# R&D for the CLIC vertex & tracking detectors

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## Requirements

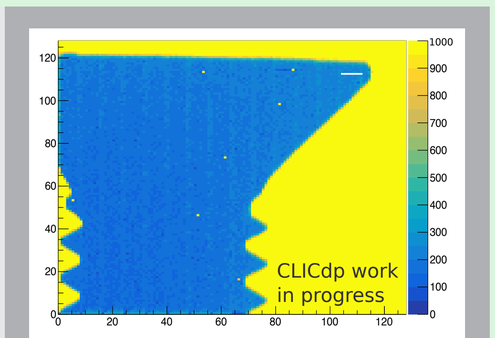
Compact LInear Collider (CLIC): concept for future high-luminosity, high-energy linear e+e- collider at CERN. Physics programme puts strict requirements on the vertex & tracking detectors.

| | Single point resolution | Pixel size | Material budget per layer | Timing resolution | Hit efficiency | Average power dissipation (using power pulsing) |
|---|---|---|---|---|---|---|
| Vertex | 3μm | ≤ 25μm x 25μm | 0.2% $X_0$ | 5ns | 99.7 - 99.9% | < 50mWcm$^{-2}$ |
| Tracking | 7μm | 30 - 50μm x 1 - 10mm | 1 - 2% $X_0$ | 5ns | 99.7 - 99.9% | < 150mWcm$^{-2}$ |

- None of the available detector technologies can fulfil all vertex/tracking requirements
- Therefore new sensors & readout technologies are under study

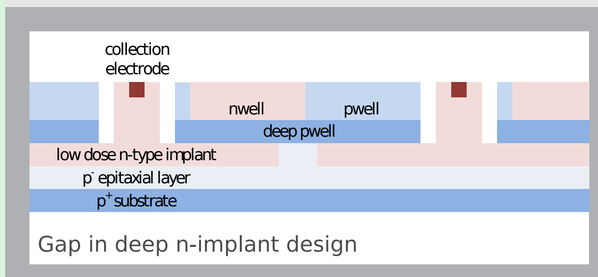
## CLICTD

CMOS sensor with SCE (Small Collection Electrode) on HR (High Resistivity) silicon:
- 180nm modified imaging process
- 128 x 16 pixels segmented into 8 subpixels of pitch 30μm x 37.5μm
- HR epitaxial layer & low dose deep n-implant used for full lateral depletion

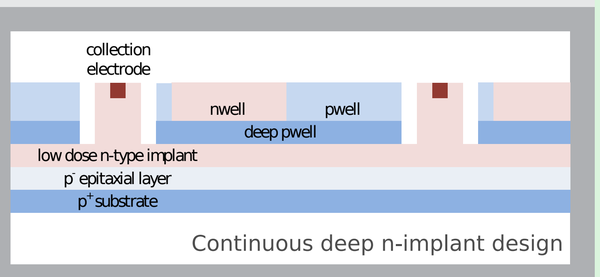



CLICTD hitmap from X-ray exposure with shadow of a screw

- Initial laboratory tests carried out on assemblies




Gap in deep n-implant design

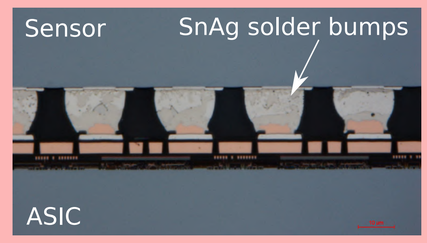



Continuous deep n-implant design

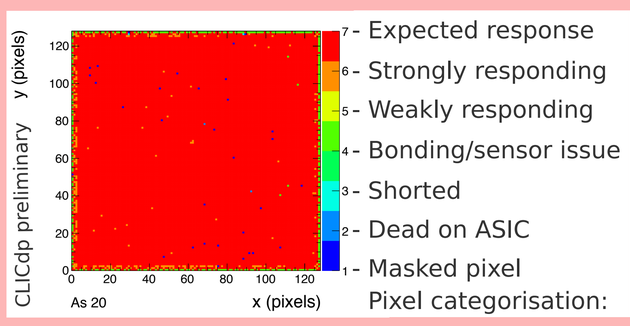
- Circuitry inside inversely doped well separated from SCE
- Small capacitance (few fF), low detection threshold (preliminarily ~180e-), low power consumption, & large signal-to-noise ratio
- Modified design: has gap in n-layer to reduce charge collection time

## CLICpix2

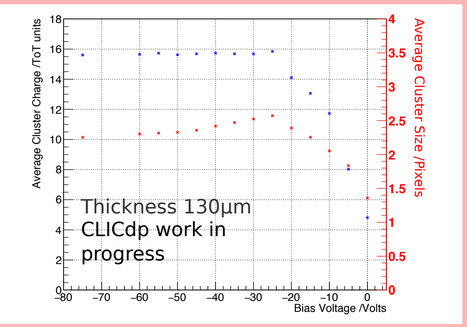
CLICpix2 readout ASICs:
- 65nm CMOS process
- Part of Timepix/Medipix family
- Bump-bonded at IZM to planar silicon sensors of thicknesses 50μm-200μm




- 128 x 128 pixels
- Pitch 25μm x 25μm
- Simultaneous 8bit ToT & 5bit ToA readout




- High quality CLICpix2 assemblies produced, 99.7% interconnect yield
- Low assembly yield due to challenging bonding process

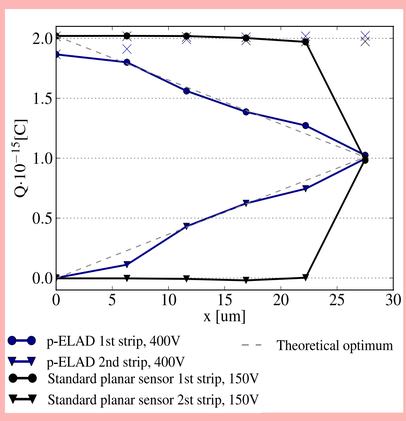



- Efficiencies of ~97%
- Optimal voltage for charge sharing=-25V
- Depletion voltage = -24V

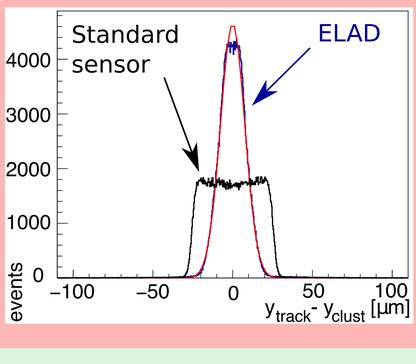
## ELADs

Addresses limitation of pixel pitch by readout electronics feature sizes & of thin sensors to binary positional resolution due to small diffusion length

- ELAD design enhances lateral drift to increase charge sharing using sensors with deep ion implants




- Electric field shape modified by implants
- More charge shared & low field regions are minimised
- Charge sharing near theoretical optimum
- Improves positional resolution for same pitch & thickness

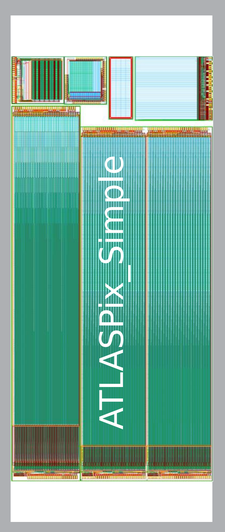



- Simulations with Allpix$^2$ & TCAD
- Improvement x2 from binary positional resolution in Monte Carlo simulation
- First prototypes being produced

MIP in TCAD: after 1.8ns

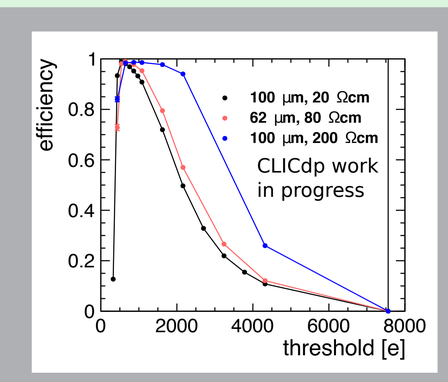
## ATLASPix

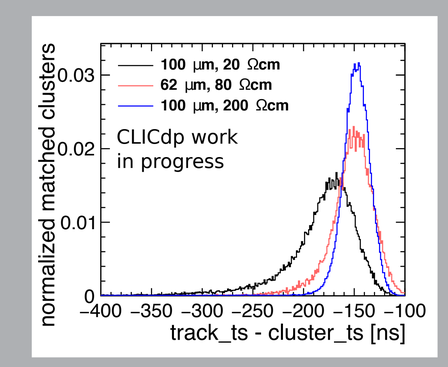
HV Monolithic Active Pixel Sensor:
- 180nm HV-CMOS processing
- Fully integrated readout
- Fast charge collection via drift
- Low material budget




ATLASPix_Simple:
- 25 x 400 pixels
- Pitch 130μm x 40μm
- 10bit ToA, 6bit ToT

Assemblies:
- Sensor resistivities from 20 to 1000Ωcm
- 100μm & 62μm thickness
- Tested in laboratory & test-beam



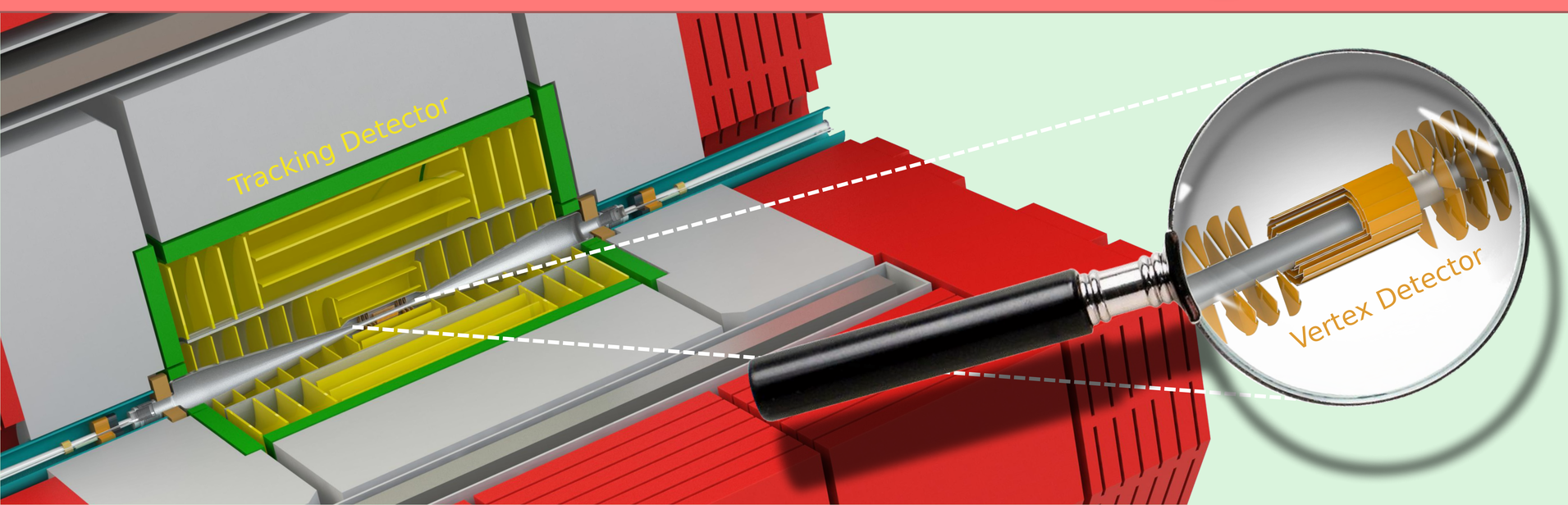

Test-beam results:
- Bias voltage down to -95V
- Results show expected dependence of performance on resistivity & sensor thickness

## Developed tools:

Caribou — Flexible pixel detector readout system

ap² allpix squared — Pixel detector simulation framework

Corryvreckan — Test-beam data reconstruction software




15th Topical Seminar on Innovative Particle & Radiation Detectors (IPRD19)

On behalf of the CLICdp collaboration

Reference: D. Dannheim et al., Detector Technologies for CLIC, CERN, 2018
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