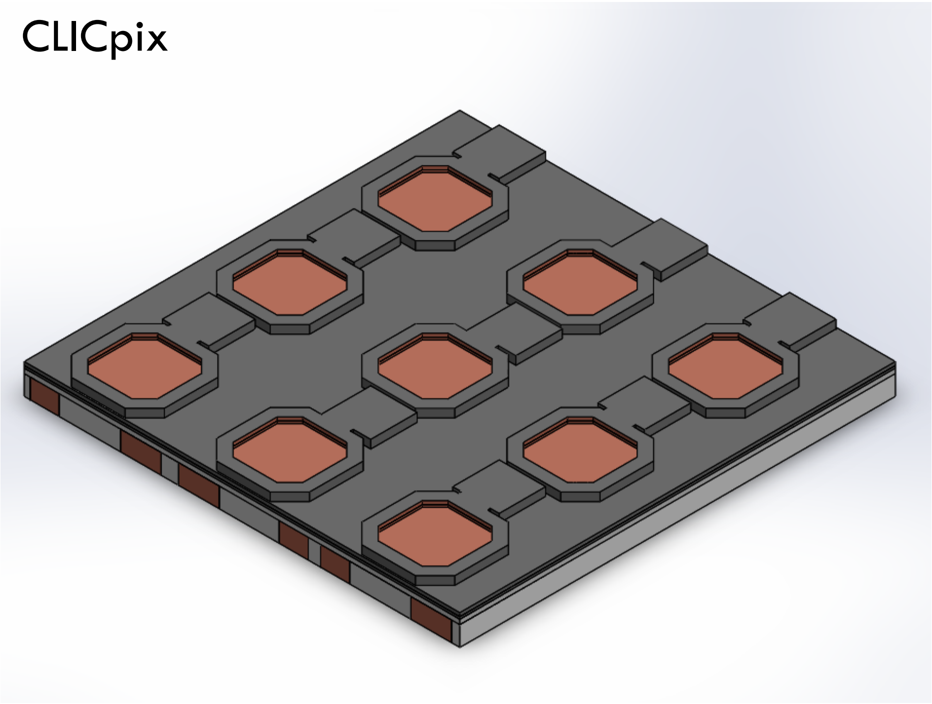
- Geometry setup / CAD /ECAD Import
- User defined and built in material libraries
- Simple and intuitive Multiphysics Problem setup
- Meshing
- Solving
- Visualization + Postprocessing
- Data Import/Export

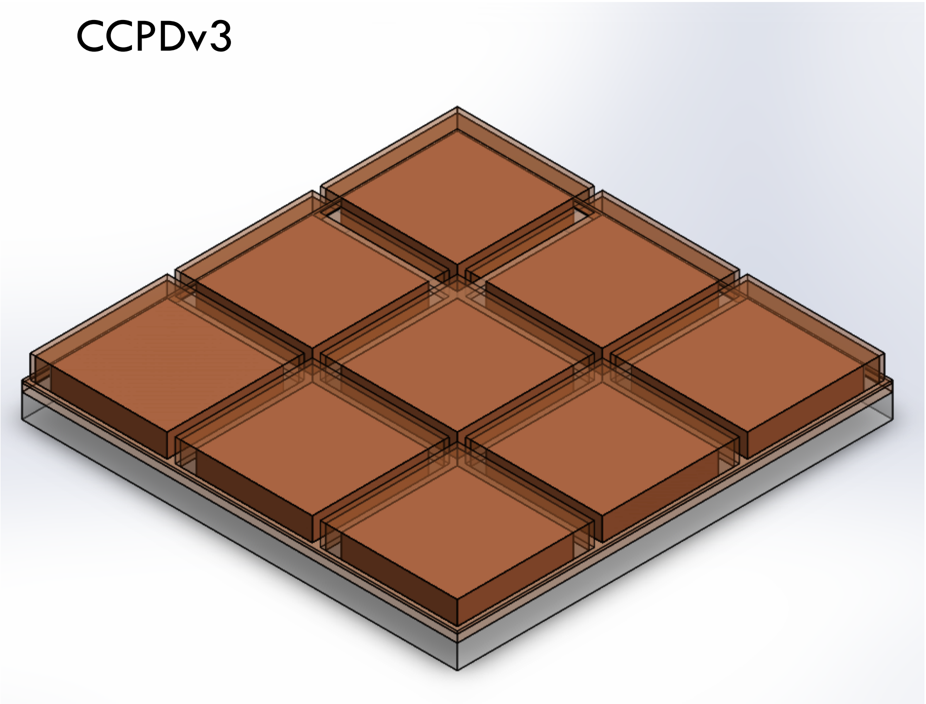
COMSOL is designed from the bottom up for arbitrary combinations of physical equations and easy user customization

Geometry

CLICpix + CCPDv3 model

- Solidworks parts



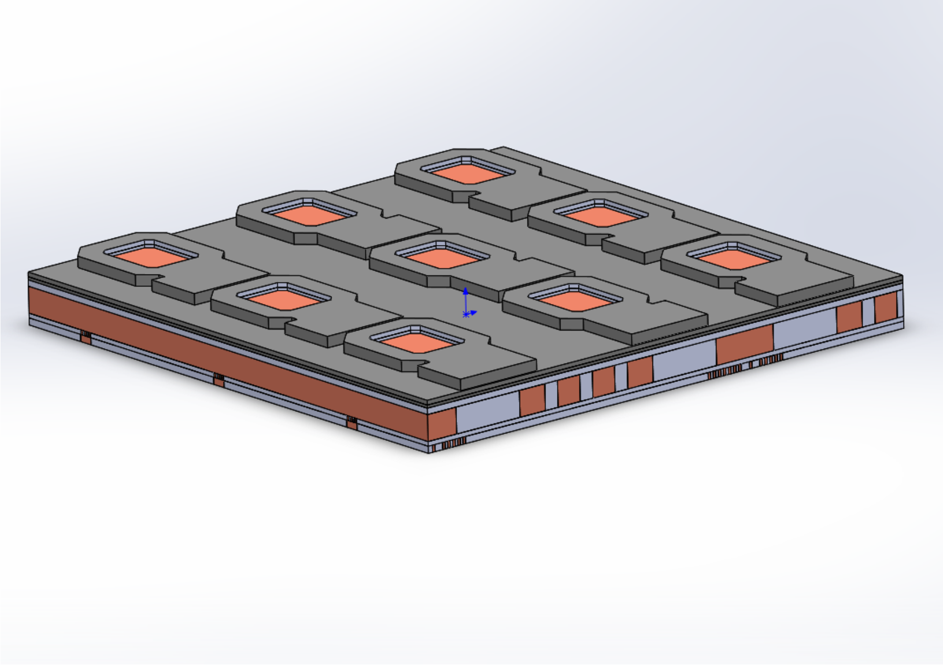


Geometry

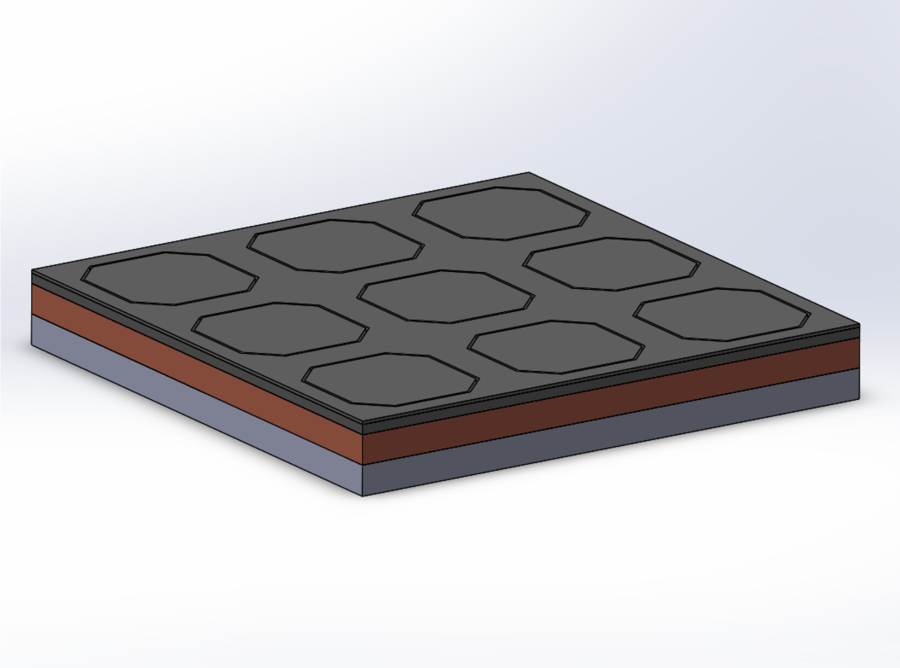
CLICpix2 + C3PD model

- Solidworks parts

CLICpix2

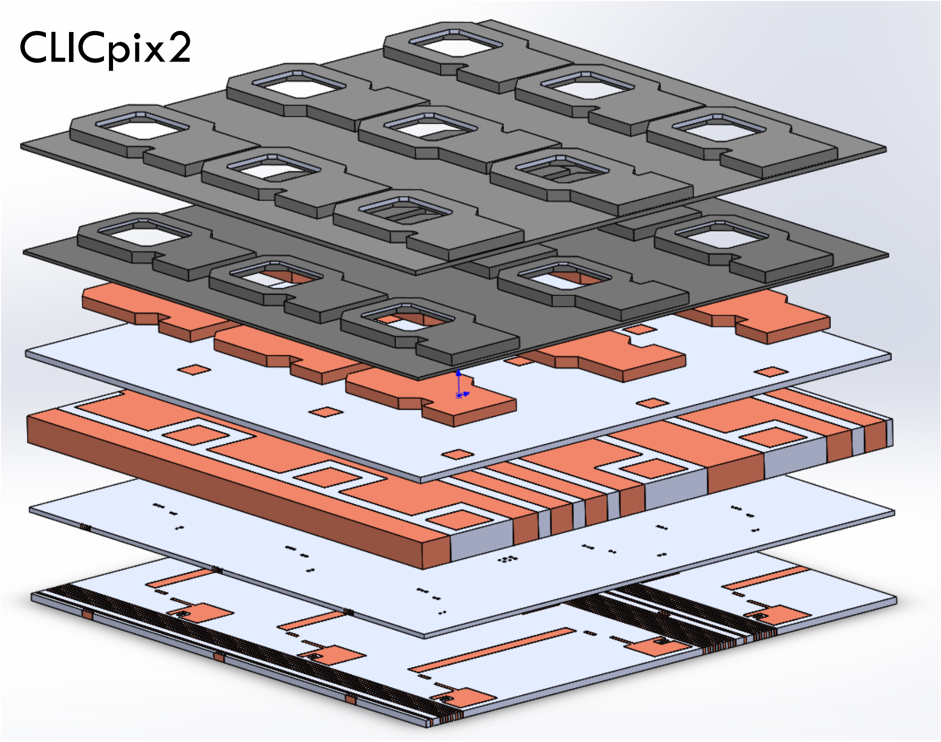


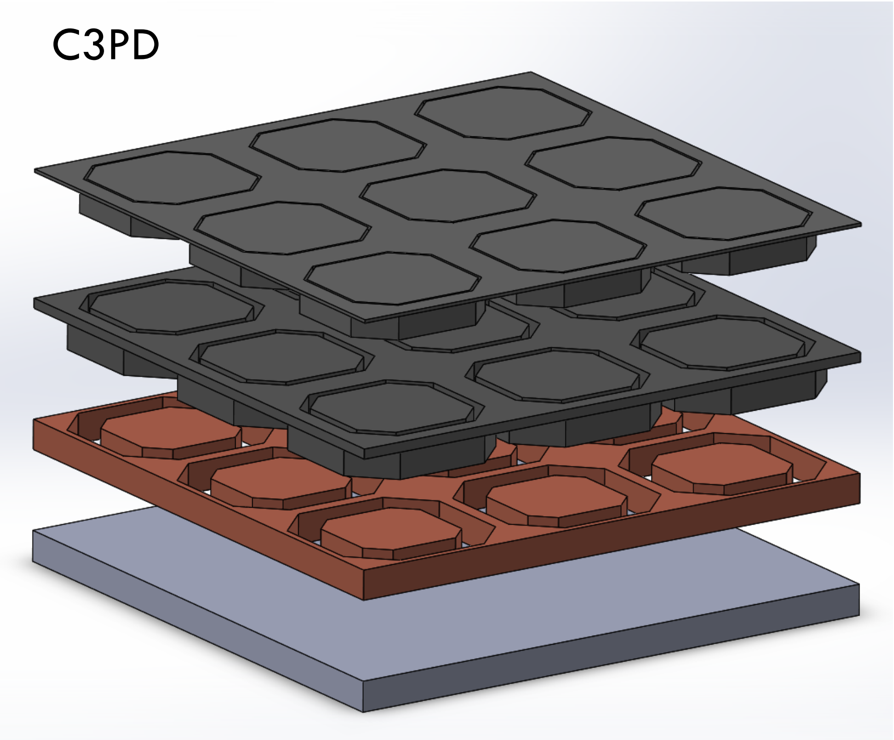
C3PD



Geometry
CLICpix2 + C3PD model

- Solidworks parts

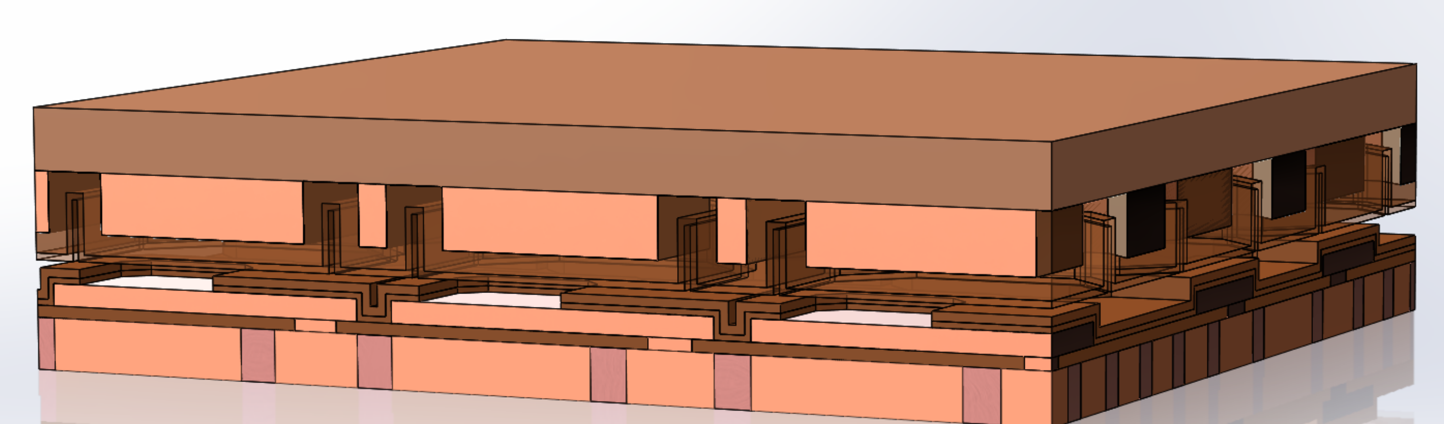




Geometry

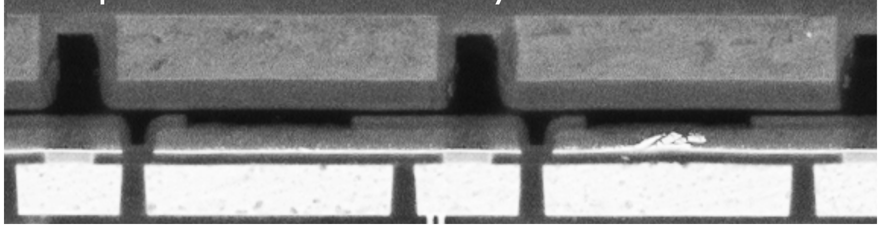
Assembly model (gap = 0.22μm)

- HV-CMOS sensor on TOP and Read-out chip on BOTTOM



CLICpix2 + C3PD model cross section

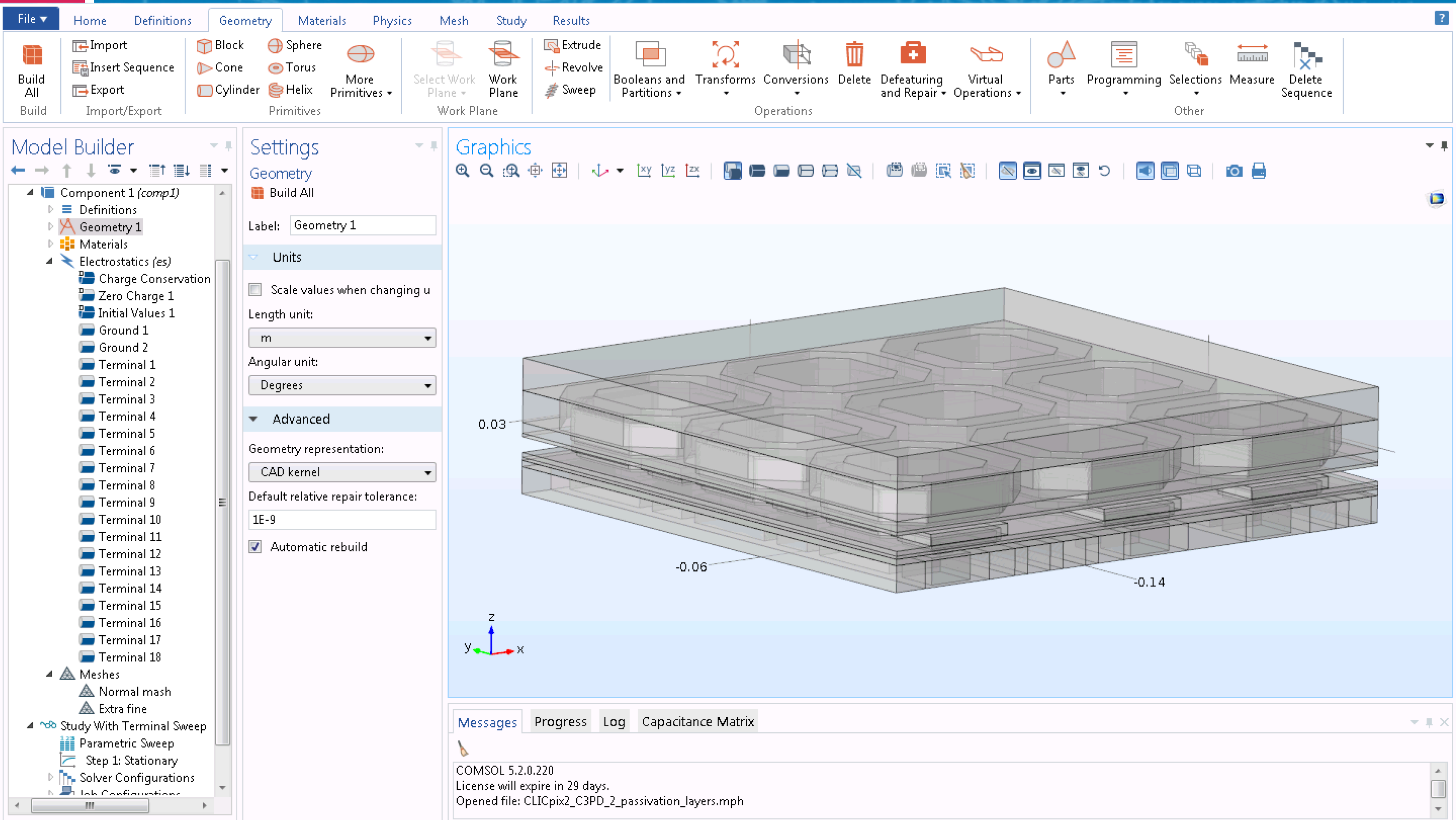
CLICpix + CCPDv3 model cross section



CLICpix + CCPDv3 assembly cross section

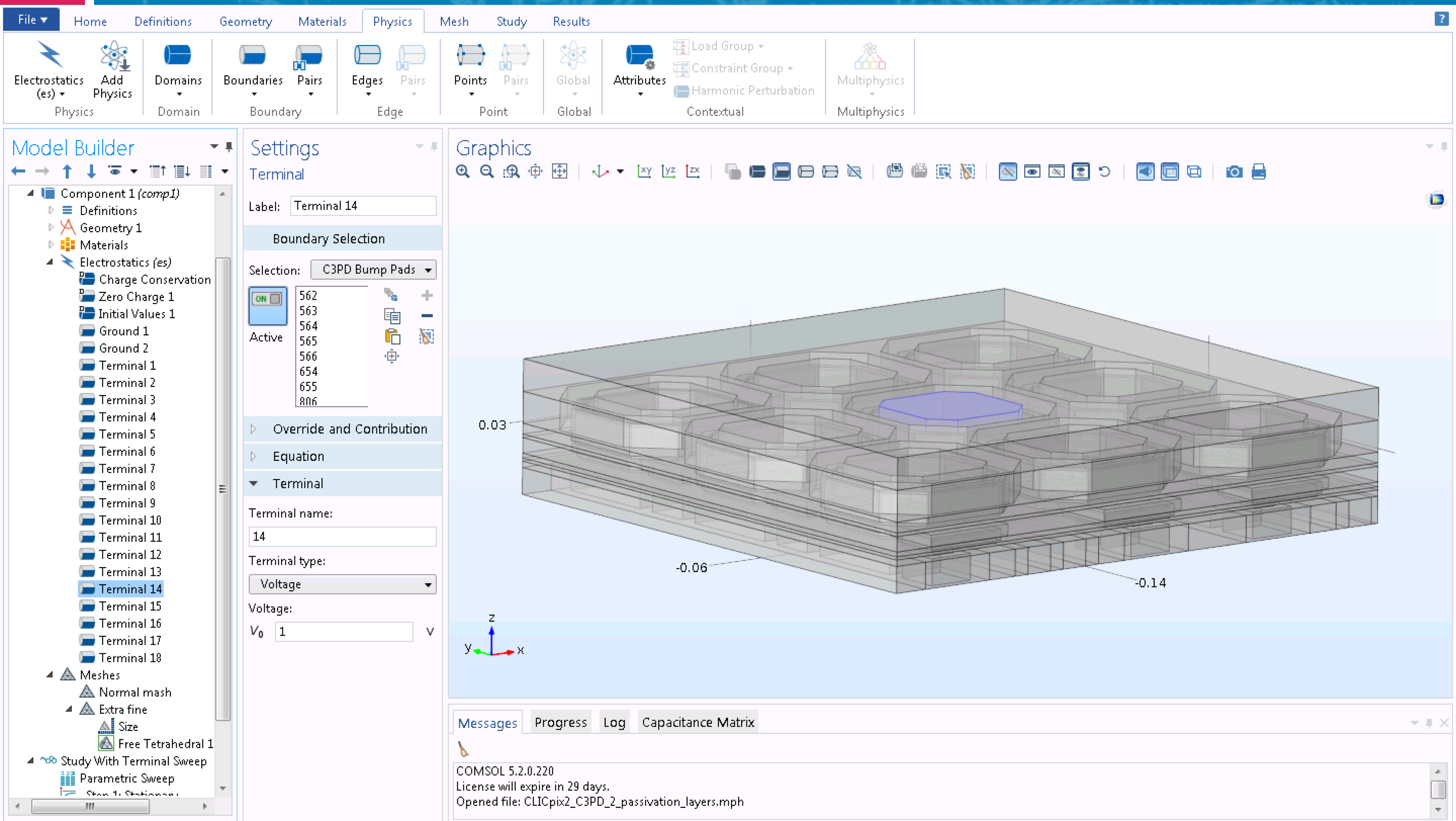
Geometry

Imported to COMSOL



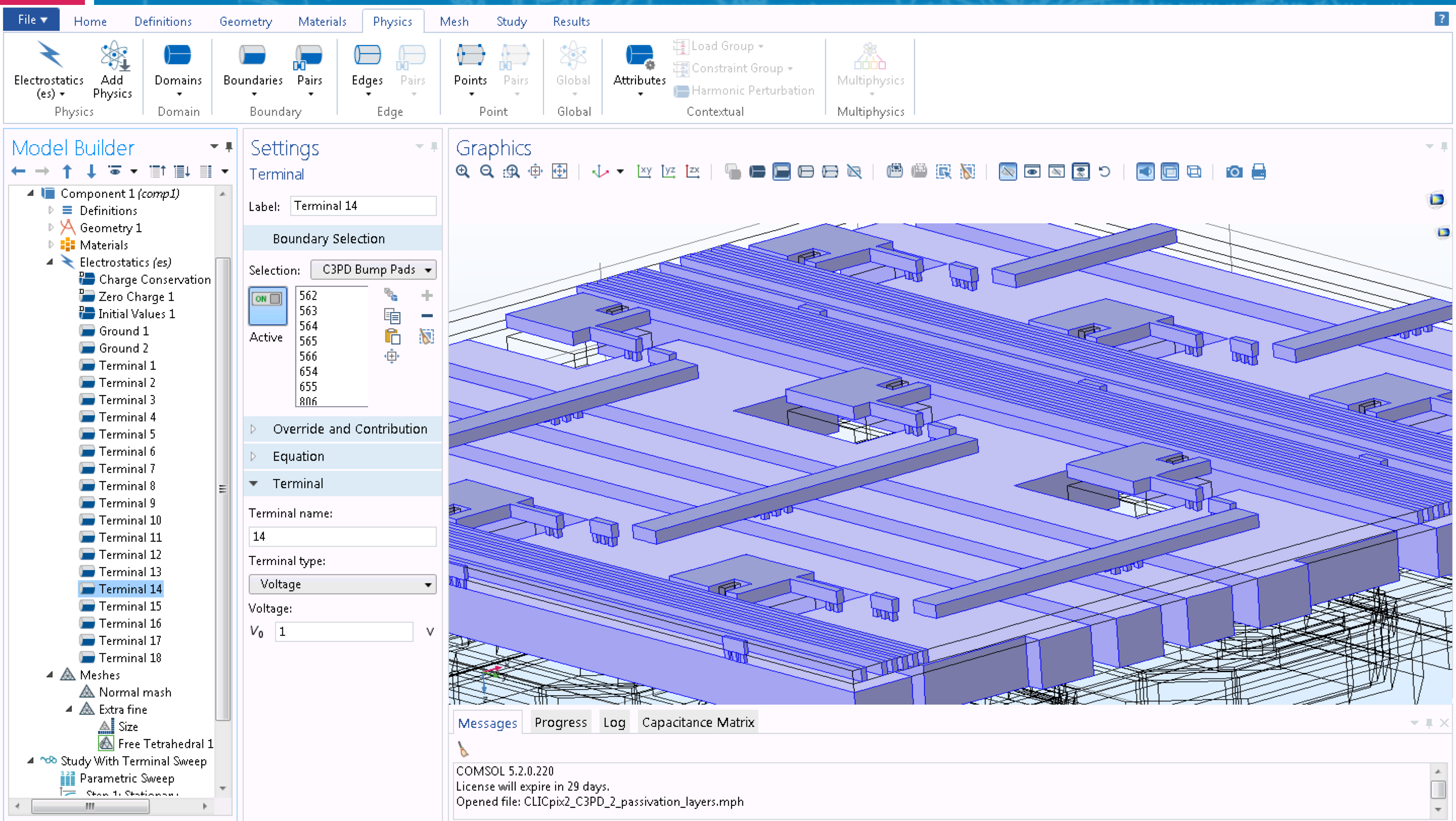
Simulation

COMSOL Multiphysics® - Pads/Terminals



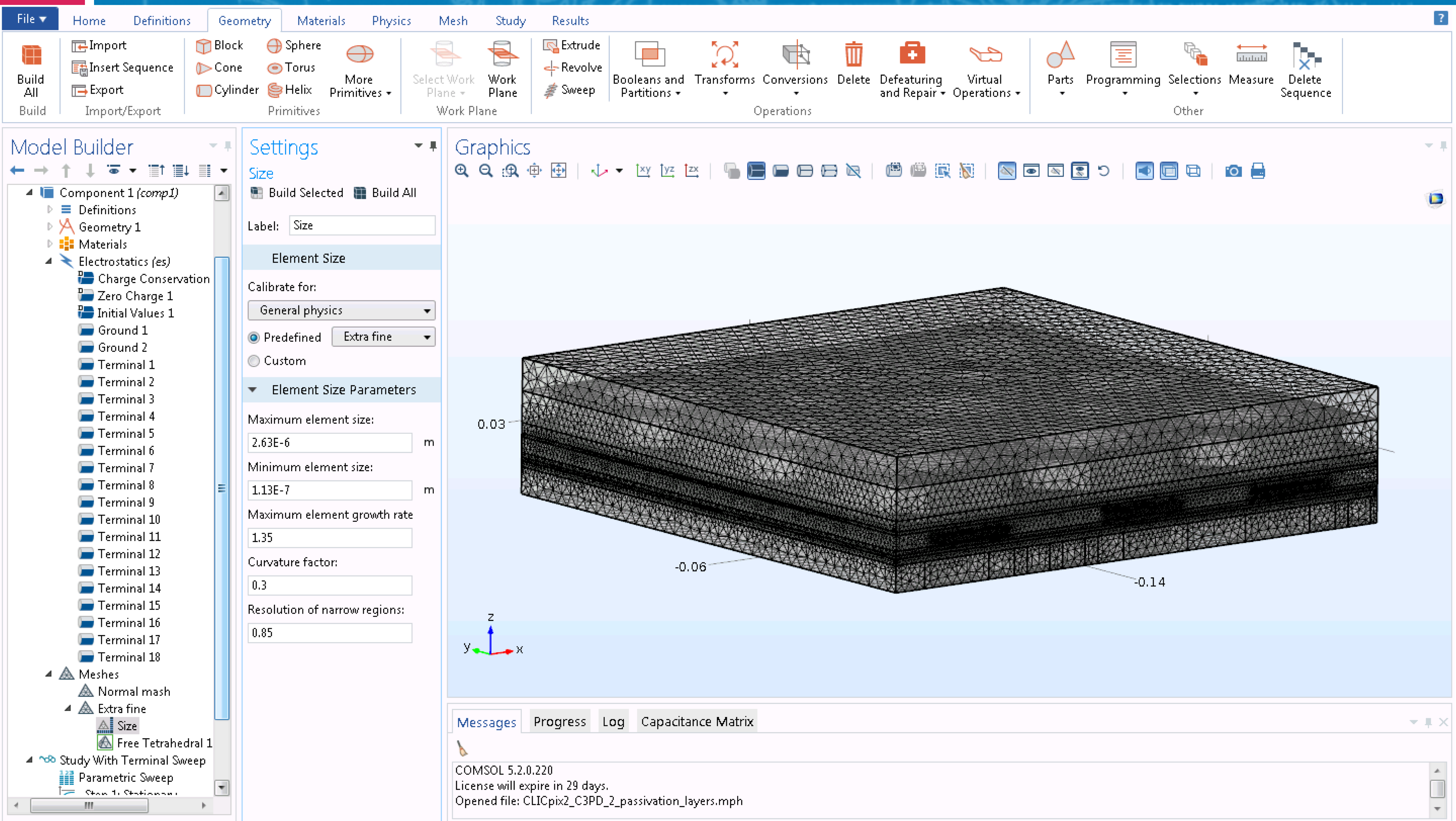
Simulation

COMSOL Multiphysics® - Metal lines (CLICpix2)



Simulation

COMSOL Multiphysics® - Mesh



Results

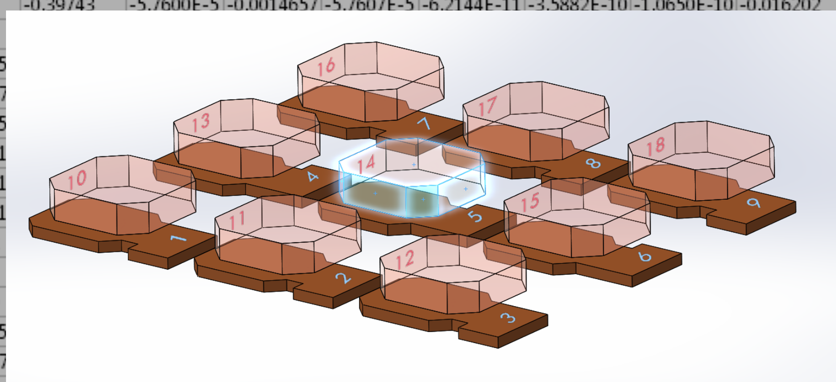
Capacitance Matrix

- Coupling/Capacitance between all the terminals (pixel pads)

Table 10 | Progress | Log

CLIXpix2 terminals

Capacitance (fF)																	
16.886	-0.39750	-1.5686E-8	-0.0014967	-5.7629E-5	-2.0997E-9	-4.2845E-10	-1.0636E-10	-7.7491E-13	-2.6928	-0.014929	-9.7037E-8	-0.0025388	-6.8890E-5	-1.2688E-8	-2.7128E-8	-4.9638E-9	-3.4026E-11
-0.39750	17.667	-0.39743	-5.7600E-5	-0.0014657	-5.7607E-5	-6.2144E-11	-3.5882E-10	-1.0650E-10	-0.016202	-2.6776	-0.014920	-3.2961E-5	-0.0024986	-6.8794E-5	-3.5494E-9	-2.3491E-8	-4.9723E-9
-1.5686E-8	-0.39743									-0.016198	-2.6927	-9.3946E-9	-3.2873E-5	-0.0025520	-2.4359E-11	-3.5197E-9	-2.8074E-8
-0.0014967	-5.7600E-5									-6.8857E-5	-1.2669E-8	-2.6898	-0.014880	-8.5992E-8	-0.0030361	-5.0761E-5	-1.0888E-8
-5.7630E-5	-0.0014657									-0.0024987	-6.8847E-5	-0.016120	-2.6746	-0.014876	-8.2951E-5	-0.0029634	-5.0759E-5
-2.0996E-9	-5.7607E-5									-3.2961E-5	-0.0025536	-8.7869E-8	-0.016122	-2.6898	-1.4377E-8	-8.3040E-5	-0.0030222
-4.2847E-10	-6.2143E-1									-4.9689E-9	-3.1233E-11	-0.0030362	-5.0752E-5	-1.0896E-8	-2.6923	-0.014942	-9.8739E-8
-1.0637E-10	-3.5882E-1									-2.8627E-8	-4.9704E-9	-8.2976E-5	-0.0029644	-5.0760E-5	-0.016151	-2.6769	-0.014938
-7.7481E-13	-1.0650E-1									-5.4247E-9	-3.3749E-8	-1.4350E-8	-8.3054E-5	-0.0030232	-9.7434E-8	-0.016157	-2.6923
-2.6928	-0.016202									-0.030083	-2.9487E-6	-0.033500	-6.8671E-4	-3.6036E-7	-2.9691E-6	-3.6108E-7	-1.5354E-9
-0.014929	-2.6776									7.0506	-0.030060	-6.8650E-4	-0.032827	-6.8641E-4	-3.6184E-7	-2.6066E-6	-3.6166E-7
-9.7041E-8	-0.014920									-0.030061	6.9887	-3.6012E-7	-6.8610E-4	-0.033467	-1.5370E-9	-3.6180E-7	-2.9708E-6
-0.0025387	-3.2961E-5									-6.8650E-4	-3.6010E-7	7.0538	-0.029399	-2.5881E-6	-0.033180	-6.8078E-4	-3.5927E-7
-6.8890E-5	-0.0024987									-0.032827	-6.8610E-4	-0.029399	7.0835	-0.029376	-6.8142E-4	-0.032472	-6.8087E-4
-1.2689E-8	-6.8793E-5	-0.0025521	-8.5996E-8	-0.014876	-2.6898	-1.0897E-8	-5.0760E-5	-0.0030231	-3.6036E-7	-6.8641E-4	-0.033467	-2.5881E-6	-0.029376	7.0533	-3.5956E-7	-6.8097E-4	-0.033181
-2.7129E-8	-3.5492E-9	-2.4360E-11	-0.0030360	-8.2949E-5	-1.4376E-8	-2.6923	-0.016151	-9.7434E-8	-2.9692E-6	-3.6183E-7	-1.5373E-9	-0.033180	-6.8142E-4	-3.5954E-7	7.0201	-0.030088	-2.9502E-6
-4.9640E-9	-2.3491E-8	-3.5195E-9	-5.0761E-5	-0.0029632	-8.3040E-5	-0.014942	-2.6769	-0.016157	-3.6109E-7	-2.6066E-6	-3.6180E-7	-6.8079E-4	-0.032472	-6.8096E-4	-0.030088	7.0499	-0.030073
-3.4016E-11	-4.9721E-9	-2.8072E-8	-1.0888E-8	-5.0758E-5	-0.0030223	-9.8737E-8	-0.014938	-2.6923	-1.5355E-9	-3.6165E-7	-2.9707E-6	-3.5927E-7	-6.8087E-4	-0.033181	-2.9502E-6	-0.030073	7.0196

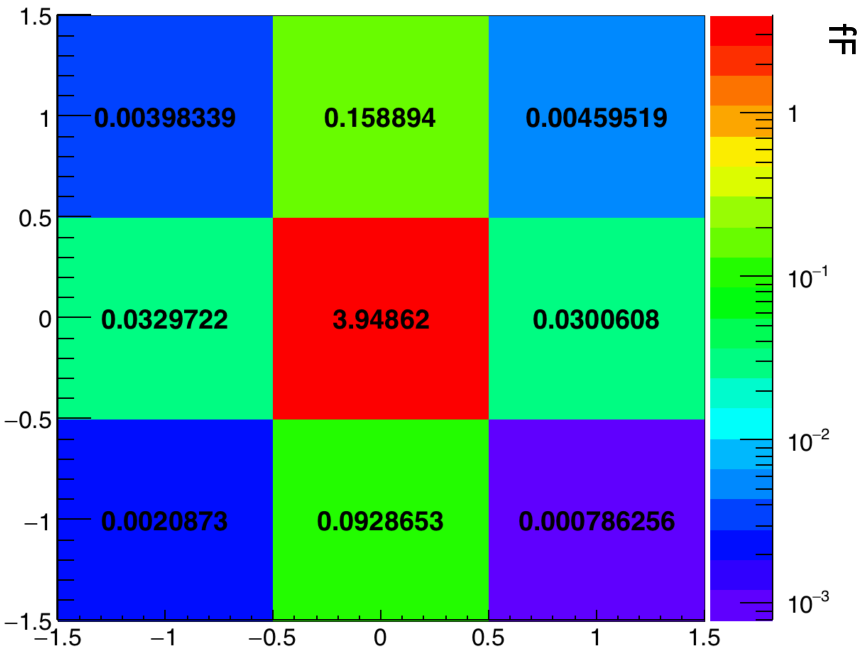


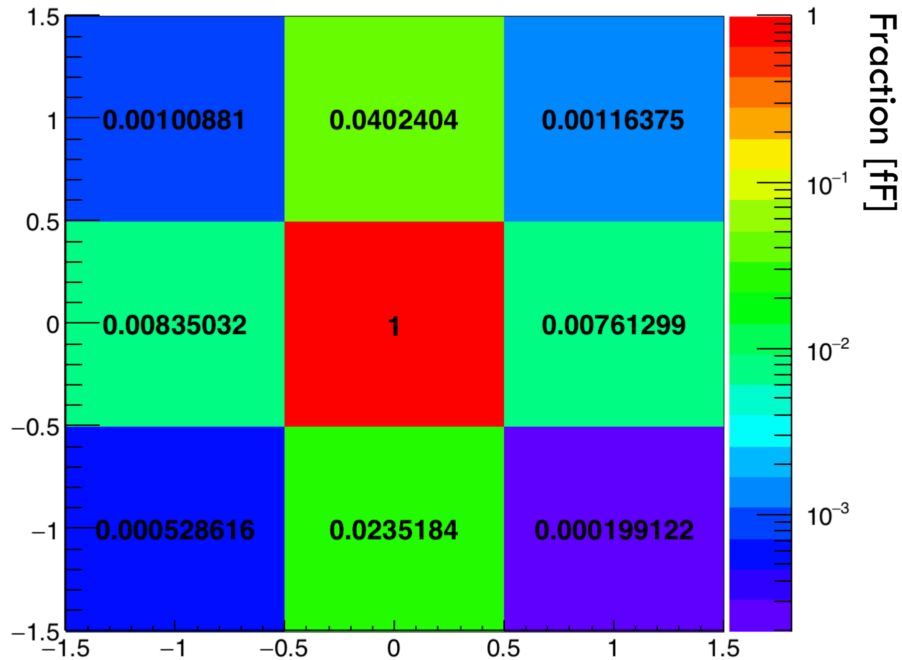
C3PD terminals

Results

Capacitance Matrix – CCPDv3➔CLICpix

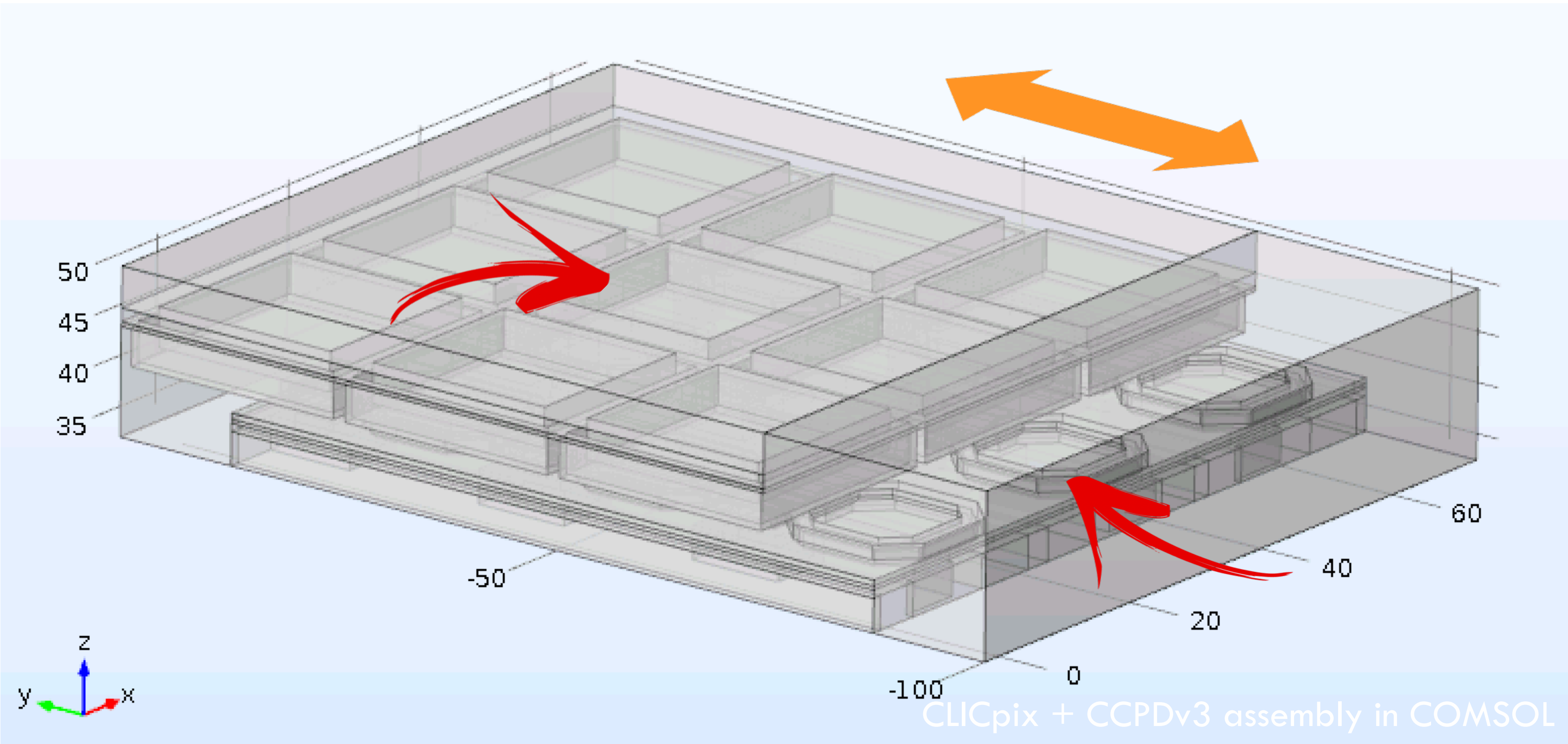
- Coupling between central pixel in CCPDv3 and other 9 pixels in the CLICpix chip
  - Fraction on right plot: $C_i = C_i / C_{center}$
- Asymmetric coupling with central top and bottom pixels (difference ~2%)





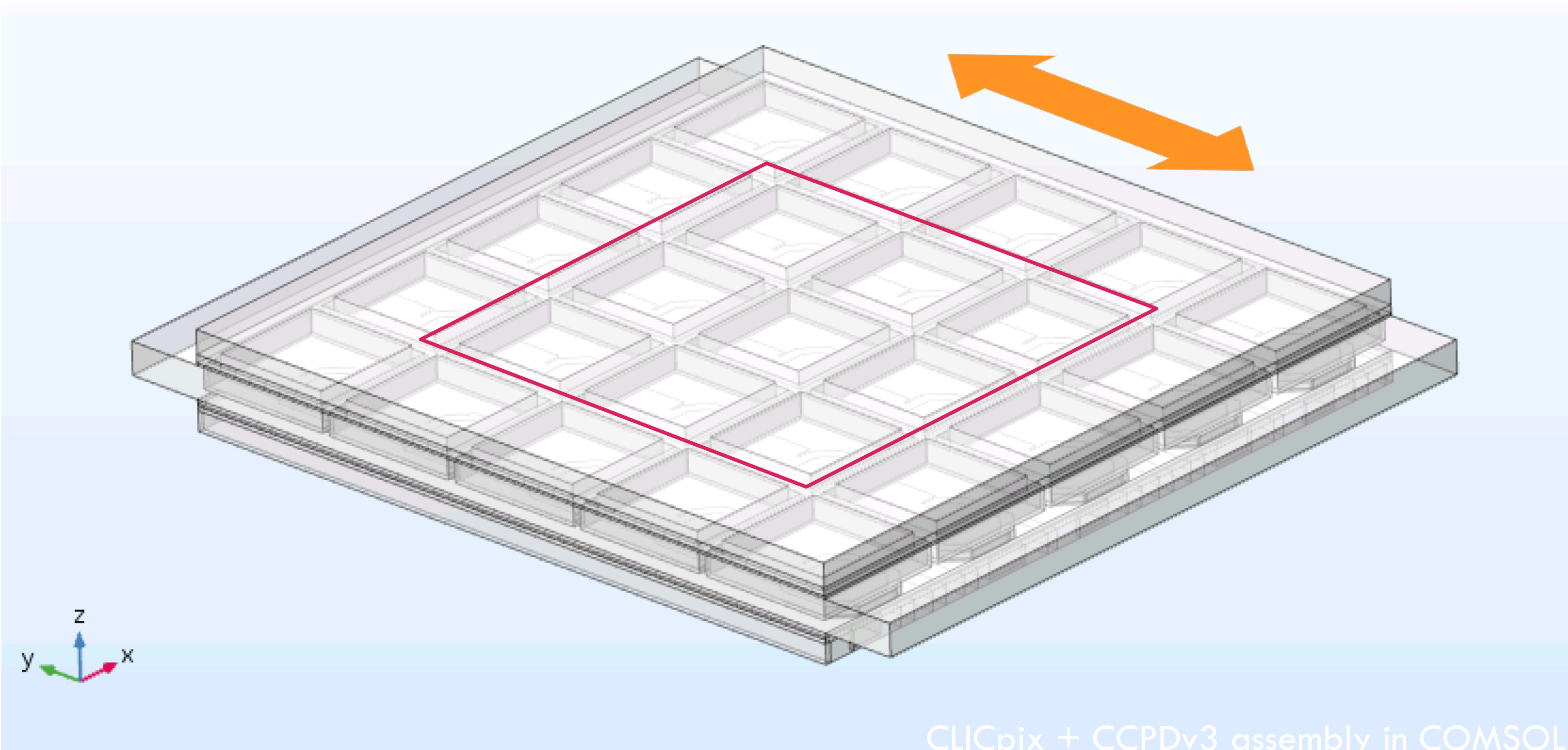
Alignment Scan

Problem with the 3x3 matrix



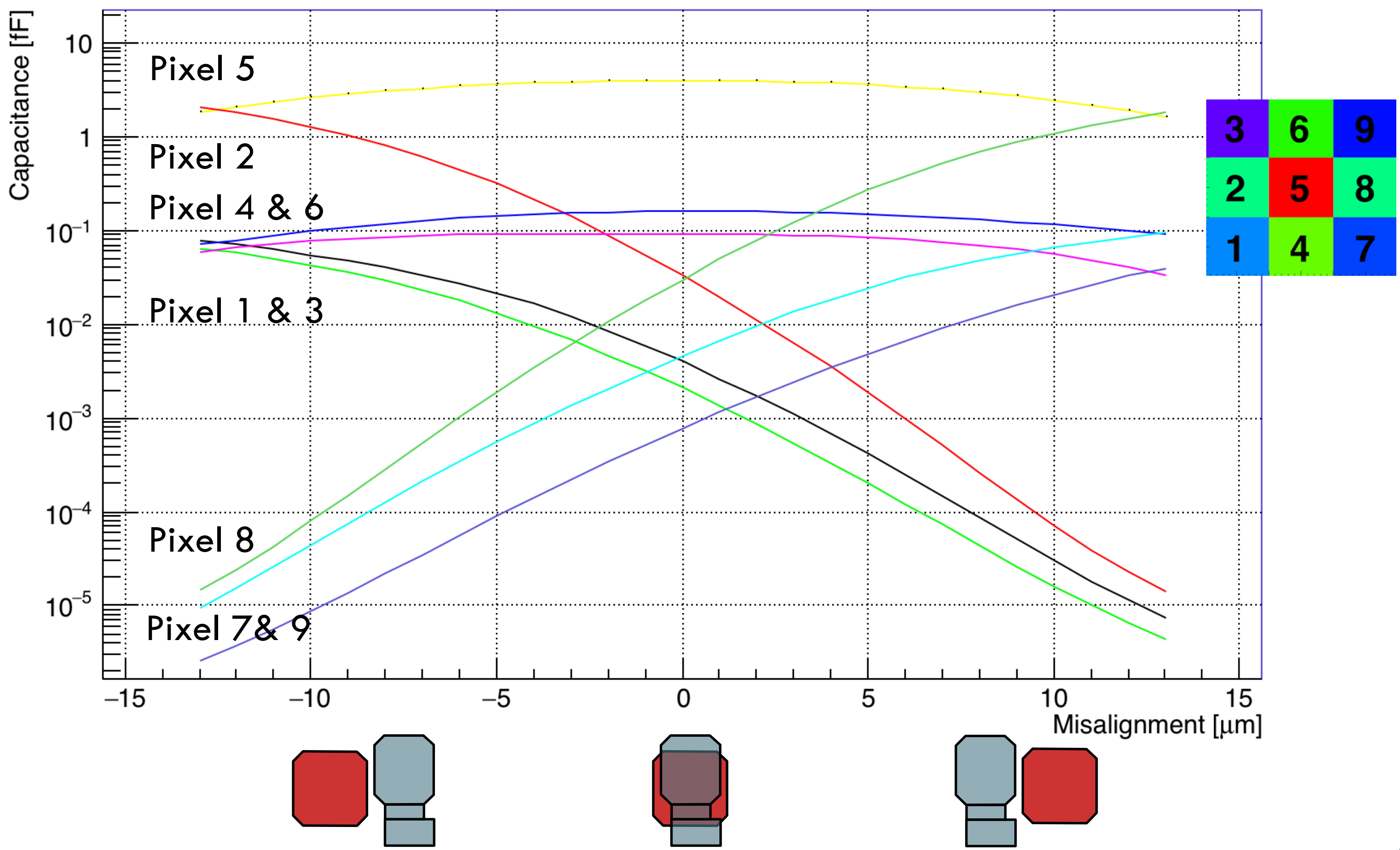
Alignment Scan

5x5 matrix, checking 3x3 central pixels



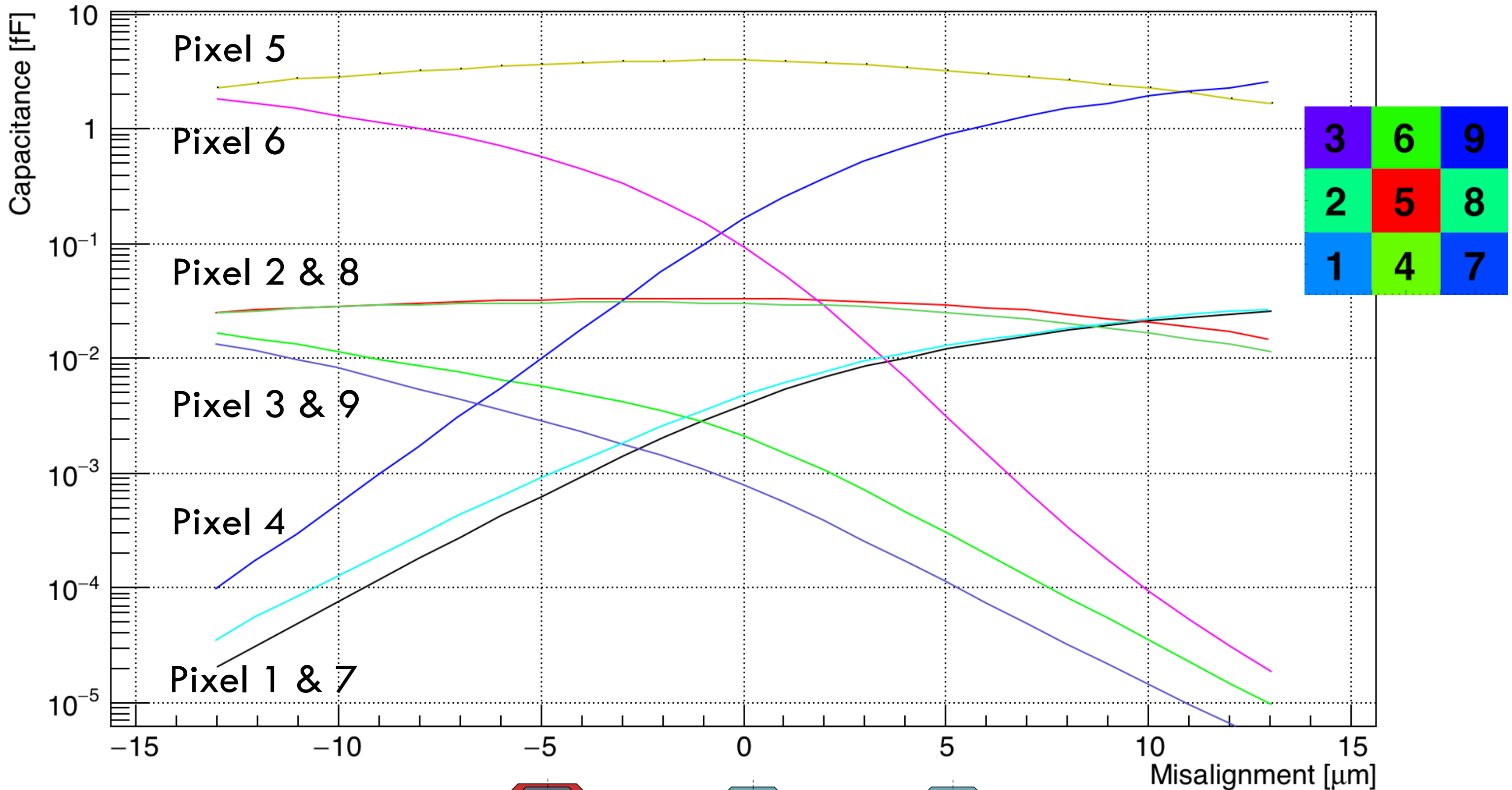
Effect on X-direction Misalignment

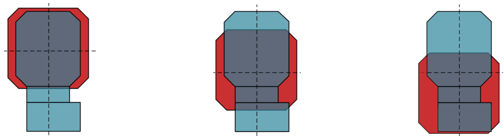
Cross Pixel Coupling (CCPDv3➔CLICpix)



Effect on Y-direction Misalignment

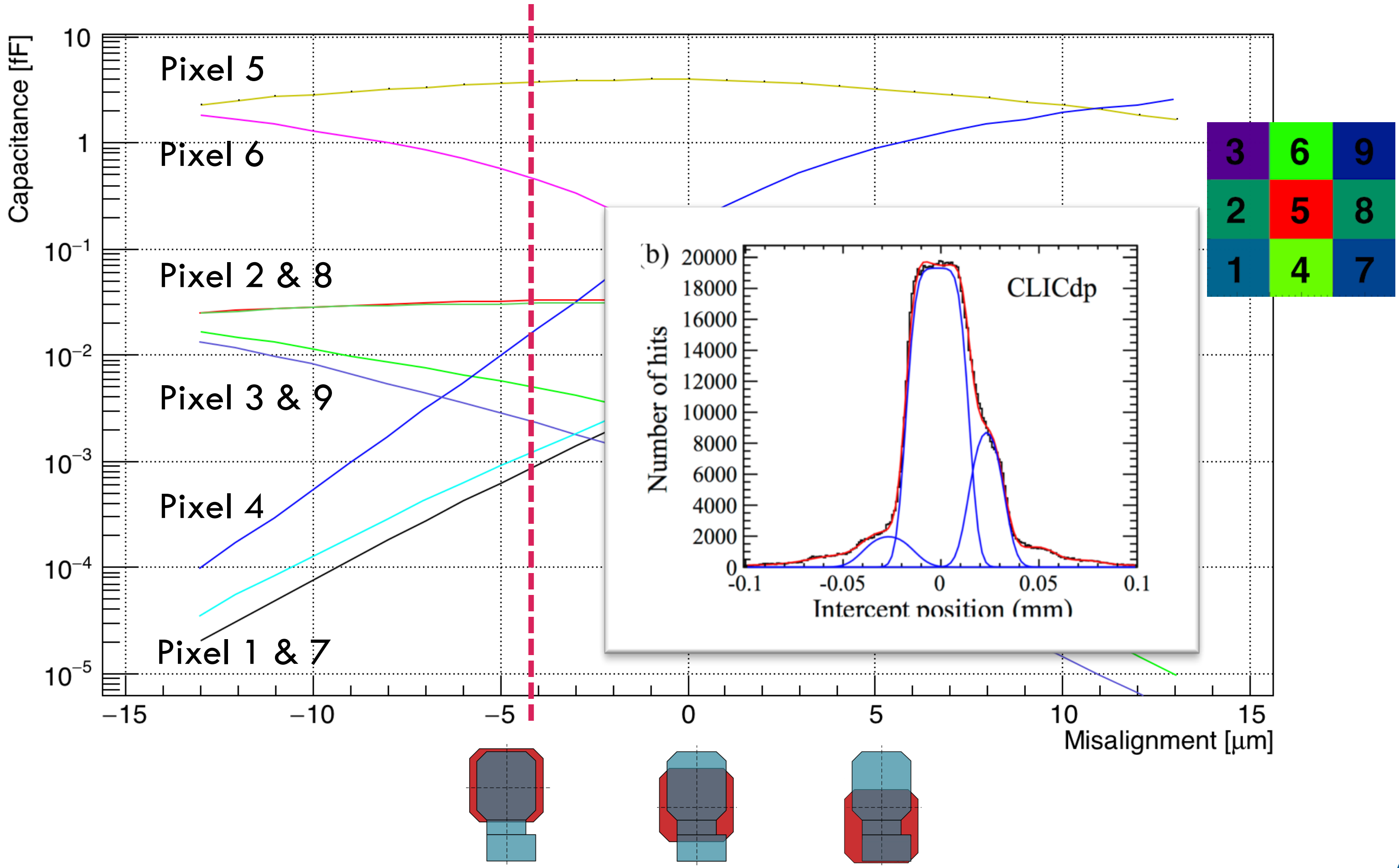
Cross Pixel Coupling (CCPDv3➔CLICpix)





Effect on Y-direction Misalignment

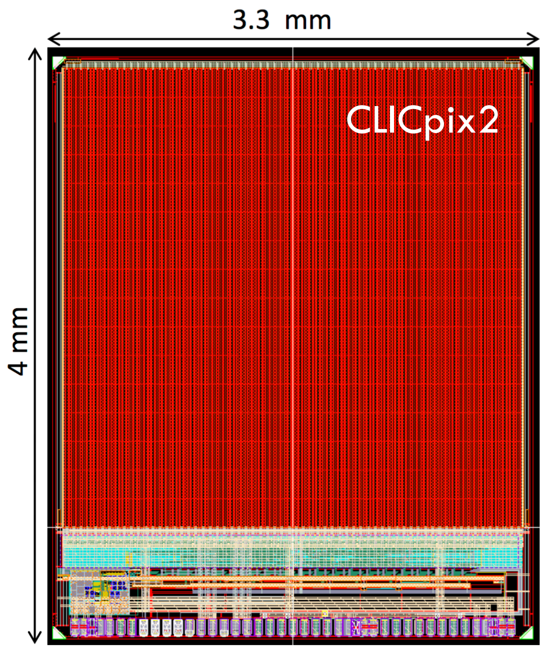
Cross Pixel Coupling (CCPDv3→CLICpix)



New Chips

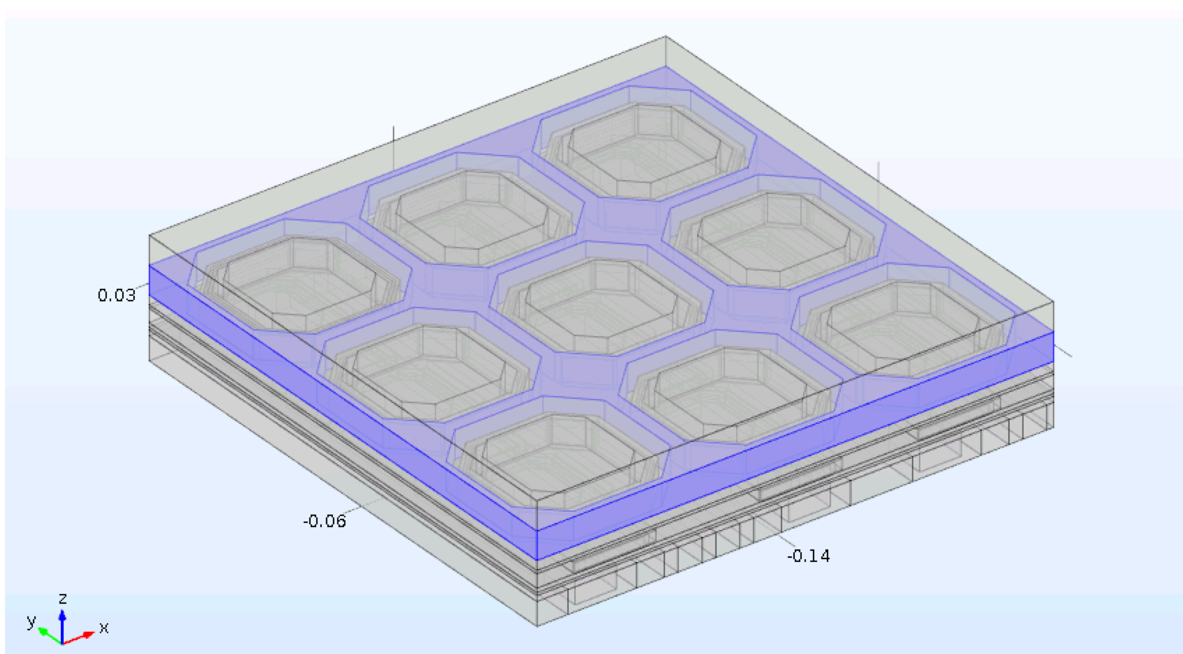
CLICpix2 and C3PD

- Improved chips based on previous CLICpix and CCPDv3
  - Bigger pixel matrix
  - Different pixel electronics
  - Guard ring around HV-CMOS pixels pads



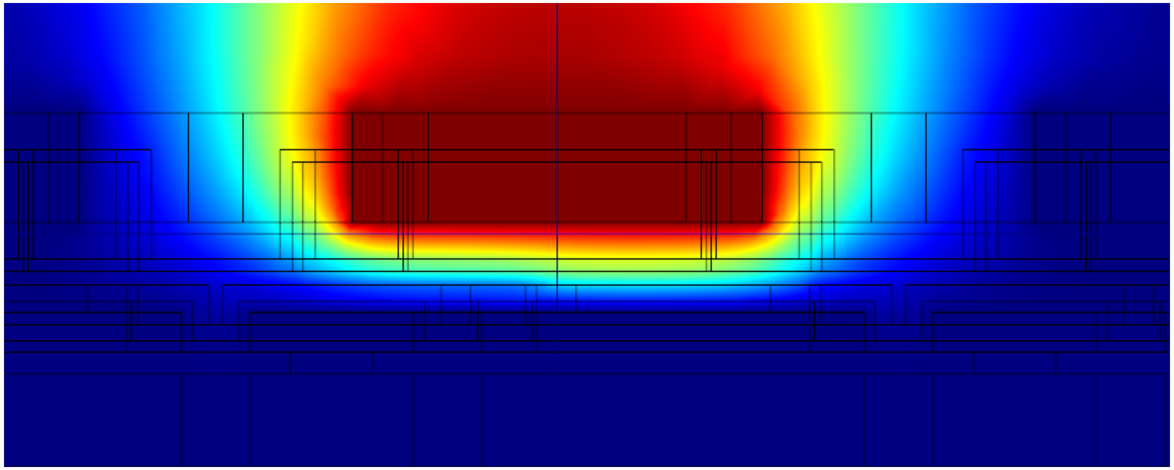
CLICpix2/C3PD Simulation
Guard Ring

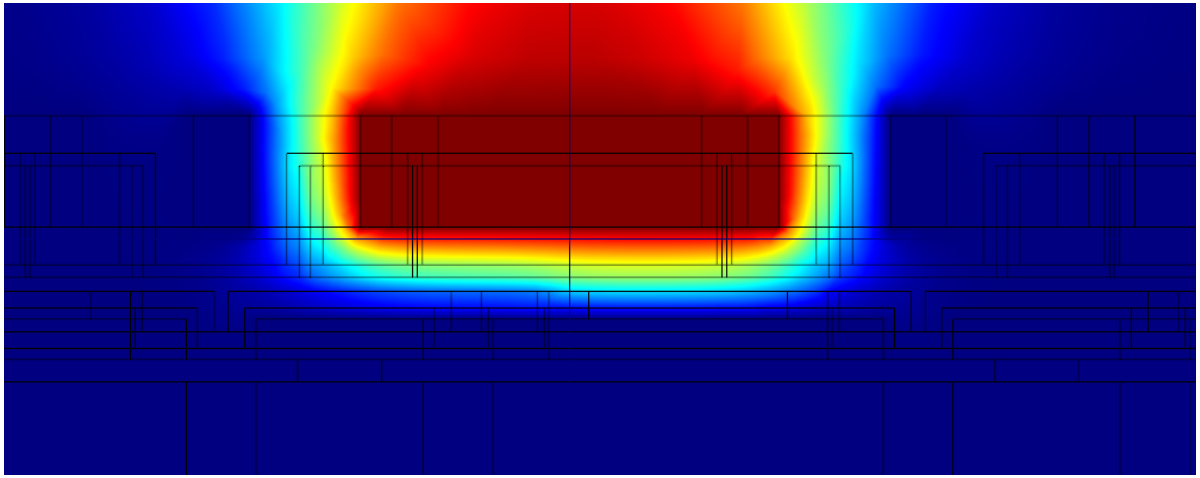
- With Guard Ring
  - Selected solid = Aluminium; **Terminal/Grounded**
- Without Guard Ring
  - Selected solid = Silica Glass; **Dielectric Coefficient = 2.09**



Results

without Guard Ring – Electric Potential



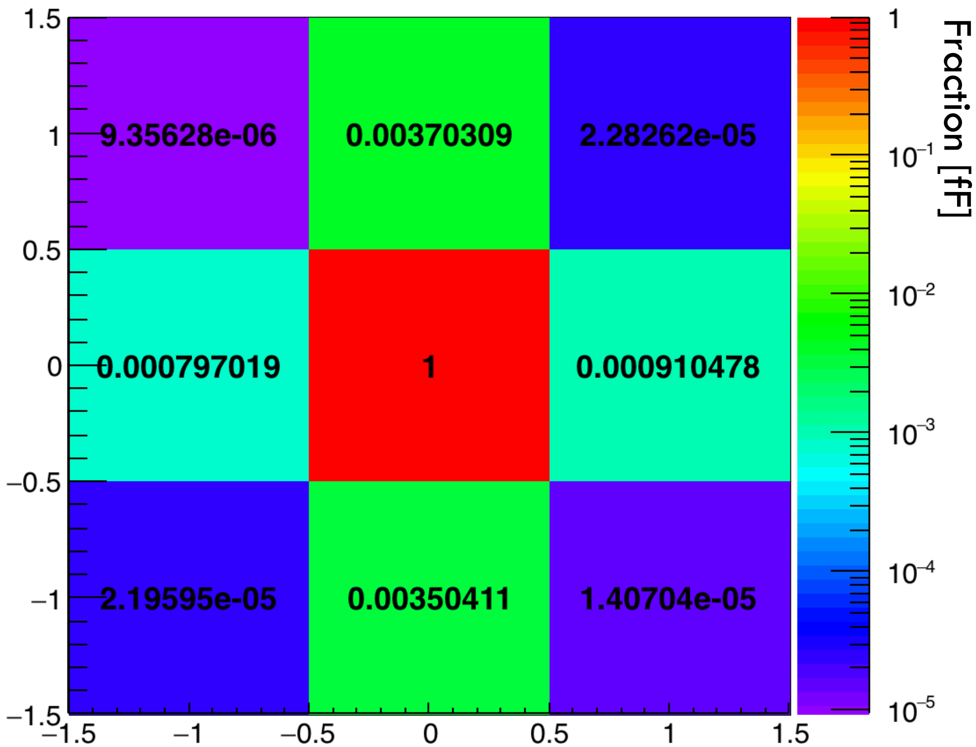


Results

C3PD→CLICpix2

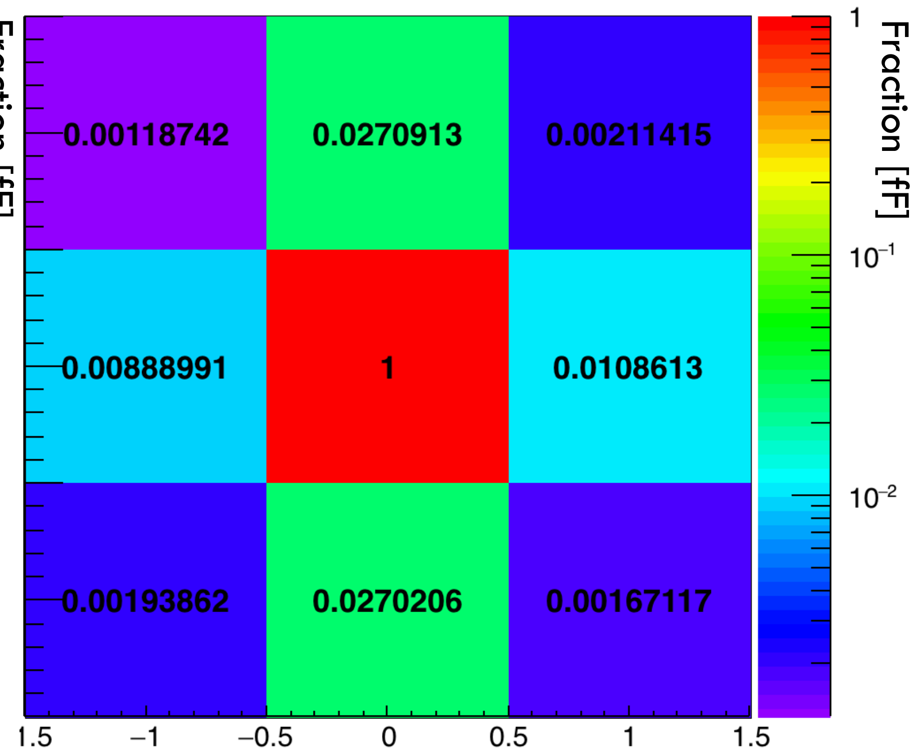
With Guard Ring

Central C3PD Pixel and CLIXpix2 terminals



Without Guard Ring

Central C3PD Pixel and CLIXpix2 terminals



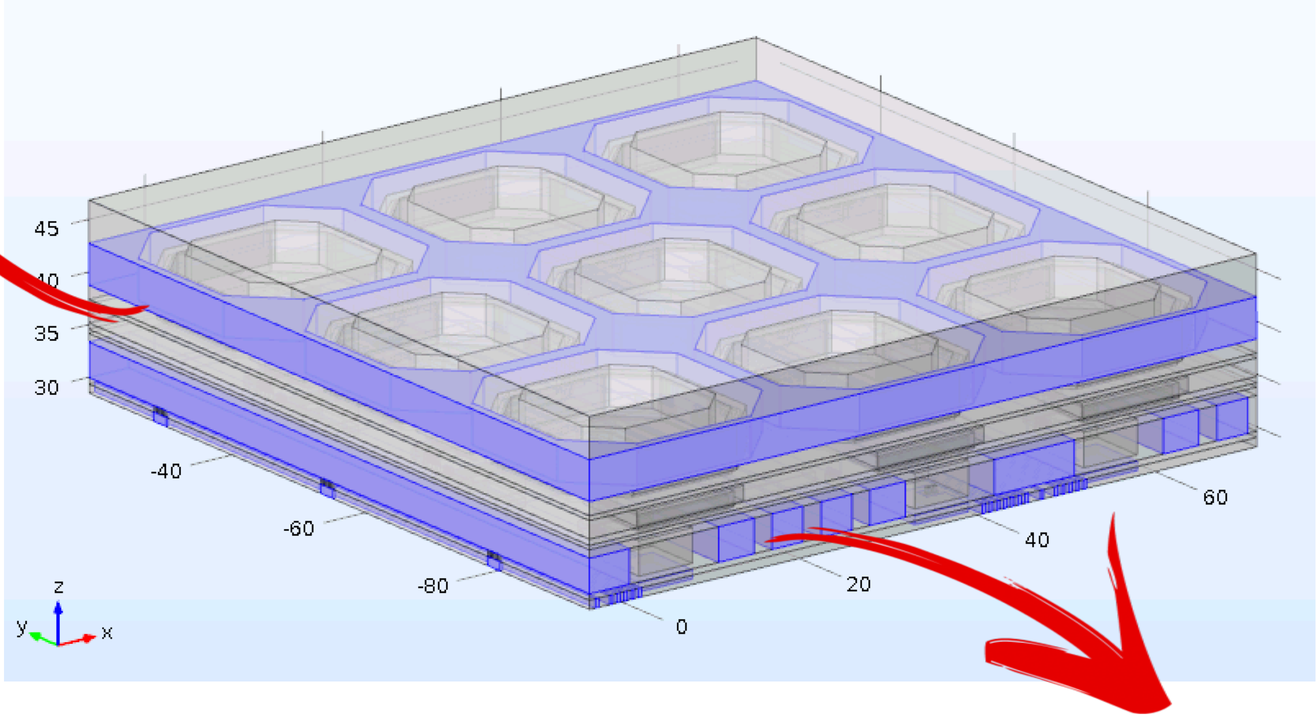
CROSS CAPACITANCE INCREASES ~10X!

Results

Capacitive Coupling to other metals

- Coupling of the central pixel in the C3PD chip with the Guard Ring and M6+M5

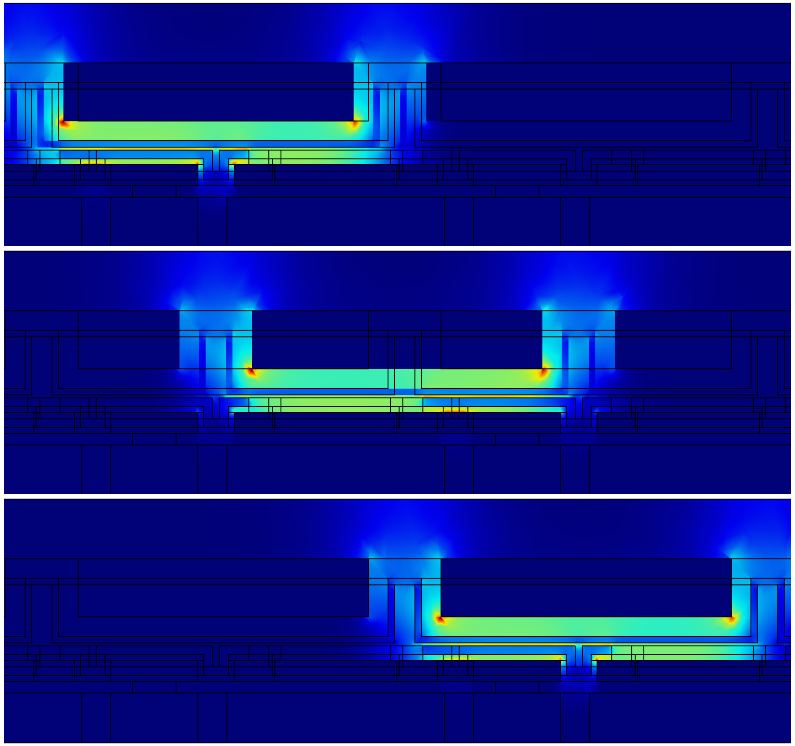
GR: 3.14 fF



M6+M5: 0.39 fF

Conclusions
and next steps

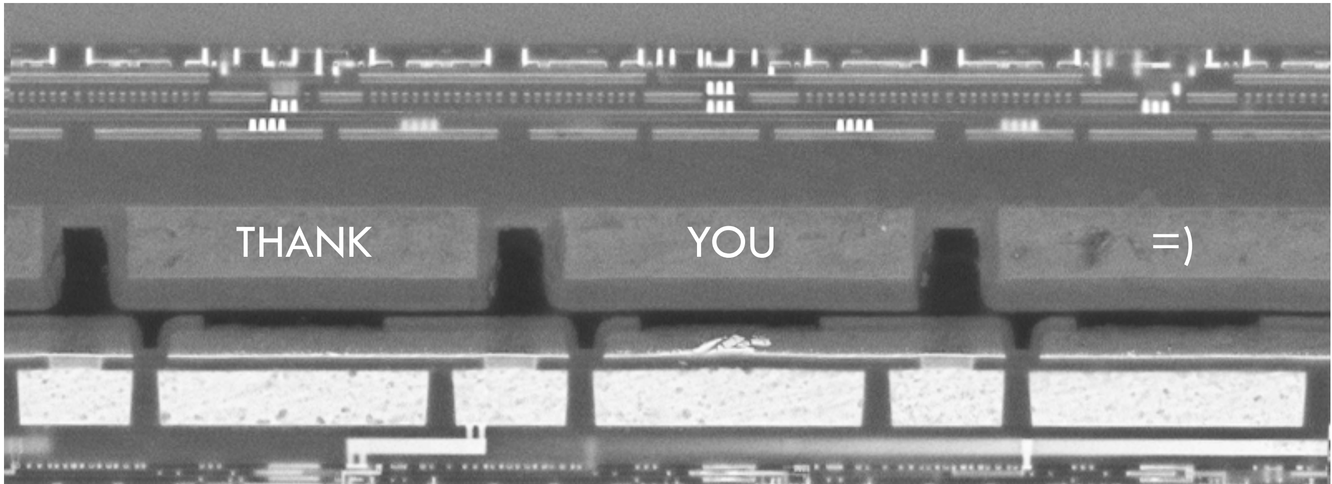
- Maxwell Capacitance Matrix
  - Figure of merit of coupling between chips
- Chips 3D model using SolidWorks
  - CLICpix + CCPDv3; CLICpix2 + C3PD
- COMSOL
  - A nice simulation software suite
  - Definition of terminals and metal layers + meshing
- Results
  - Coupling between the pixels
  - Effect of Guard-Rings around pixel pads
  - Misalignment effects



CCPDv3 shifting from -13 to 13 um away from ideal alignment. Color scale shows the electric field norm.

Conclusions
and next steps

- Next Steps
  - Analyze the misalignment effect in data from test beam
  - Create a digitizer for HV-CMOS sensors
    - Simulate, using TCAD/AllPix/Geant4, the readout chain
      - Optimize pixel pads geometry; induced charge sharing effects and etc…

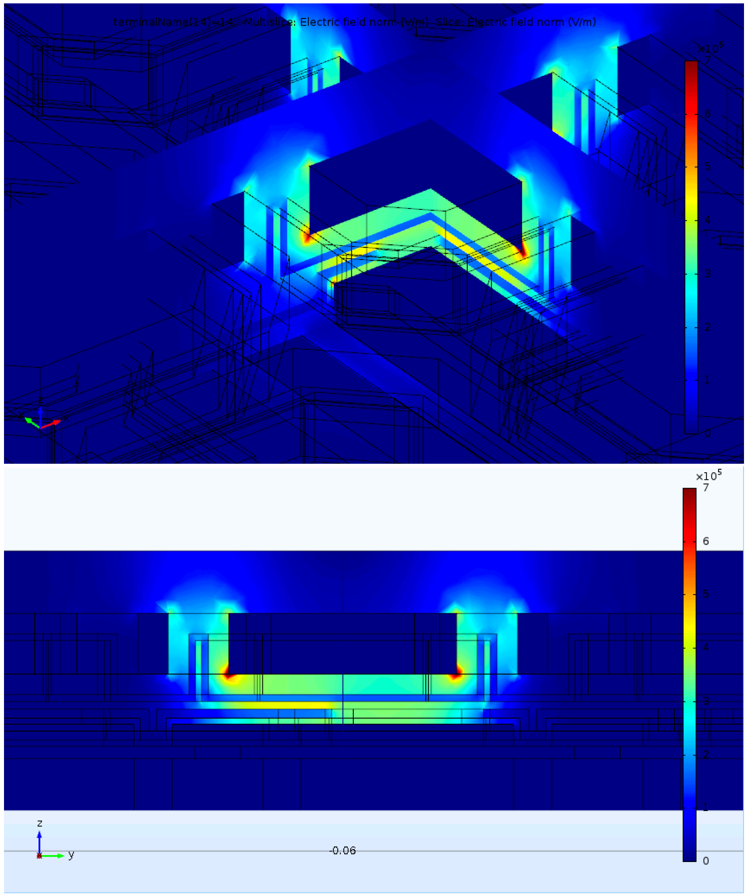


Cross section SEM picture of the CLICpix + CCPDv3 assembly

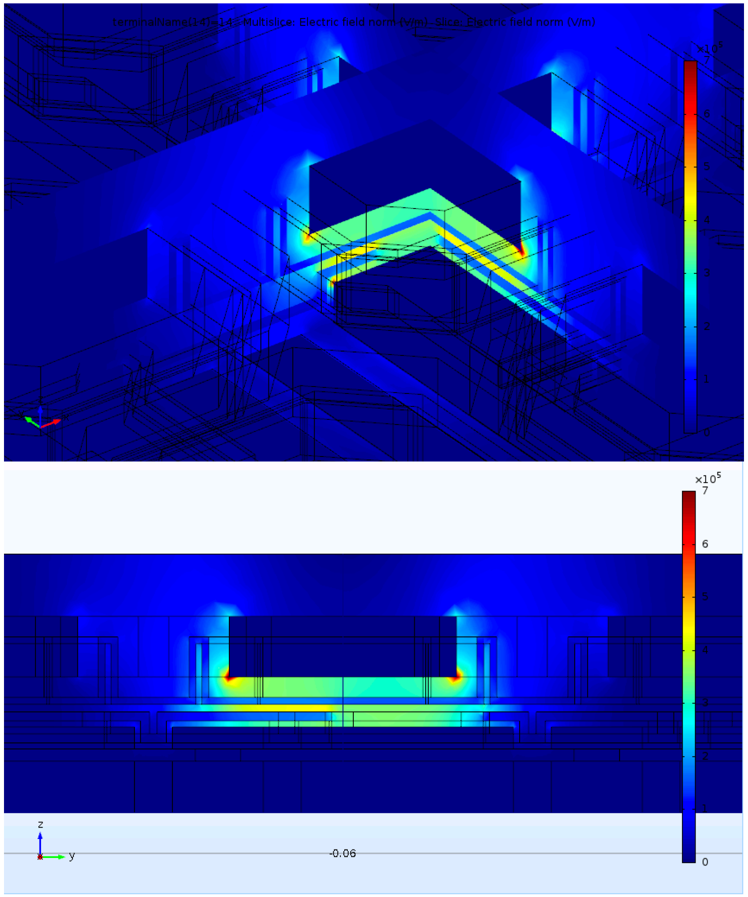
Results

without Guard Ring – Electric Field

With Guard Ring

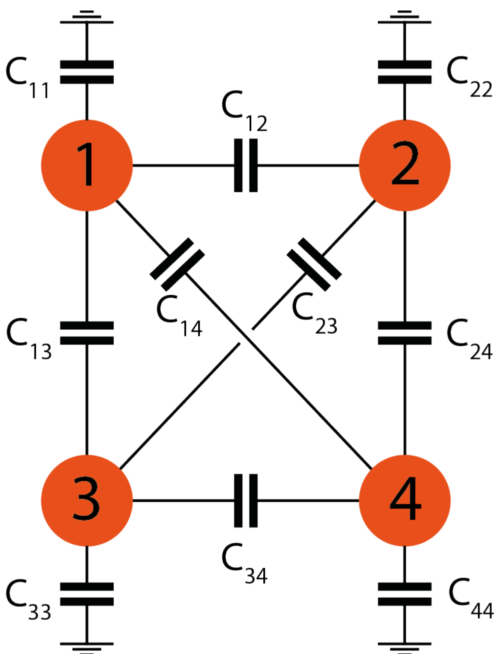


Without Guard Ring



Objective

- Calculate the capacitance between pixels in the CLICpix2 and C3PD chips
  - Maxwell Capacitance Matrix
    - E. Di Lorenzo, FastFieldSolvers, *The Maxwell Capacitance Matrix*, White Paper WP110301



- $$Q_i = \sum_{j=1}^{N+1} C_{ij}\varphi_j$$
- $$Q_1 = C_{11}\cdot V_1 + C_{12}\cdot(V_1 - V_2) + C_{13}\cdot(V_1 - V_3) + C_{14}\cdot(V_1 - V_4)$$
- $$Q_1 = (C_{11} + C_{12} + C_{13} + C_{14})\cdot V_1 - C_{12}\cdot V_2 - C_{13}\cdot V_3 - C_{14}\cdot V_4$$
- $$\begin{vmatrix} C_{11}+C_{12}+C_{13}+C_{14} & -C_{12} & -C_{13} & -C_{14} \end{vmatrix}$$

$$\begin{bmatrix} C_{11}+C_{12}+C_{13}+C_{14} & -C_{12} & -C_{13} & -C_{14} \\ -C_{21} & C_{21}+C_{22}+C_{23}+C_{24} & -C_{23} & -C_{24} \\ -C_{31} & -C_{32} & C_{31}+C_{32}+C_{33}+C_{34} & -C_{34} \\ -C_{41} & -C_{42} & -C_{43} & C_{41}+C_{42}+C_{43}+C_{44} \end{bmatrix}$$

$$\begin{bmatrix} C_{11}+C_{12}+\cdots+C_{1n} & -C_{12} & \cdots & -C_{1n} \\ -C_{21} & C_{21}+C_{22}+\cdots+C_{2n} & \cdots & -C_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ -C_{n1} & -C_{n2} & \cdots & C_{n1}+C_{n2}+\cdots+C_{nn} \end{bmatrix}$$

Capacitance

and its geometrical nature (quantitatively)

arXiv:physics/0702253

$$Q_i = \oint_{S_i} \sigma_i \, dS = -\varepsilon_0 \oint_{S_i} \nabla\phi \cdot \mathbf{n}_i \, dS, \quad (1) \qquad \sigma_i = \varepsilon_0 \mathbf{E} \cdot \mathbf{n}_i = -\varepsilon_0 \nabla\phi \cdot \mathbf{n}_i$$

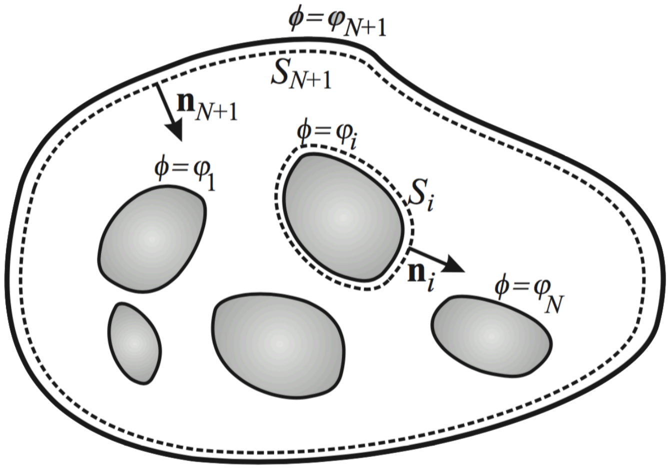
$$\phi(S_i) = \varphi_i, \quad \phi = \sum_{j=1}^{N+1} \varphi_j f_j \quad (2) \qquad f_j(S_i) = \delta_{ij}$$

Potential depends only on the chosen surface!

Applying grad in (2) and replacing it in (1)

$$Q_i = -\epsilon_0 \sum_{j=1}^{N+1} \oint_{S_i} \varphi_i f_j \cdot \mathbf{n}_i \, dS = \sum_{j=1}^{N+1} C_{ij} \varphi_j$$

$$C_{ij} \equiv -\varepsilon_0 \oint_{S_i} \nabla f_j \cdot \mathbf{n}_i \, dS$$



$$S_T = S_1 + \ldots + S_N + S_{N+1}$$

Simulation

COMSOL Multiphysics®

- Simulation Tool for Electrical, Mechanical, Fluid Flow, and Chemical Applications
  - Arbitrarily include **equations** describing a **material property**, **boundary**, **source** or **sink** term, or a unique set of **partial differential equations**

COMSOL Multiphysics®

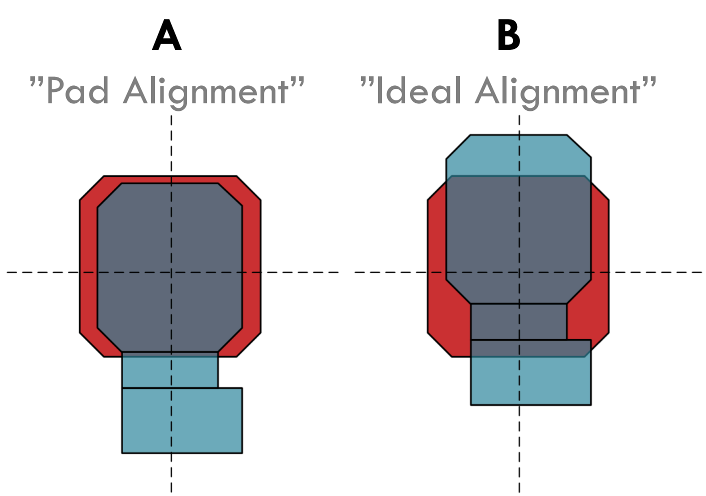
COMSOL Server™

ELECTRICAL	MECHANICAL	FLUID	CHEMICAL	MULTIPURPOSE	INTERFACING	
AC/DC Module	Heat Transfer Module	CFD Module	Chemical Reaction Engineering Module	Optimization Module	LiveLink™ *for* MATLAB®	LiveLink™ *for* Excel®
RF Module	Structural Mechanics Module	Mixer Module	Batteries & Fuel Cells Module	Material Library	CAD Import Module	Design Module
Wave Optics Module	Nonlinear Structural Materials Module	Microfluidics Module	Electrodeposition Module	Particle Tracing Module	ECAD Import Module	LiveLink™ *for* SOLIDWORKS®
Ray Optics Module	Geomechanics Module	Subsurface Flow Module	Corrosion Module		LiveLink™ *for* Inventor®	LiveLink™ *for* AutoCAD®
MEMS Module	Fatigue Module	Pipe Flow Module	Electrochemistry Module		LiveLink™ *for* Revit®	LiveLink™ *for* PTC® Creo® Parametric™
Plasma Module	Multibody Dynamics Module	Molecular Flow Module			LiveLink™ *for* PTC® Pro/ENGINEER®	LiveLink™ *for* Solid Edge®
Semiconductor Module	Acoustics Module				File Import *for* CATIA® V5	

Chips Alignment

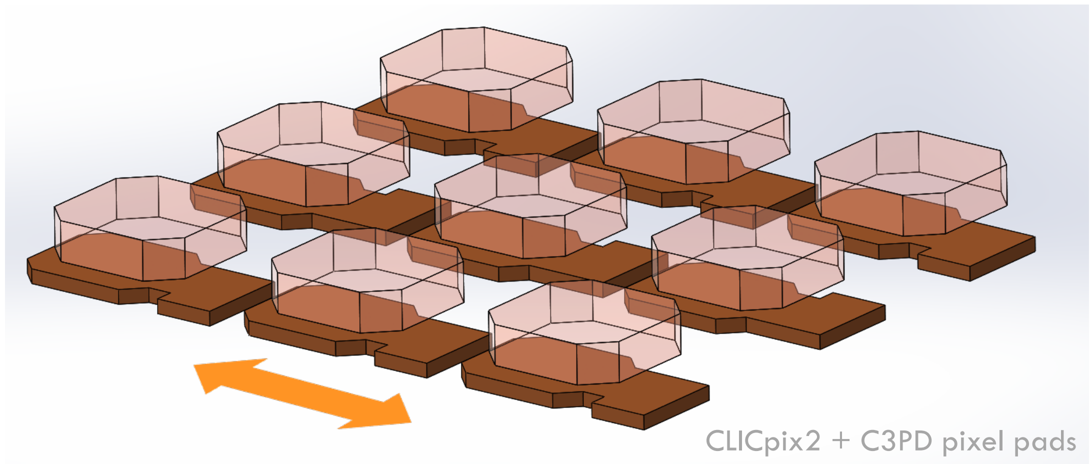
Two proposals

- Two alignment marks on the two sides of the chips
  - two different implementations of the alignment



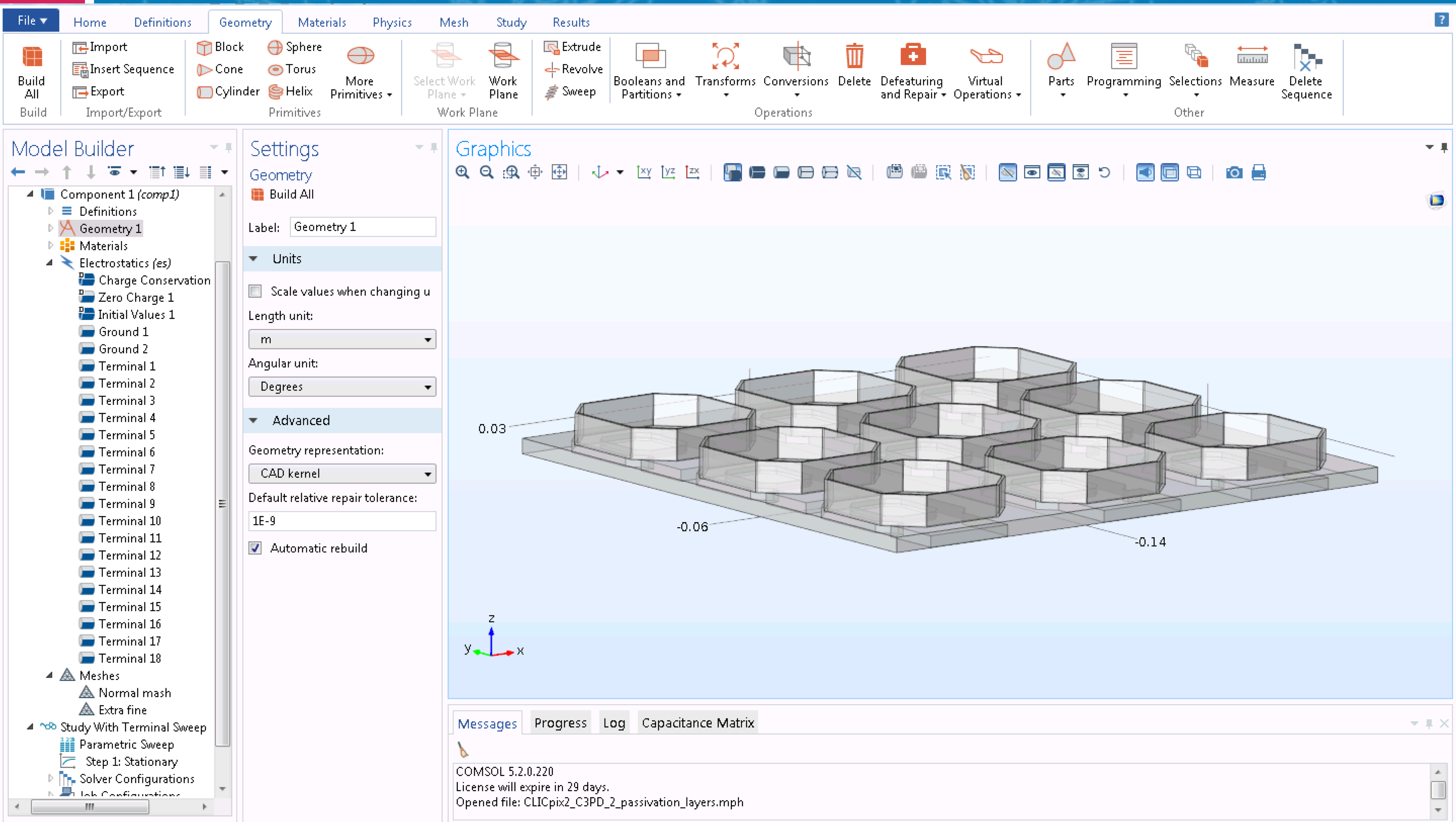
Used for Cross Section Measurements on **early assemblies**

Used For Test Beam on **later samples**



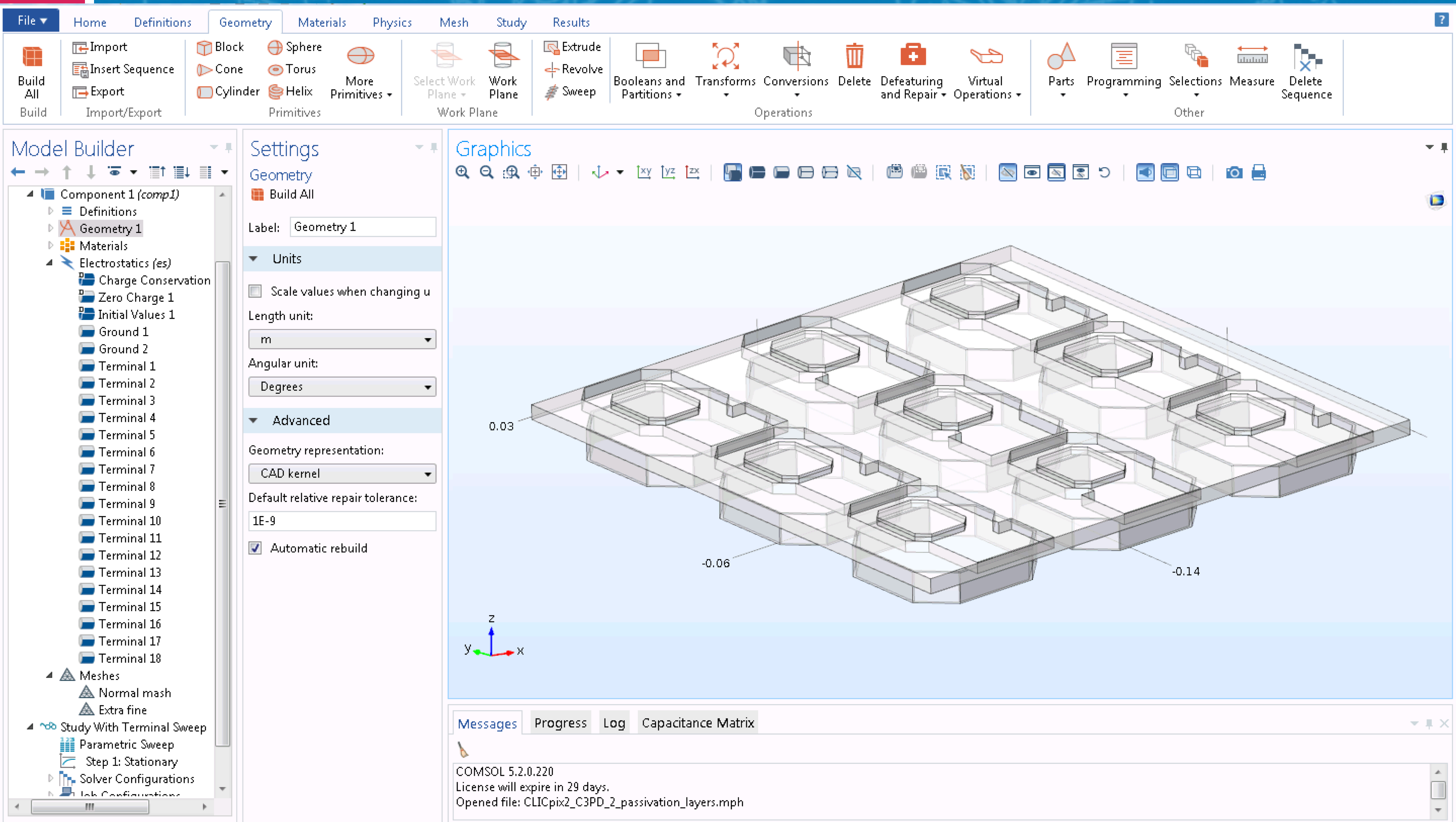
Geometry

Empty space = Glue Layer (2µm)



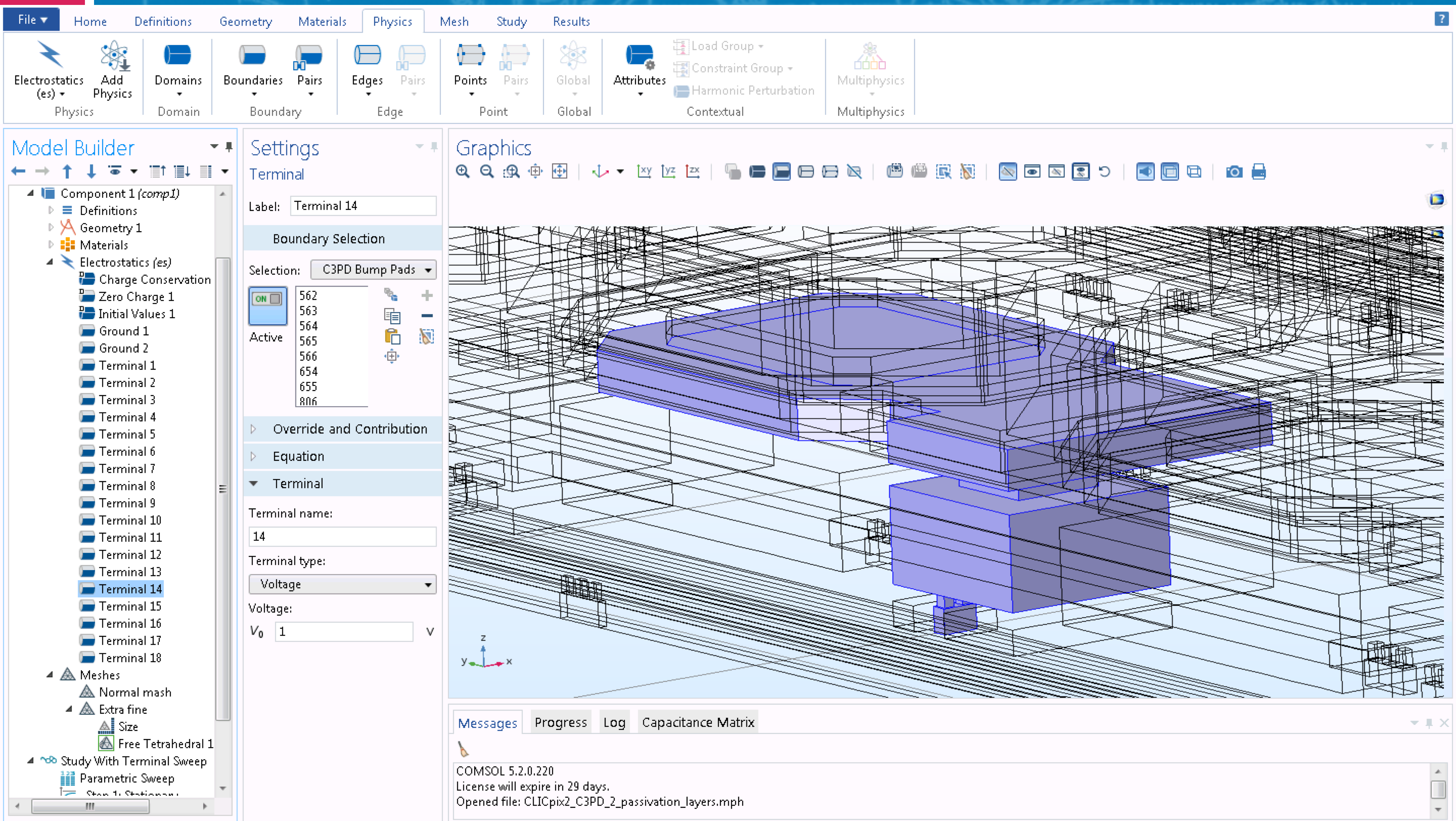
Geometry

Empty space = Glue Layer (2μm)



Simulation

COMSOL Multiphysics® - Terminals



Results

Capacitance Matrix

COMSOL path: Results ➔ Derived Values ➔ Global Matrix Evaluation ➔ Electrostatics ➔ Terminals ➔ Capacitance

Table 10 | Progress | Log

Capacitance (fF)																	
16.886	-0.39750	-1.5686E-8	-0.0014967	-5.7629E-5	-2.0997E-9	-4.2845E-10	-1.0636E-10	-7.7491E-13	-2.6928	-0.014929	-9.7037E-8	-0.0025388	-6.8890E-5	-1.2688E-8	-2.7128E-8	-4.9638E-9	-3.4026E-11
-0.39750	17.667	-0.39743	-5.7600E-5	-0.0014657	-5.7607E-5	-6.2144E-11	-3.5882E-10	-1.0650E-10	-0.016202	-2.6776	-0.014920	-3.2961E-5	-0.0024986	-6.8794E-5	-3.5494E-9	-2.3491E-8	-4.9723E-9
-1.5686E-8	-0.39743	17.327	-2.0964E-9	-5.7615E-5	-0.0015754	-4.5234E-13	-6.1819E-11	-4.4904E-10	-1.0170E-7	-0.016198	-2.6927	-9.3946E-9	-3.2873E-5	-0.0025520	-2.4359E-11	-3.5197E-9	-2.8074E-8
-0.0014967	-5.7600E-5	-2.0965E-9	16.887	-0.39736	-1.2395E-8	-0.0024343	-1.5725E-4	-3.3025E-9	-0.0025387	-6.8857E-5	-1.2669E-8	-2.6898	-0.014880	-8.5992E-8	-0.0030361	-5.0761E-5	-1.0888E-8
-5.7630E-5	-0.0014657	-5.7616E-5	-0.39736	17.667	-0.39730	-1.5718E-4	-0.0022368	-1.5725E-4	-3.2963E-5	-0.0024987	-6.8847E-5	-0.016120	-2.6746	-0.014876	-8.2951E-5	-0.0029634	-5.0759E-5
-2.0996E-9	-5.7607E-5	-0.0015754	-1.2395E-8	-0.39730	17.329	-3.3007E-9	-1.5728E-4	-0.0023546	-9.4453E-9	-3.2961E-5	-0.0025536	-8.7869E-8	-0.016122	-2.6898	-1.4377E-8	-8.3040E-5	-0.0030222
-4.2847E-10	-6.2143E-11	-4.5311E-13	-0.0024343	-1.5718E-4	-3.3008E-9	16.881	-0.39729	-1.4502E-8	-3.3869E-8	-4.9689E-9	-3.1233E-11	-0.0030362	-5.0752E-5	-1.0896E-8	-2.6923	-0.014942	-9.8739E-8
-1.0637E-10	-3.5882E-10	-6.1818E-11	-1.5725E-4	-0.0022367	-1.5728E-4	-0.39729	17.665	-0.39736	-5.4210E-9	-2.8627E-8	-4.9704E-9	-8.2976E-5	-0.0029644	-5.0760E-5	-0.016151	-2.6769	-0.014938
-7.7481E-13	-1.0650E-10	-4.4904E-10	-3.3025E-9	-1.5725E-4	-0.0023547	-1.4502E-8	-0.39736	17.328	-3.8498E-11	-5.4247E-9	-3.3749E-8	-1.4350E-8	-8.3054E-5	-0.0030232	-9.7434E-8	-0.016157	-2.6923
-2.6928	-0.016202	-1.0169E-7	-0.0025386	-3.2962E-5	-9.4447E-9	-3.3868E-8	-5.4207E-9	-3.8488E-11	7.0207	-0.030083	-2.9487E-6	-0.033500	-6.8671E-4	-3.6036E-7	-2.9691E-6	-3.6108E-7	-1.5354E-9
-0.014929	-2.6776	-0.016198	-6.8857E-5	-0.0024986	-3.2961E-5	-4.9687E-9	-2.8627E-8	-5.4247E-9	-0.030083	7.0506	-0.030060	-6.8650E-4	-0.032827	-6.8641E-4	-3.6184E-7	-2.6066E-6	-3.6166E-7
-9.7041E-8	-0.014920	-2.6927	-1.2670E-8	-6.8845E-5	-0.0025535	-3.1196E-11	-4.9703E-9	-3.3749E-8	-2.9487E-6	-0.030061	6.9887	-3.6012E-7	-6.8610E-4	-0.033467	-1.5370E-9	-3.6180E-7	-2.9708E-6
-0.0025387	-3.2961E-5	-9.3938E-9	-2.6898	-0.016120	-8.7866E-8	-0.0030362	-8.2977E-5	-1.4350E-8	-0.033500	-6.8650E-4	-3.6010E-7	7.0538	-0.029399	-2.5881E-6	-0.033180	-6.8078E-4	-3.5927E-7
-6.8890E-5	-0.0024987	-3.2873E-5	-0.014880	-2.6746	-0.016122	-5.0752E-5	-0.0029644	-8.3054E-5	-6.8671E-4	-0.032827	-6.8610E-4	-0.029399	7.0835	-0.029376	-6.8142E-4	-0.032472	-6.8087E-4
-1.2689E-8	-6.8793E-5	-0.0025521	-8.5996E-8	-0.014876	-2.6898	-1.0897E-8	-5.0760E-5	-0.0030231	-3.6036E-7	-6.8641E-4	-0.033467	-2.5881E-6	-0.029376	7.0533	-3.5956E-7	-6.8097E-4	-0.033181
-2.7129E-8	-3.5492E-9	-2.4360E-11	-0.0030360	-8.2949E-5	-1.4376E-8	-2.6923	-0.016151	-9.7434E-8	-2.9692E-6	-3.6183E-7	-1.5373E-9	-0.033180	-6.8142E-4	-3.5954E-7	7.0201	-0.030088	-2.9502E-6
-4.9640E-9	-2.3491E-8	-3.5195E-9	-5.0761E-5	-0.0029632	-8.3040E-5	-0.014942	-2.6769	-0.016157	-3.6109E-7	-2.6066E-6	-3.6180E-7	-6.8079E-4	-0.032472	-6.8096E-4	-0.030088	7.0499	-0.030073
-3.4016E-11	-4.9721E-9	-2.8072E-8	-1.0888E-8	-5.0758E-5	-0.0030223	-9.8737E-8	-0.014938	-2.6923	-1.5355E-9	-3.6165E-7	-2.9707E-6	-3.5927E-7	-6.8087E-4	-0.033181	-2.9502E-6	-0.030073	7.0196

Results

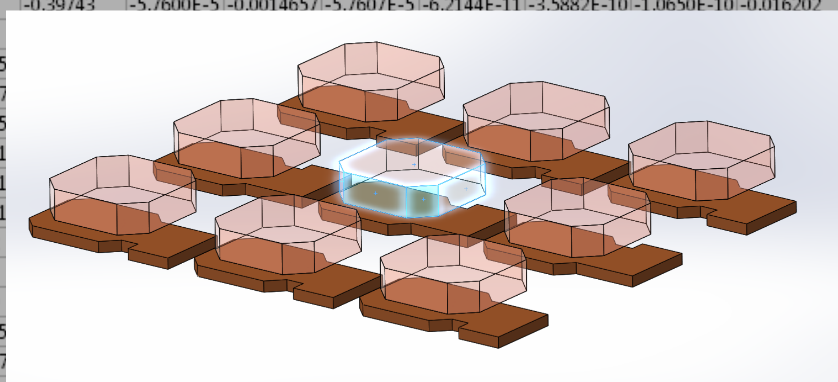
Capacitance Matrix

COMSOL path: Results ➔ Derived Values ➔ Global Matrix Evaluation ➔ Electrostatics ➔ Terminals ➔ Capacitance

Table 10 | Progress | Log

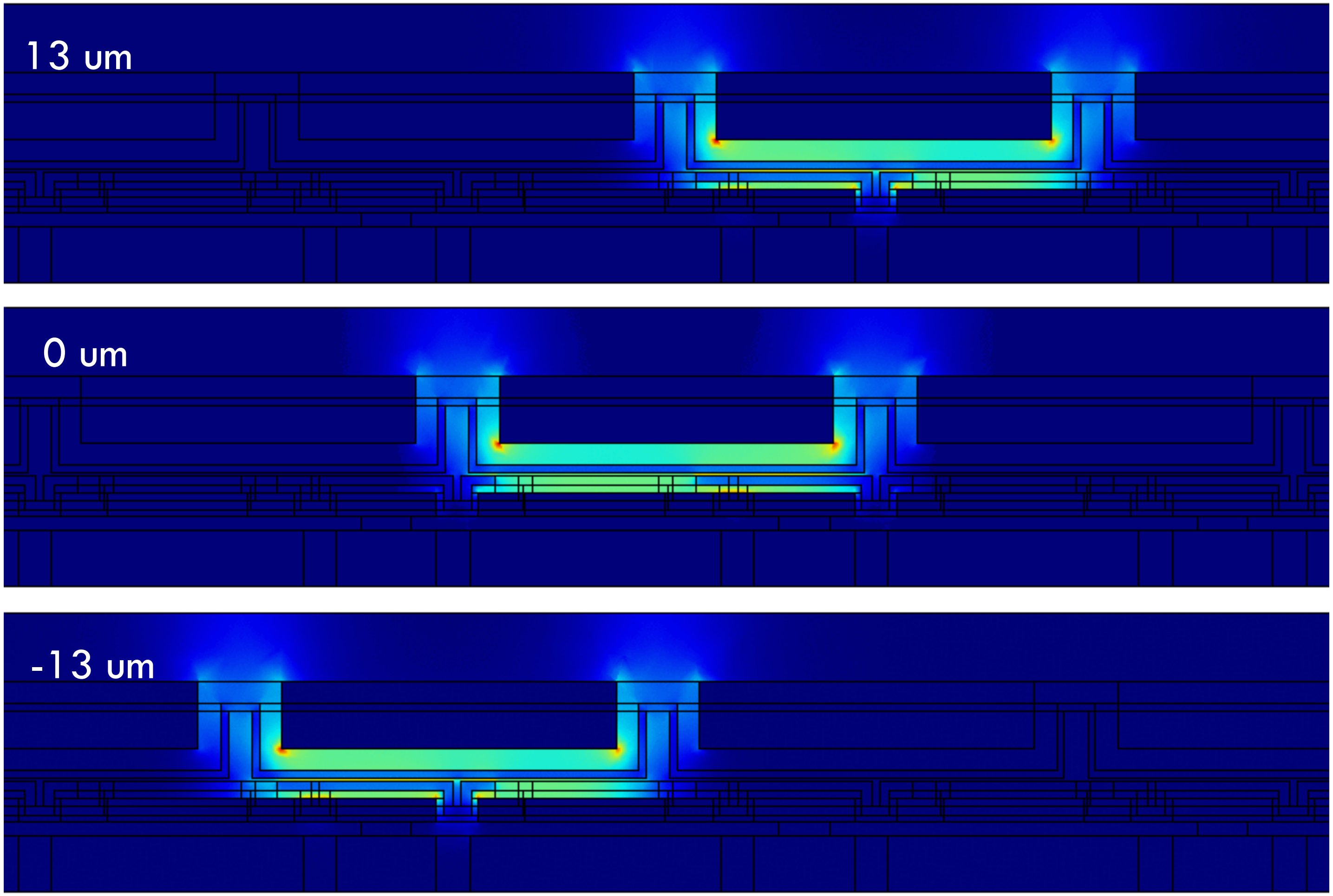
Terminal 14 = Middle C3PD pixel

Capacitance (fF)																	
16.886	-0.39750	-1.5686E-8	-0.0014967	-5.7629E-5	-2.0997E-9	-4.2845E-10	-1.0636E-10	-7.7491E-13	-2.6928	-0.014929	-9.7037E-8	-0.0025388	-6.8890E-5	-1.2688E-8	-2.7128E-8	-4.9638E-9	-3.4026E-11
-0.39750	17.667	-0.39743	-5.7600E-5	-0.0014657	-5.7607E-5	-6.2144E-11	-3.5882E-10	-1.0650E-10	-0.016202	-2.6776	-0.014920	-3.2961E-5	-0.0024986	-6.8794E-5	-3.5494E-9	-2.3491E-8	-4.9723E-9
-1.5686E-8	-0.39743	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.016198	-2.6927	-9.3946E-9	-3.2873E-5	-0.0025520	-2.4359E-11	-3.5197E-9	-2.8074E-8
-0.0014967	-5.7600E-5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.8857E-5	-1.2669E-8	-2.6898	-0.014880	-8.5992E-8	-0.0030361	-5.0761E-5	-1.0888E-8
-5.7630E-5	-0.0014657	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.0024987	-6.8847E-5	-0.016120	-2.6746	-0.014876	-8.2951E-5	-0.0029634	-5.0759E-5
-2.0996E-9	-5.7607E-5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.2961E-5	-0.0025536	-8.7869E-8	-0.016122	-2.6898	-1.4377E-8	-8.3040E-5	-0.0030222
-4.2847E-10	-6.2143E-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4.9689E-9	-3.1233E-11	-0.0030362	-5.0752E-5	-1.0896E-8	-2.6923	-0.014942	-9.8739E-8
-1.0637E-10	-3.5882E-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.8627E-8	-4.9704E-9	-8.2976E-5	-0.0029644	-5.0760E-5	-0.016151	-2.6769	-0.014938
-7.7481E-13	-1.0650E-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-5.4247E-9	-3.3749E-8	-1.4350E-8	-8.3054E-5	-0.0030232	-9.7434E-8	-0.016157	-2.6923
-2.6928	-0.016202	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.030083	-2.9487E-6	-0.033500	-6.8671E-4	-3.6036E-7	-2.9691E-6	-3.6108E-7	-1.5354E-9
-0.014929	-2.6776	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.0506	-0.030060	-6.8650E-4	-0.032827	-6.8641E-4	-3.6184E-7	-2.6066E-6	-3.6166E-7
-9.7041E-8	-0.014920	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.030061	6.9887	-3.6012E-7	-6.8610E-4	-0.033467	-1.5370E-9	-3.6180E-7	-2.9708E-6
-0.0025387	-3.2961E-5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.8650E-4	-3.6010E-7	7.0538	-0.029399	-2.5881E-6	-0.033180	-6.8078E-4	-3.5927E-7
-6.8890E-5	-0.0024987	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.032827	-6.8610E-4	-0.029399	7.0835	-0.029376	-6.8142E-4	-0.032472	-6.8087E-4
-1.2689E-8	-6.8793E-5	-0.0025521	-8.5996E-8	-0.014876	-2.6898	-1.0897E-8	-5.0760E-5	-0.0030231	-3.6036E-7	-6.8641E-4	-0.033467	-2.5881E-6	-0.029376	7.0533	-3.5956E-7	-6.8097E-4	-0.033181
-2.7129E-8	-3.5492E-9	-2.4360E-11	-0.0030360	-8.2949E-5	-1.4376E-8	-2.6923	-0.016151	-9.7434E-8	-2.9692E-6	-3.6183E-7	-1.5373E-9	-0.033180	-6.8142E-4	-3.5954E-7	7.0201	-0.030088	-2.9502E-6
-4.9640E-9	-2.3491E-8	-3.5195E-9	-5.0761E-5	-0.0029632	-8.3040E-5	-0.014942	-2.6769	-0.016157	-3.6109E-7	-2.6066E-6	-3.6180E-7	-6.8079E-4	-0.032472	-6.8096E-4	-0.030088	7.0499	-0.030073
-3.4016E-11	-4.9721E-9	-2.8072E-8	-1.0888E-8	-5.0758E-5	-0.0030223	-9.8737E-8	-0.014938	-2.6923	-1.5355E-9	-3.6165E-7	-2.9707E-6	-3.5927E-7	-6.8087E-4	-0.033181	-2.9502E-6	-0.030073	7.0196



Misalignment Scan (Via direction)

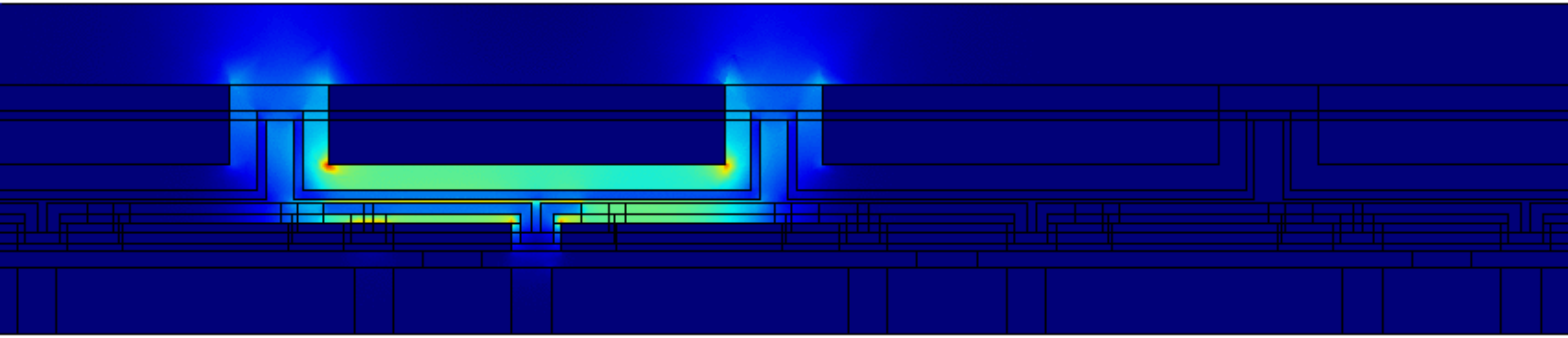
Electric field norm between pixels



CCPDv3 shifting from -13 to 13 um away from ideal alignment.
Color scale shows the electric field norm.

Misalignment Scan (Via direction)

Electric field norm between pixels



Animated GIF - CCPDv3 shifting from -13 to 13 um away from ideal alignment.
Color scale shows the electric field norm.