Silicon Technologies for the CLIC Vertex Detector

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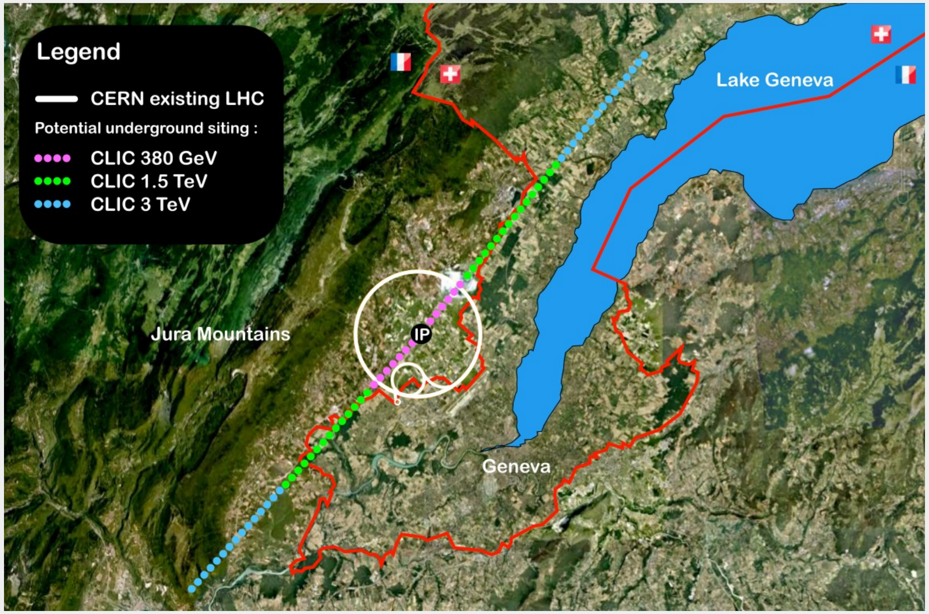
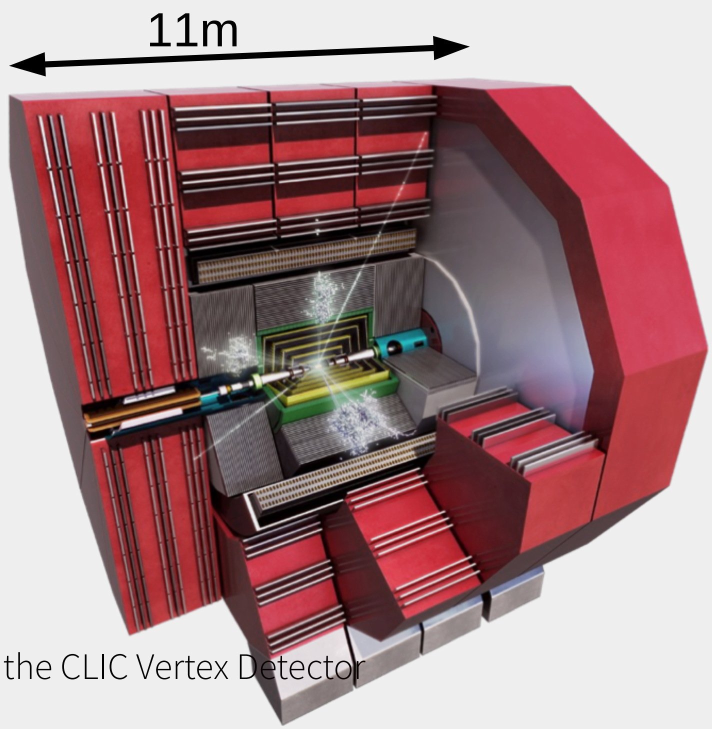
on behalf of the CLICdp Collaboration

The Compact Linear Collider

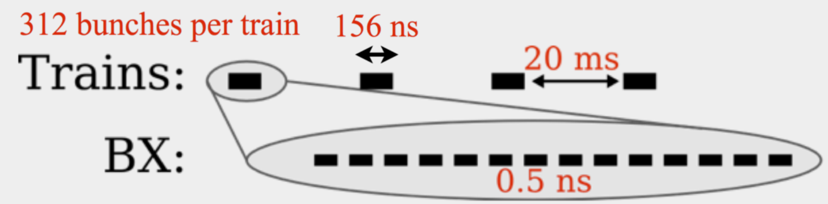
- Proposed linear collider with novel **two-beam acceleration** method
- Achieves high field gradients ~100 MV/m
- Construction in **3 stages**
  - from 380 GeV (11 km) to 3 TeV (50 km)
  - Physics goals: precision SM Higgs, Top and BSM physics
  - Luminosity at 3 TeV: $6x10^{34}$ $cm^{-2}s^{-1}$
- Requirements in **CLIC detector** driven by
  - Precision required for physics
  - Experimental conditions: Beam-induced background , Beam structure



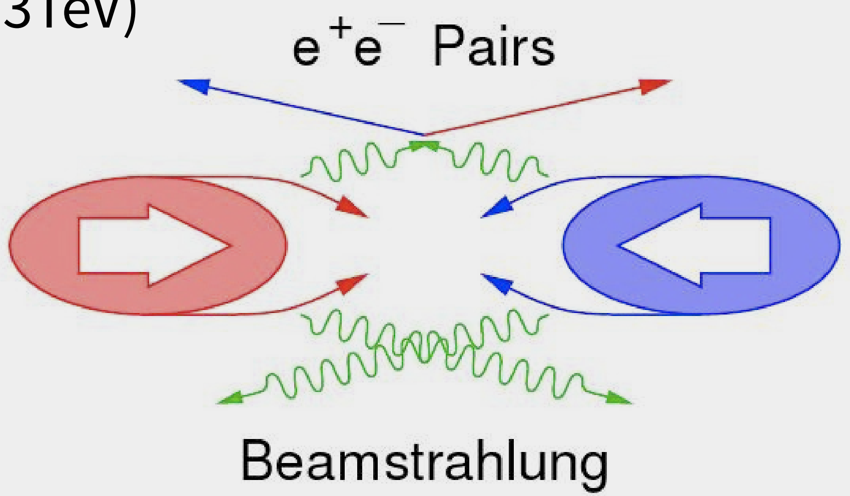


Experimental Conditions at CLIC

- CLIC beam structure drives design
  - Spacing between bunches: 0.5ns
  - Trains of 312 bunches, 50Hz repetition rate
  - Transverse beam size ~nm



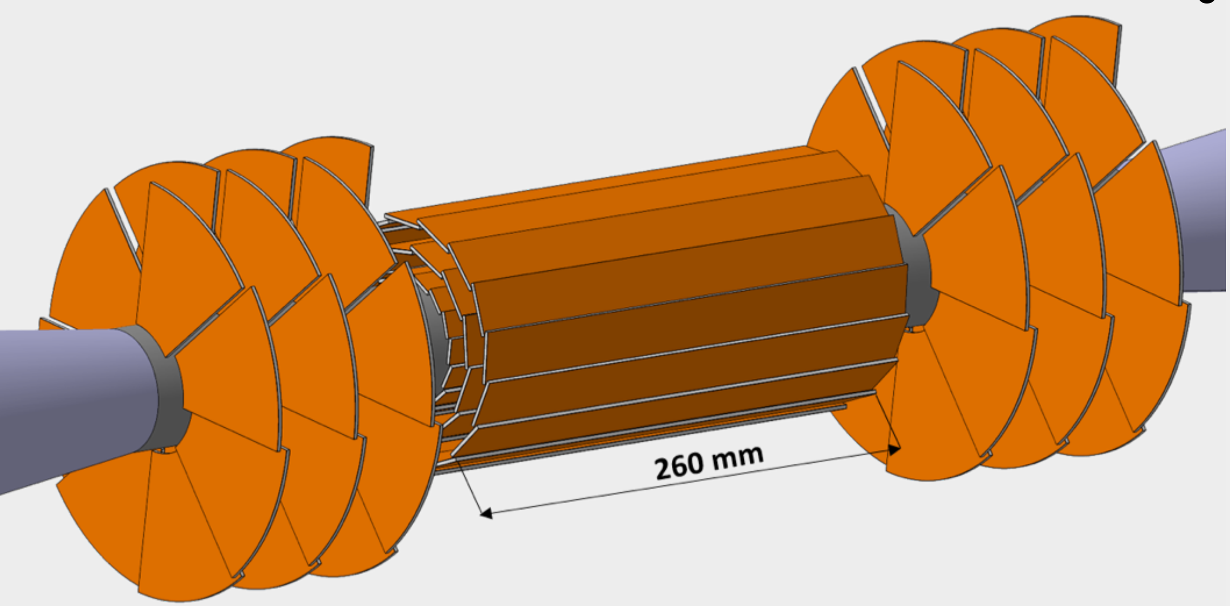
- High bunch density leads to interactions between bunches
  - Large experimental background from **γ γ → hadrons / e+e-** (beamstrahlung):
    ~100 particles/BX within acceptance (at 3TeV)
  - Mostly in forward direction
  - Timing cuts can reduce impact



- **Low radiation** environment
  - Factor 10^4 lower than at LHC

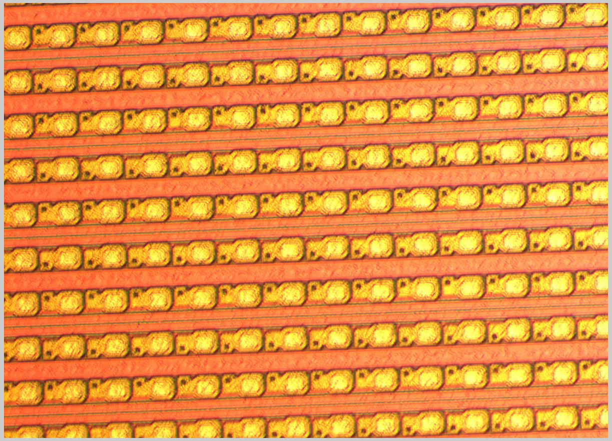
The CLIC Vertex Detector

- Requirements
  - **Low material budget:** 0.2 % X_0 per layer (~200µm of Si)
  - **Low power consumption:** forced air flow, power pulsing
  - **Fast timing to reduce backgrounds:** 10 ns timestamping
  - **High spatial resolution:** 3 µm single hit resolution



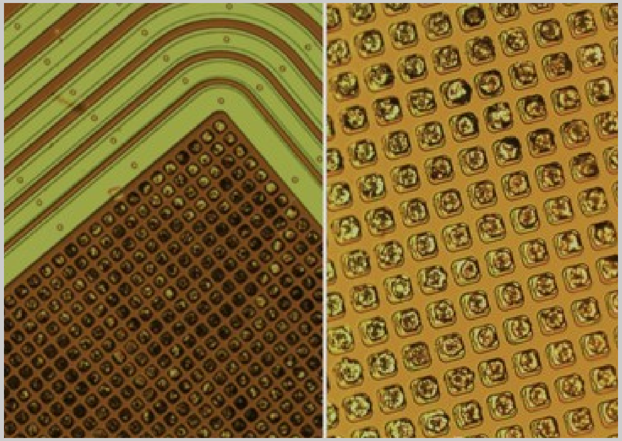
- Current Design
  - Hybrid pixel detector: 50µm ASIC, 50µm sensor
  - 25µm square pixels
  - Either planar sensors or capacitively coupled active sensors

Overview



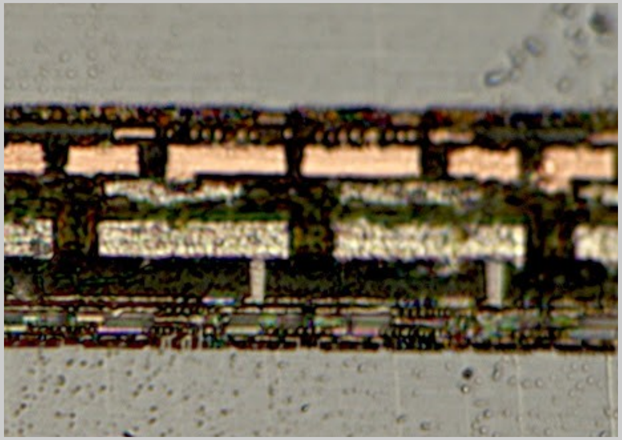
Readout ASICs

- CLICpix, CLICpix2



Planar Sensors

- Thin sensors
- Active edge



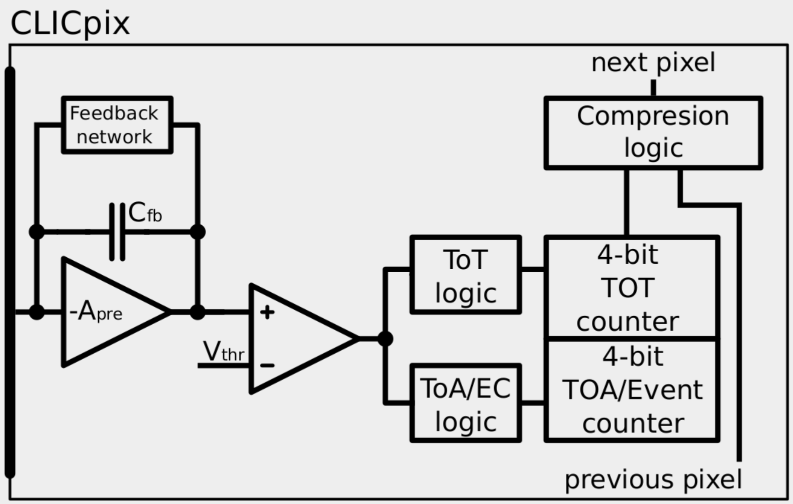
Active Sensors

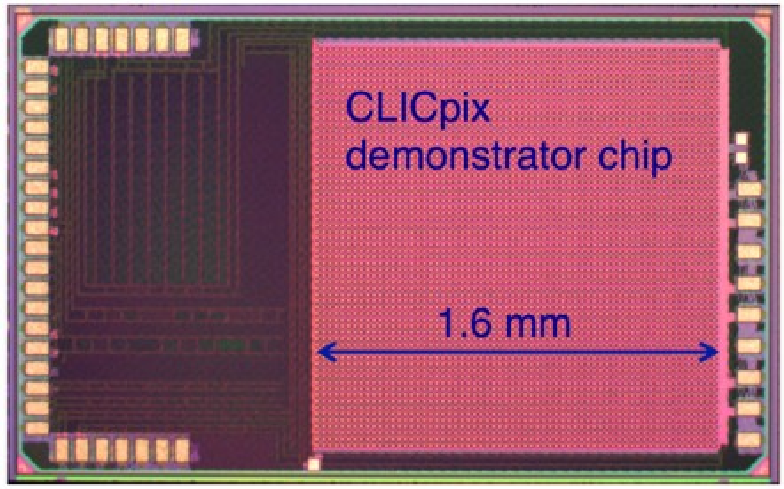
- CCPDv3, C3PD
- Capacitively coupled

Not covered here: Powering, Cooling, Light-weight Supports, Detector Integration and more...

The CLICpix Prototype Readout Chip

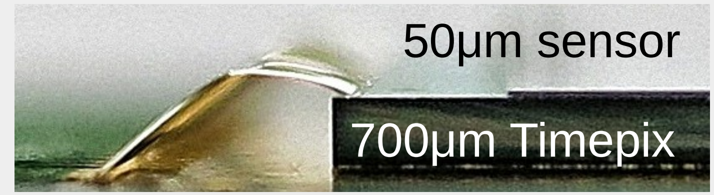
- First prototype ASIC to meet CLIC vertex detector requirements
  - Timepix/Medipix chip family
  - 65nm CMOS, small pitch 25µm x 25µm
- Active matrix of 64 x 64 pixels
- Simultaneous per-pixel measurement of 4-bit ToT and 4-bit ToA
- Shutter-based acquisition with (optional) on-chip compression
- Power pulsing of the pixel matrix

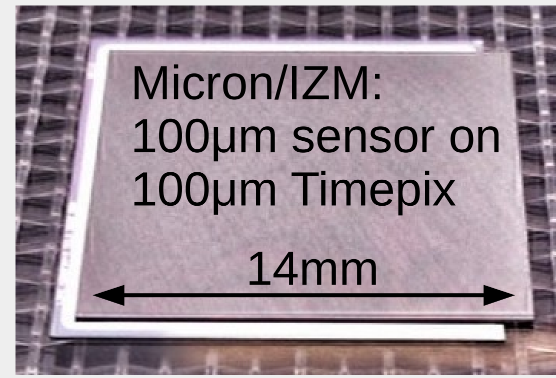


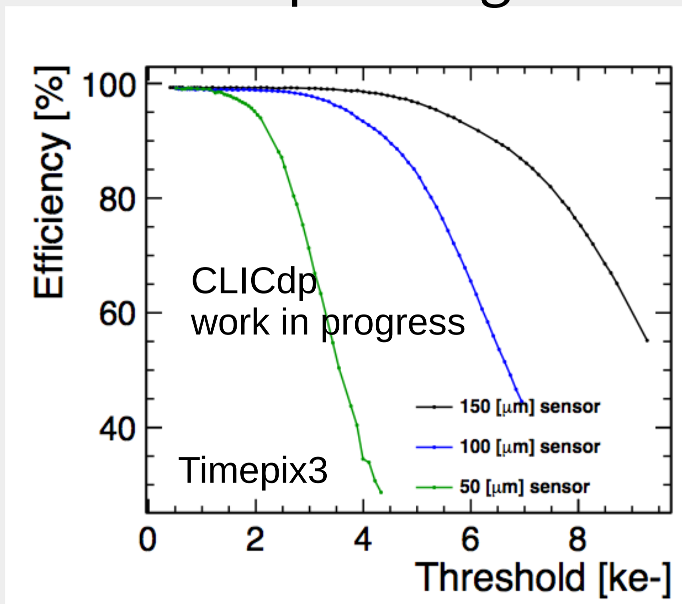


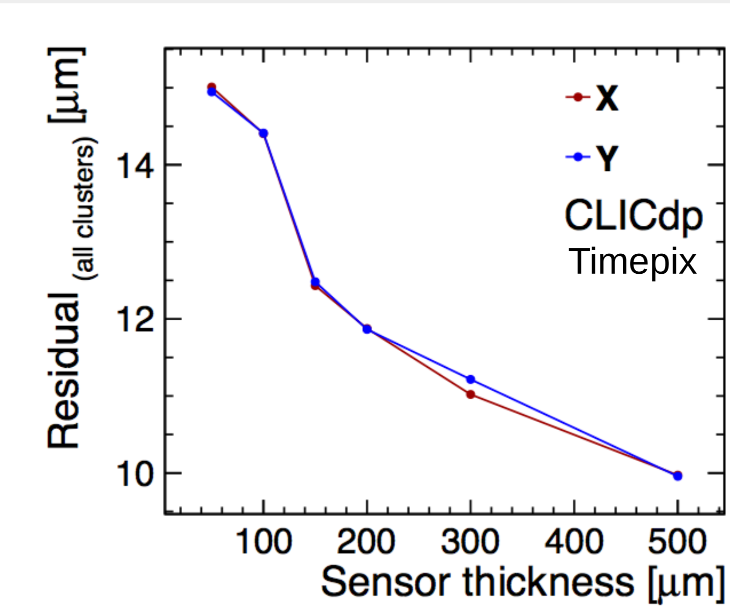
Planar Sensors - Thin

- Test beam studies using Timepix(3) ASIC
- Sensors, 50 - 500µm thick, 55µm pitch
  - Thinnest (full) assembly: 100µm + 100µm
- Study performance of thin planar sensors
  - High detection efficiency even for 50µm thin sensor under normal operating conditions
  - Resolution limited by charge sharing / cluster size





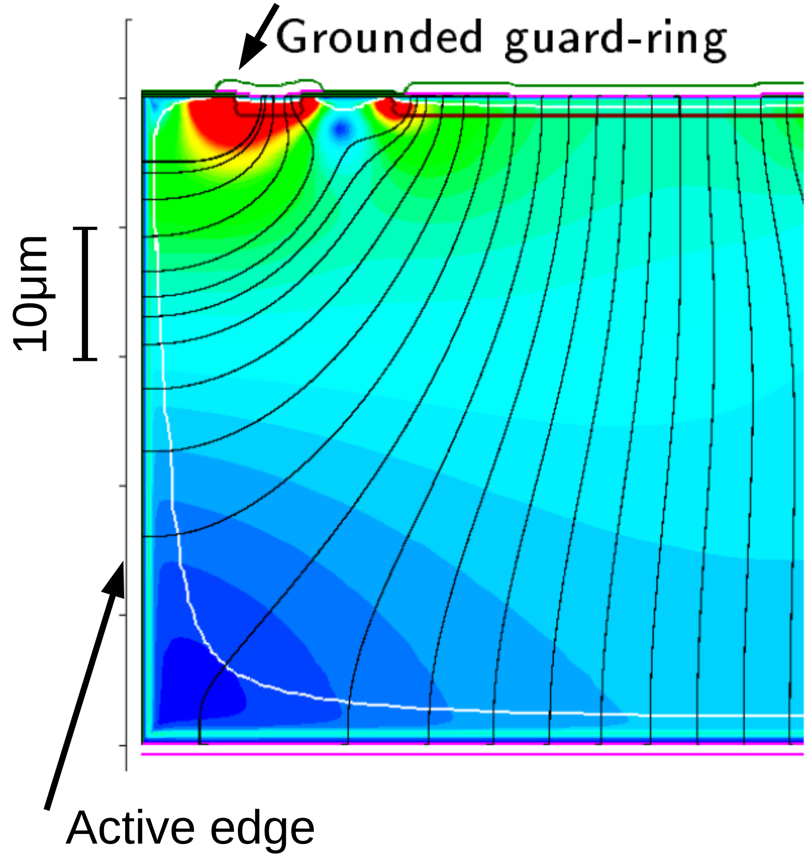




Planar Sensors – Active Edge

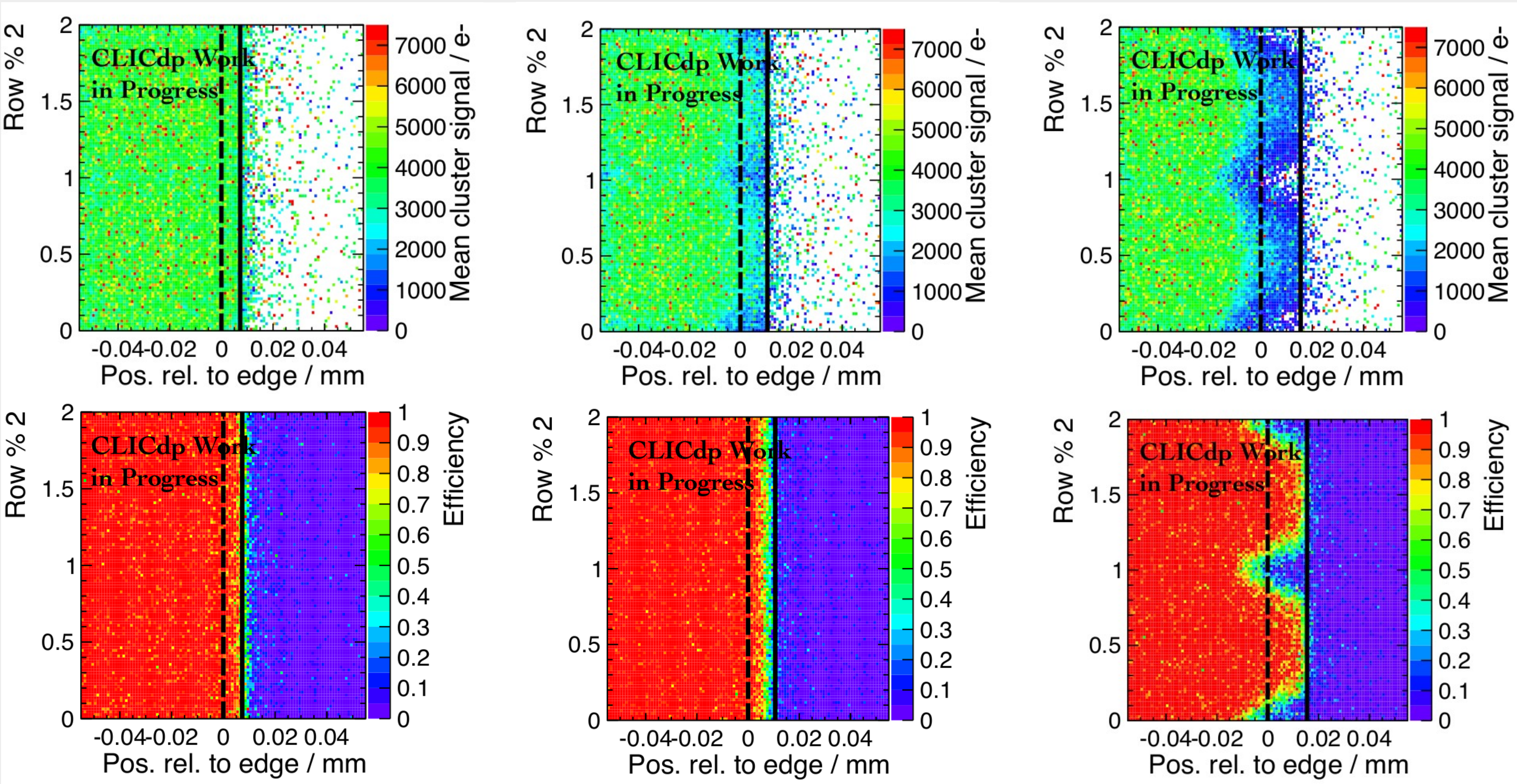
- Study feasibility of thin sensors with active edge
  - Using Timepix3 readout ASICs
- Sensors: Advacam MPW
  - 50µm thick n-in-p sensors
  - DRIE (Deep Reactive-Ion Etching)
  - Implantation on sensor side → extension of backside electrode
  - Different guard ring (GR) designs
- Measurements in agreement with TCAD simulations

TCAD simulation:
electric field in edge region



Planar Sensors – Active Edge, 50µm thick

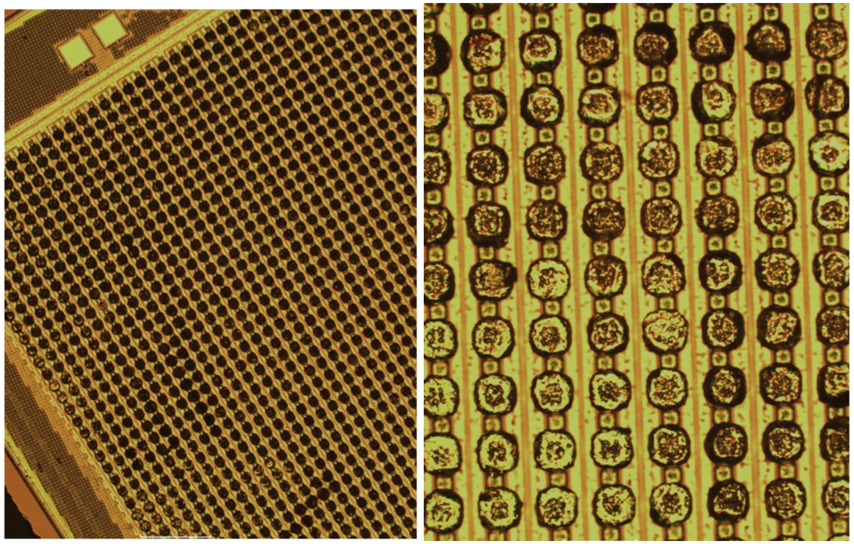
- Without GR and with floating GR:
  fully efficient up to the physical sensor edge
- With grounded GR:
  signal/efficiency loss



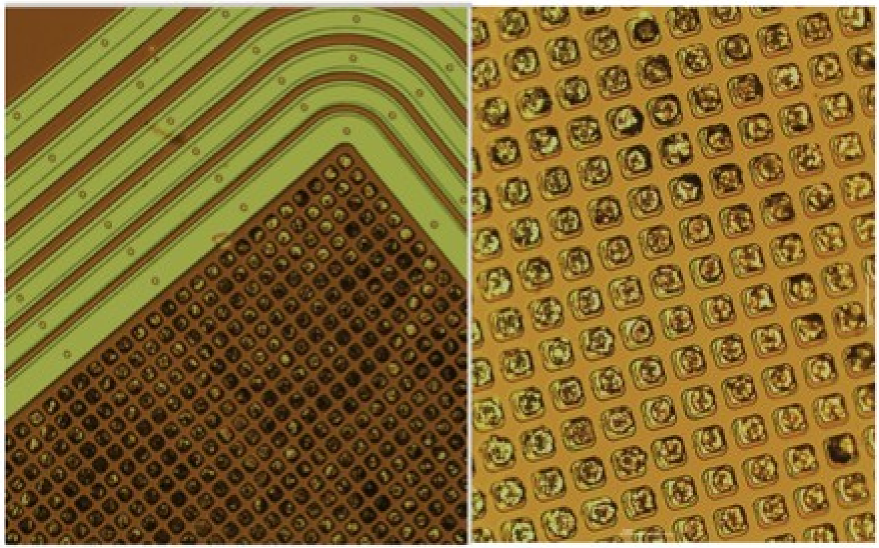
Planar Sensors – Small Pitch

- Single-chip Indium bump bonding process developed at SLAC
  - No access to ASIC wafers → small sensor (1.6mm x 1.6mm)
  - Small pitch (25µm)
- Test assemblies with CLICpix ASIC and 50-200µm n-in-p sensors
  - Microscope pictures of bump/UBM deposition

CLICpix Readout ASIC

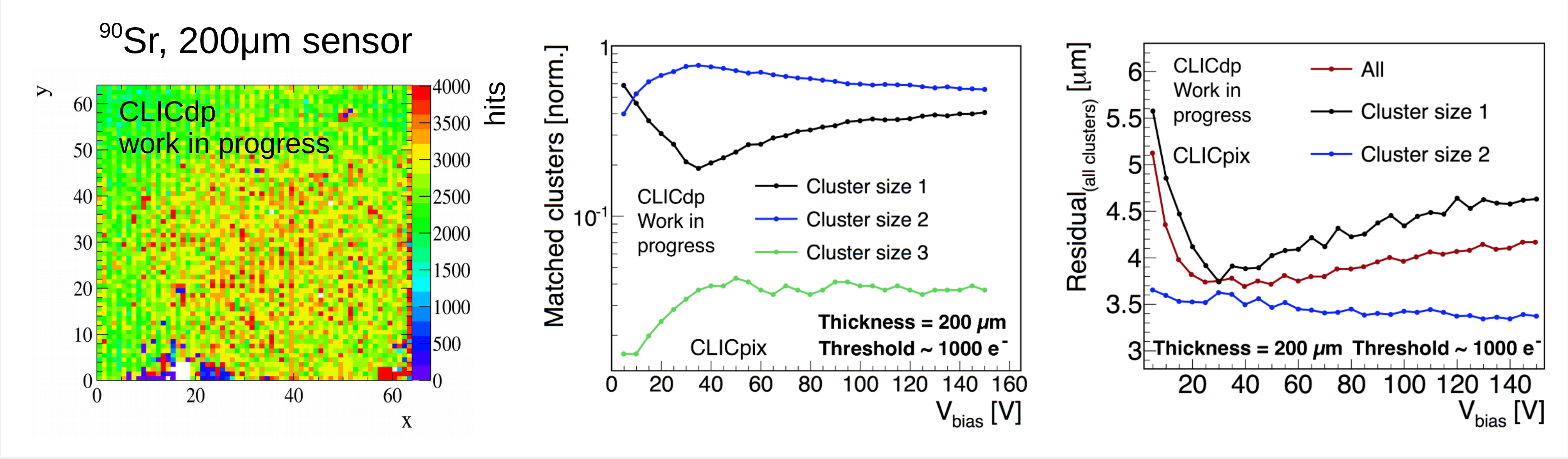


200µm n-in-p sensor (Micron)



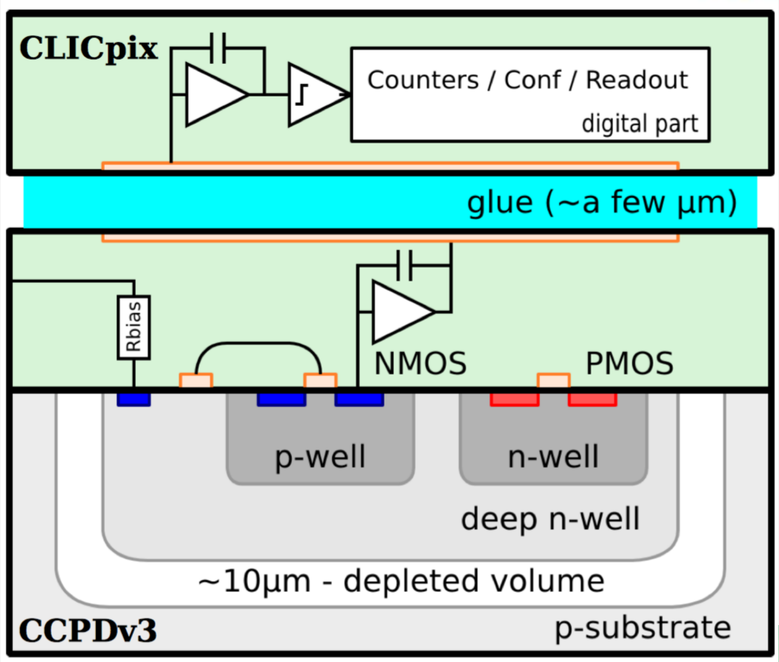
Planar Sensors – Small Pitch

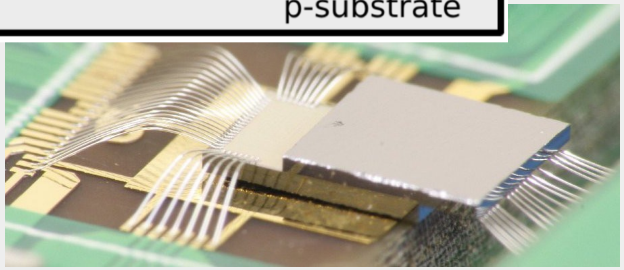
- Large spread in quality, bad/missing connection for 2 – 25%
  - Optimization of bump bonding process ongoing
- Test beam measurements: 200µm sensor, threshold 1ke
  - High detection efficiency, > 99.5 %
  - About 4µm single point resolution
- Analysis of assembly with 50µm thickness still ongoing

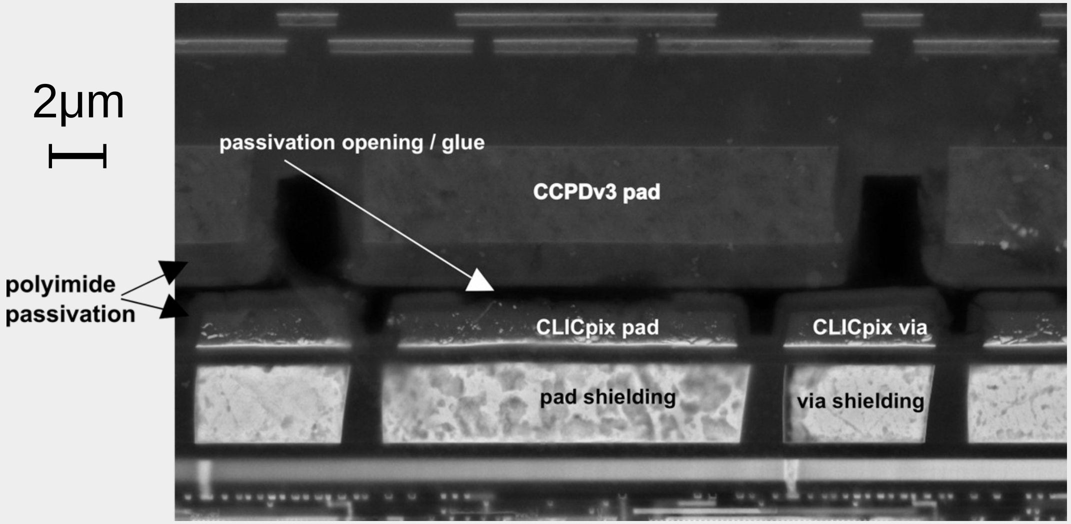


Capacitively Coupled Active Sensor: CCPDv3

- 180nm HV-CMOS active sensor
  - capacitively coupled to ASIC
  - Bias voltage > 60 V possible
- 64 x 64 pixel matrix, 25µm pitch
  - Designed to fit CLICpix ASIC
  - 120ns amplifier peaking time



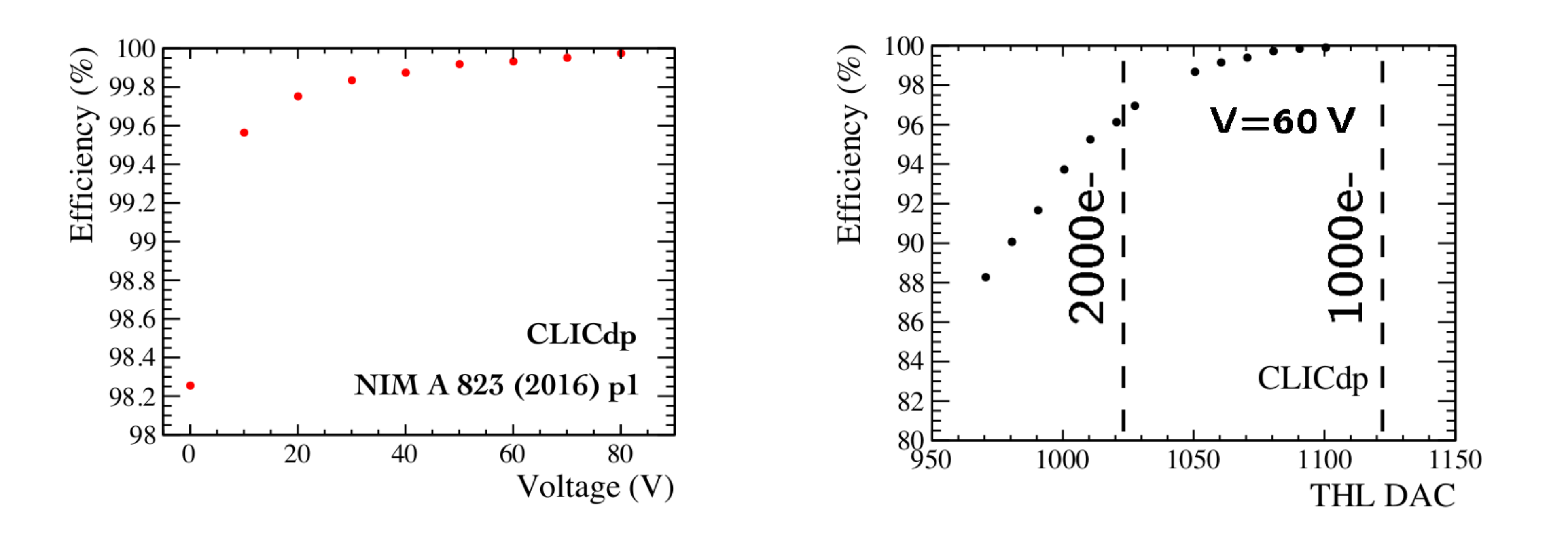




- Comprehensive studies
  - Glueing procedure/force
  - Sensitivity to mis-alignments
  - Cross coupling

Capacitively Coupled Sensor: CCPDv3

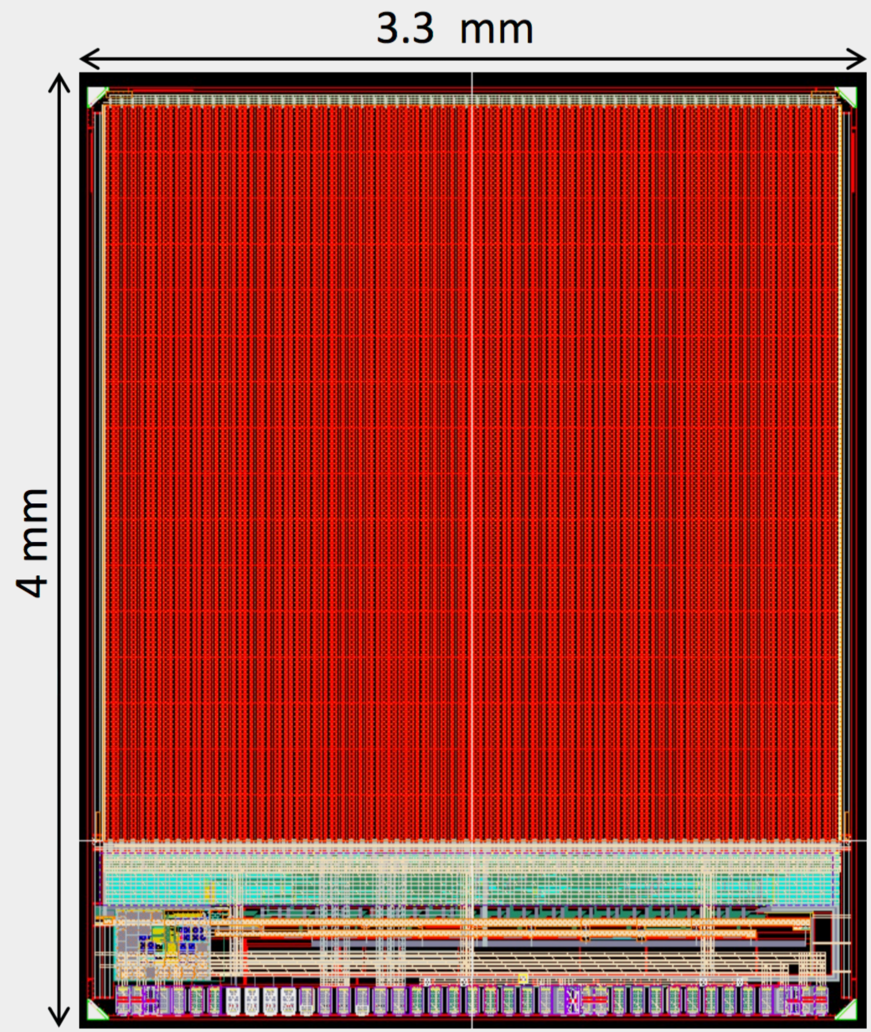
- CLICpix – CCPDv3 assembly characterized in test beam
  - High detection efficiency, even without bias voltage
  - Spatial resolution of 6.1 μm (telescope resolution of 1.6 μm subtracted)



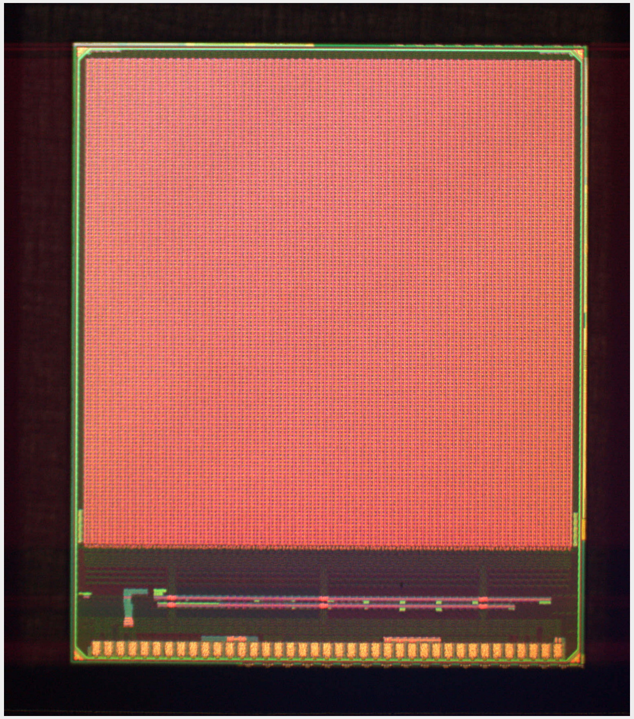
- Detailed studies and comparison with TCAD simulations underway
  - Angular scans, cross-coupling studies

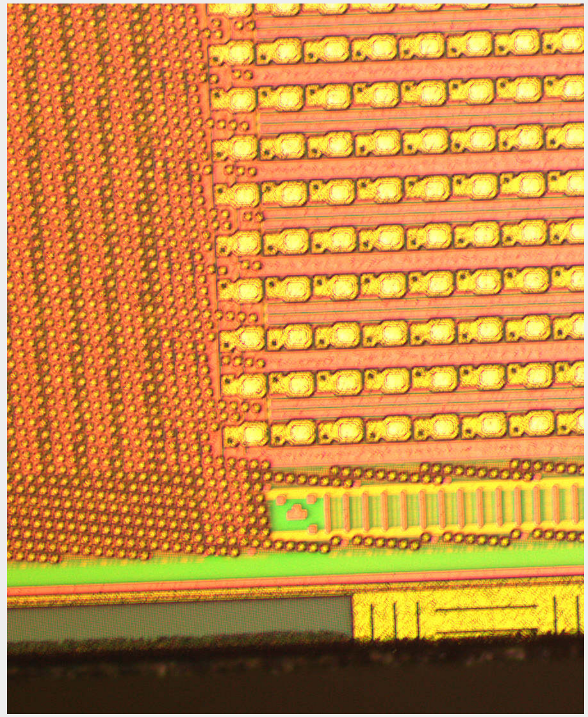
The CLICpix2 Prototype

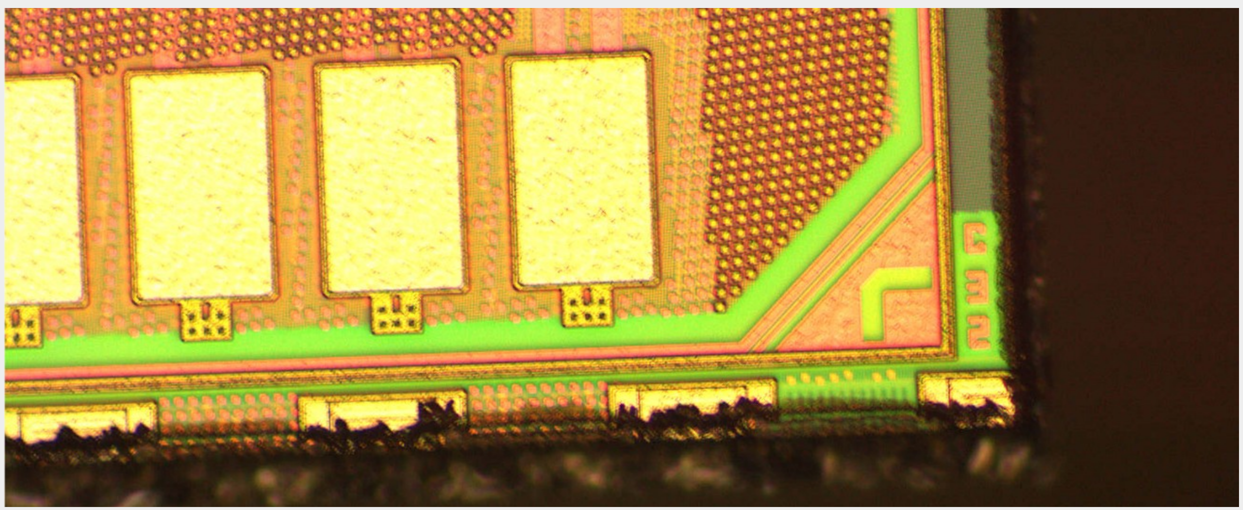
- Advancement of CLICpix design
  - Larger matrix of 128 x 128 pixels (3.2 x 3.2 mm^2 active area)
  - More precise pixel cells (5bit ToT, 8bit ToA)
  - Improved noise isolation, removal of cross talk observed in first CLICpix
  - Faster readout with 8/10b encoding
  - Integrated circuits for test pulses and band gap reference
- Status
  - Received diced chips
  - Lab testing ongoing

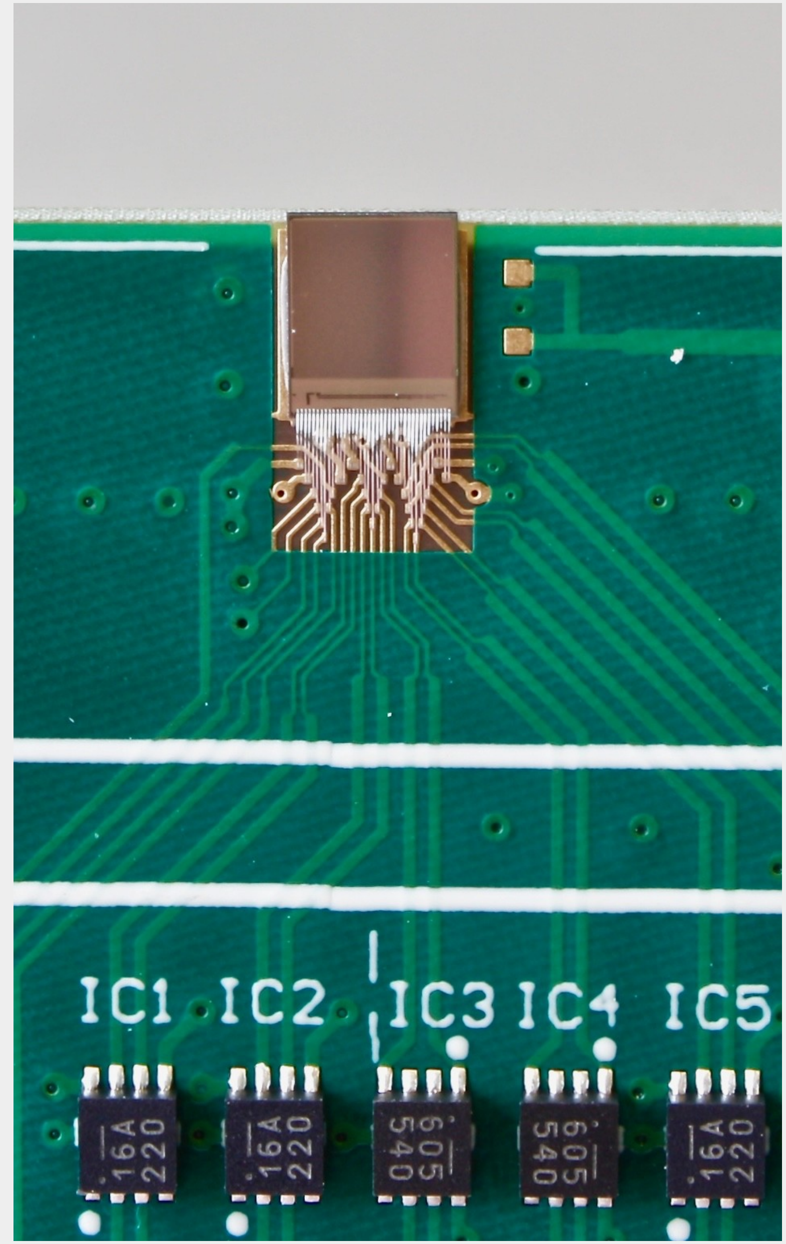


CLICpix2 (Microscope) Images

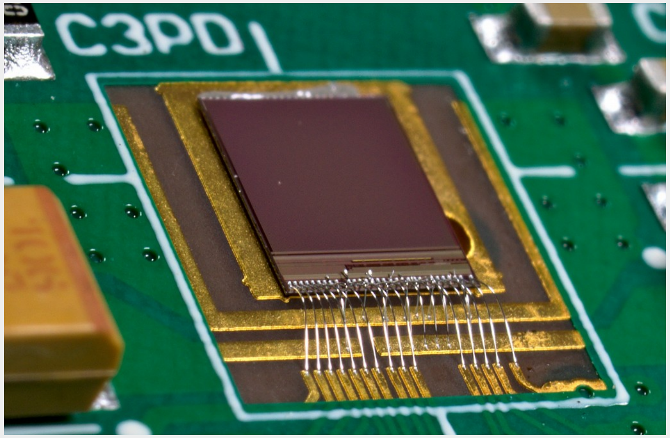




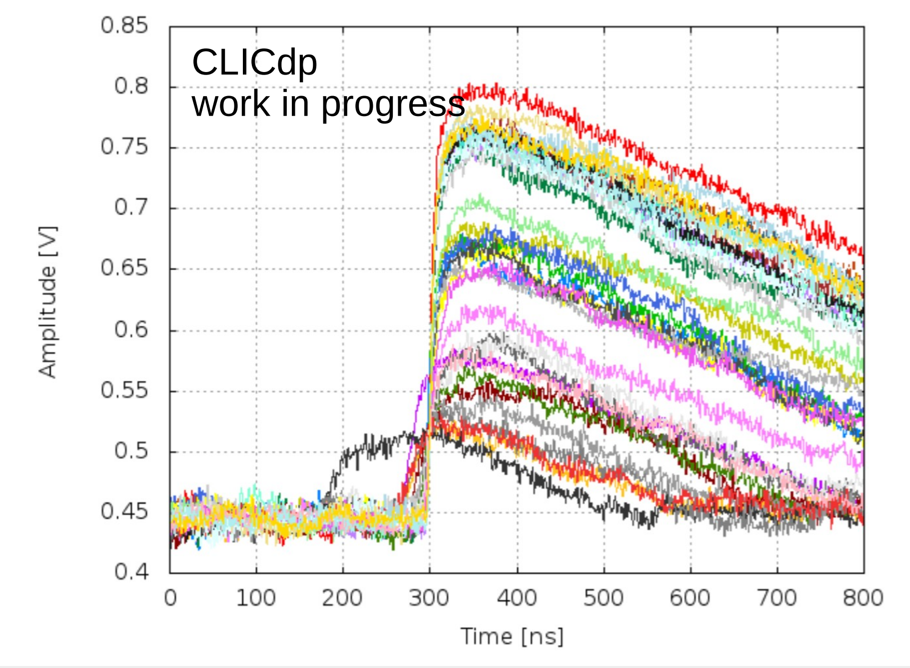




C3PD – CLIC Capacitively Coupled Pixel Detector



- Major redesign of CCPDv3
  - Unity gain buffer, power pulsing circuitry
  - Improved test pulse injection
  - Monitoring of 3x3 pixel region via I2C
- First laboratory test performed with ^{55}Fe source
  - 20ns amplifier rise time
  - High gain, optimum S/N ~ 60
- Some samples thinned to 50µm
  - No performance degradation
- Full tests soon with the CLICpix2 ASIC



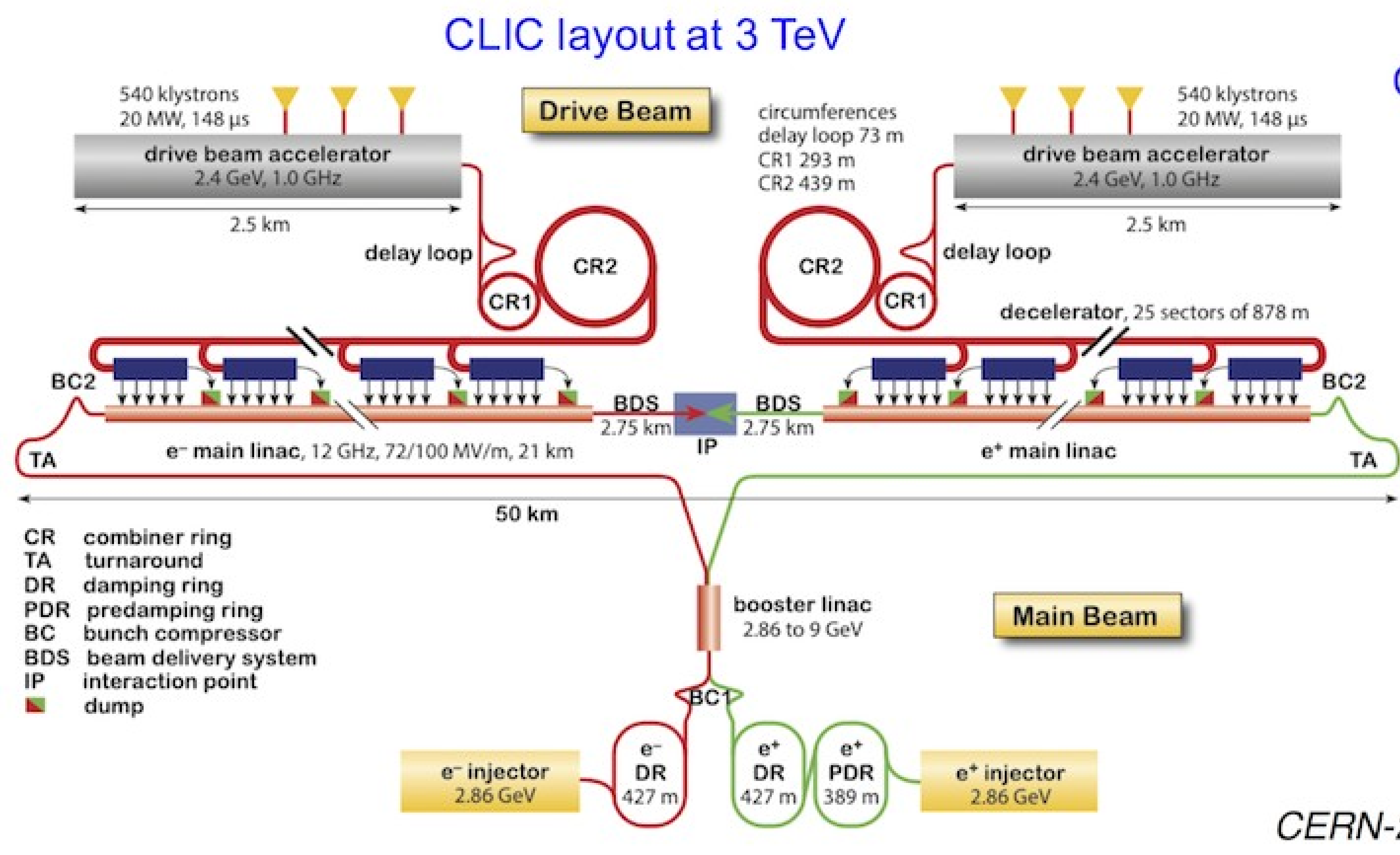
Summary

- Proposed CLIC linear e+e- collider poses challenges to vertex
  - Good spatial and temporal resolution, minimum material
- Comprehensive R&D program for CLIC Vertex Detector
  - Excellent efficiency achieved with thin sensors with fast readout
  - Validated simulation tools will help R&D in reaching position resolution goal
- Next iteration of sensors and ASICs already on the way

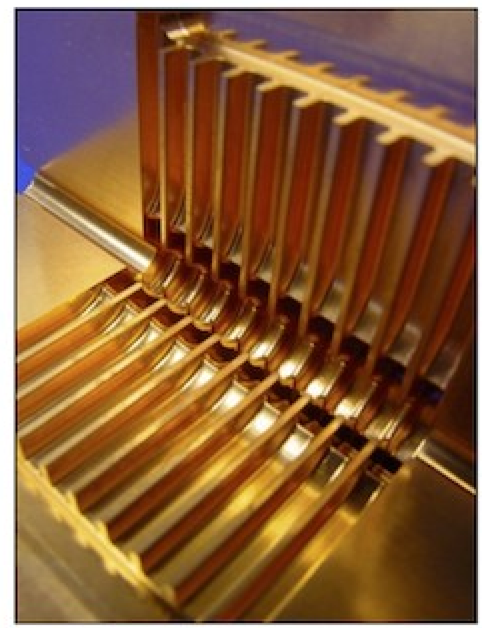
CLIC detector & physics Collaboration

- 29 institutes

CLIC Accelerator Complex

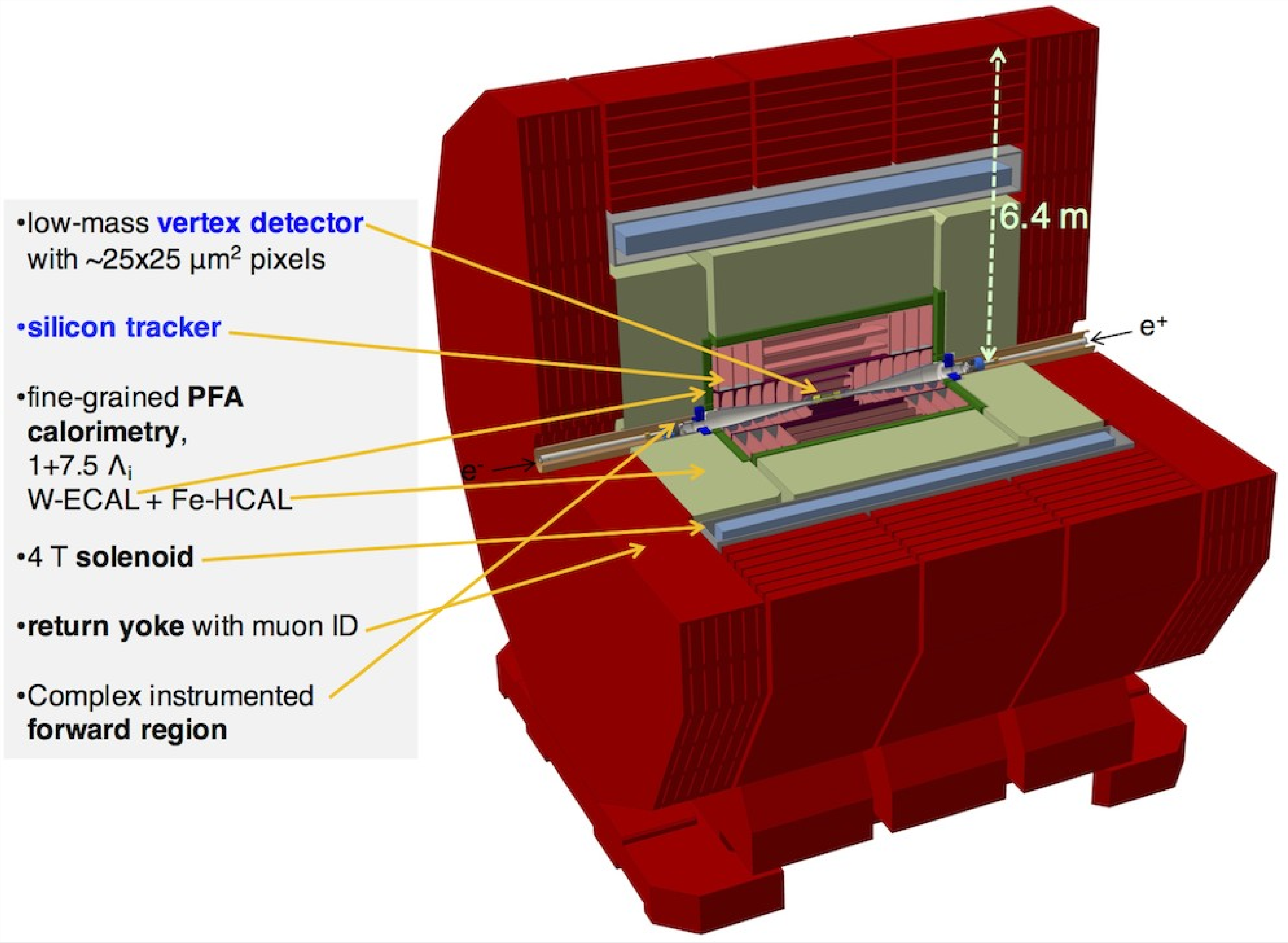


CLIC accelerating structure



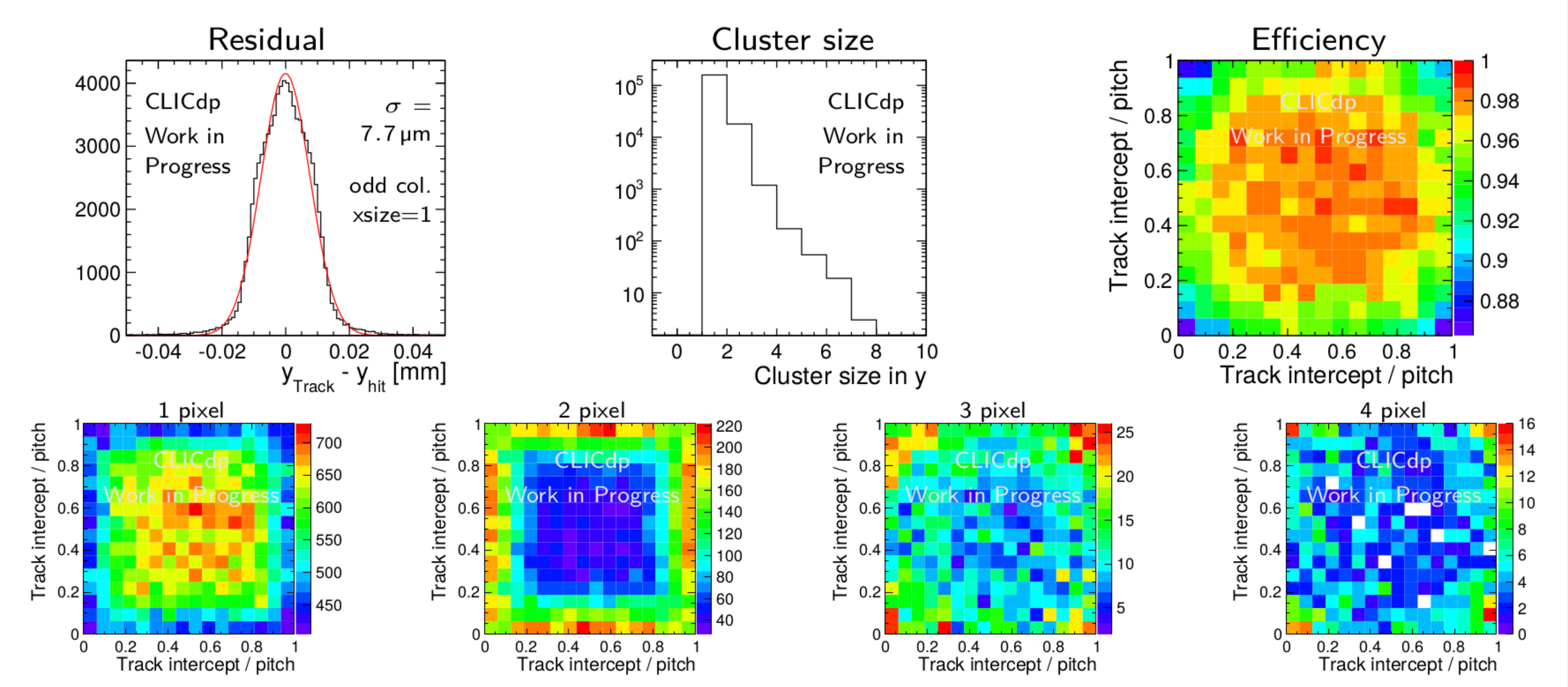
CERN-2012-007

CLIC Detector Concept



CLICpix with thin planar sensor: Analysis results

- 5V bias, ~ 1300 e − threshold, 50 μm thin sensor

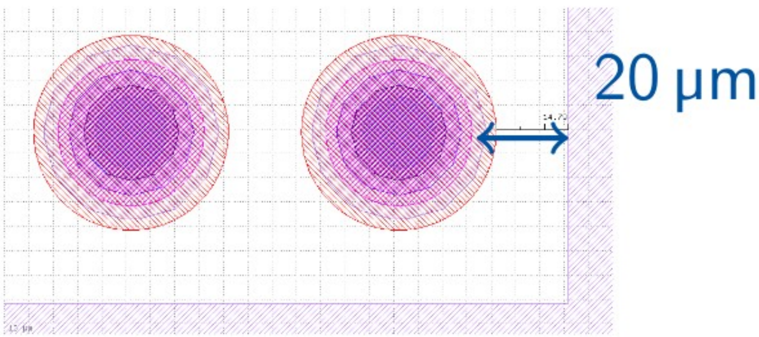


- DUT performance as expected from 50 μm thin sensor
- Telescope pointing resolution of 2 μm allows for in-pixel studies even with 25 μm small pixels

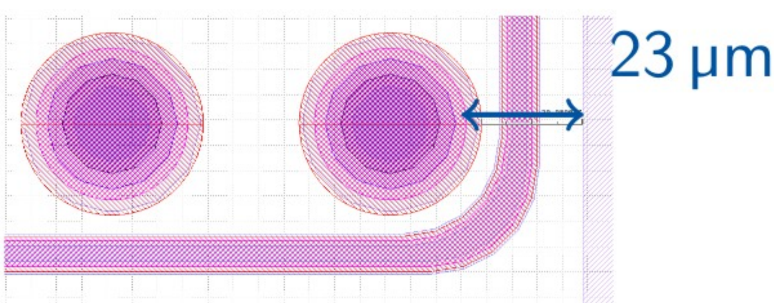
Active Edge Sensors: Guard Ring Layouts

- Advacam active edge MPW run, 50µm to 150µm thick, Timepix3 footprint, 55µm pitch
- 4 different guard ring layouts implemented
- Edge distance is defined as the distance between the last n-implant and the cut edge

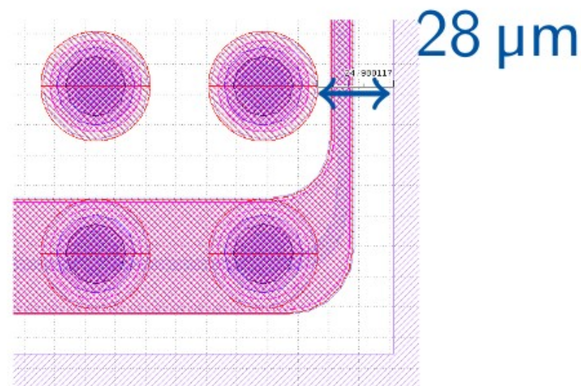
- ▶ 20 µm edge, no guard-ring



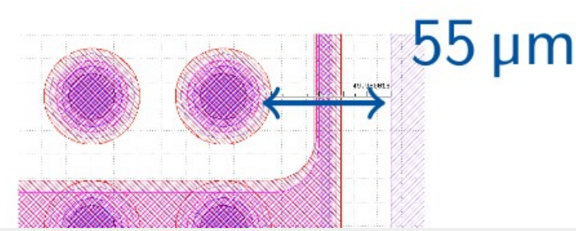
- ▶ 23 µm edge, floating guard-ring



- ▶ 28 µm edge, GND guard-ring



- ▶ 55 µm edge, GND guard-ring



CCPDv3 vs. C3PD