UK Activities on CMOS MAPS

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Science & Technology Facilities Council
Rutherford Appleton Laboratory

Outline

Recent R&D Collaborations

- CALICE-UK (ILC calorimetry): Birmingham, Cambridge, Manchester, RAL/STFC, Imperial College (IC), University College, Royal Holloway.
- SPiDer (vertexing/tracking at LC): Bristol, Birmingham, IC, Oxford, Queen Mary, RAL/STFC.
- Arachnid (generic vertexing/tracking/calorimetry): Bristol, Birmingham, Queen Mary, RAL/STFC, Daresbury/STFC.
- Low-Mass and Plume (low-mass structures): RAL/STFC, Bristol, Oxford with DESY, IPHC/Strasbourg, IK-Frankfurt.
- UK MAPS (LC sensor testing): Bristol, Queen Mary, RAL/STFC. Awaiting outcome of grant request.

Monolithic Active Pixel Sensors (MAPS)

Useful Features

- Low Cost: 0.18 μm CMOS, mature industrial process.
- Low Power: low voltage and absence of standing currents.
- Low Material: very thin overall (30-50 μm).
- Radiation Tolerant: Achilles sensor is tolerant to 20 Mrad.
- High Granularity: pixel sizes down to $\sim$1 μm.

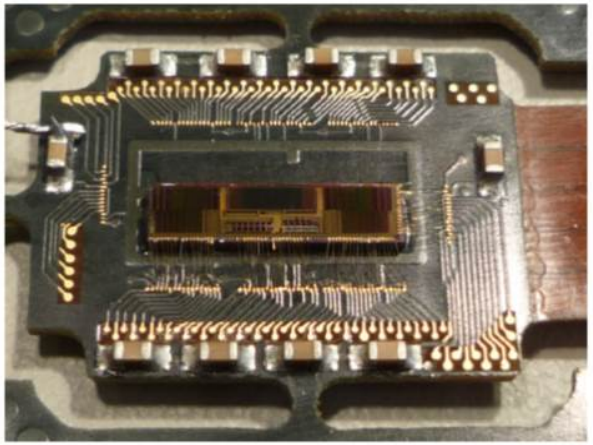
Additional Features developed

- Deep p-well/InMAPS: improved charge collection.
- High resistivity epitaxial layers: radiation hardness, improved charge collection.
- 4T structures: in-pixel structures, correlated double sampling (CDS), improved S/N, low power (effectively 10μW/row).
- Stitching: large structures (13.9 cm $\times$ 12 cm have been achieved).

HMRM and Sophia

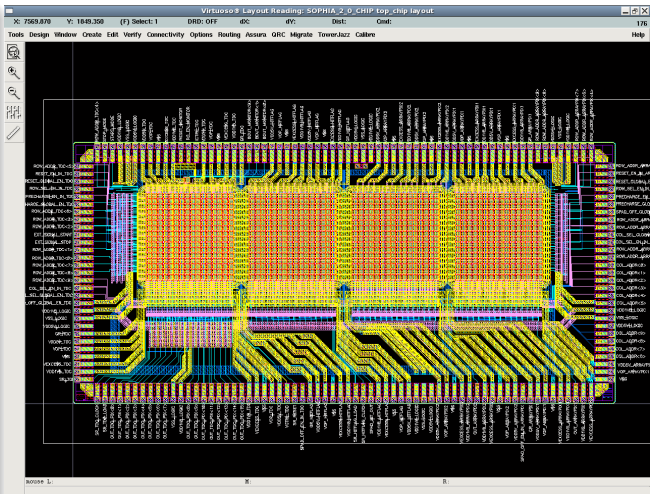
Highly Miniaturised Radiation Monitor

- Sensor size : 50x50 μm, 250 μm thick, 10.3 mm by 2.4 mm.
- Low noise, rad tolerant, designed for ESA.
- To be launched on Tech Demo Satellite.



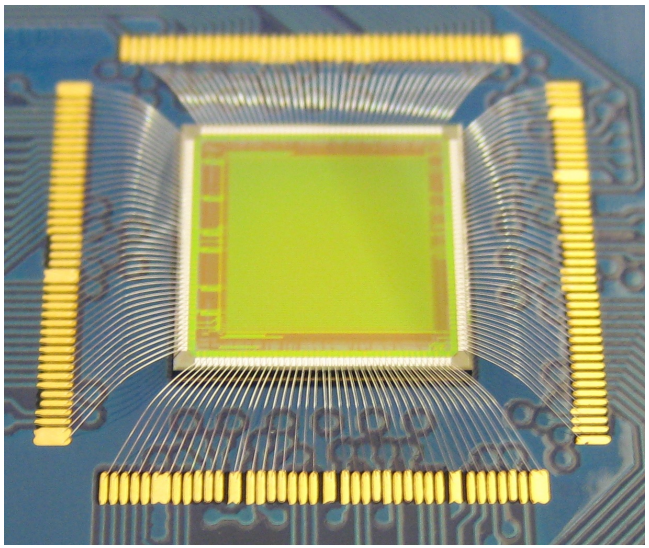
Single Photon Avalanche Detectors

- 0.18 μm CMOS, alternative to APDs and CCDs.
- Targetting FLIM, 3D imaging, astronomy, PET and mass spectroscopy.
- Photon Detection Probability up to 27%
- Timing resolution: 0.5 ns FWHM.



PImMS 1 & 2 - Pixel Imaging Mass Spectroscopy

- Based on TPAC.
- Event-based time-stamping pixel sensor.
- 382×382 $70\,\mu\mathrm{m}$ pixels.
- 80MHz, $12.5\,\mathrm{ns}$ time resolution.
- 12 bit timestamp storage.
- 4 registers per pixel for multiple event detection.
- Per pixel trim, mask and comparator.
- Analogue readout for focusing and event size measurement.
- Gadolinium thin film coating used in neutron imaging.

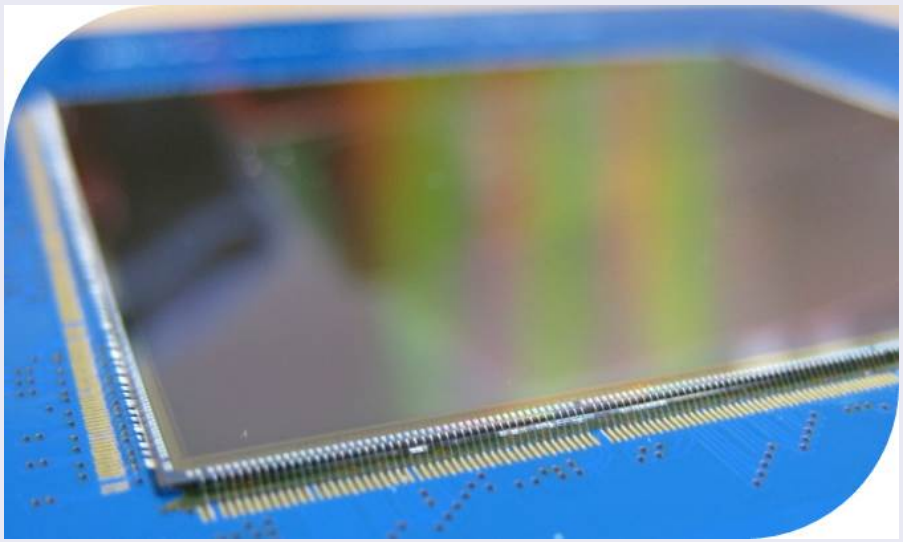


PiMMS 1 camera

Achilles for TEM and Lassena for X-ray imaging

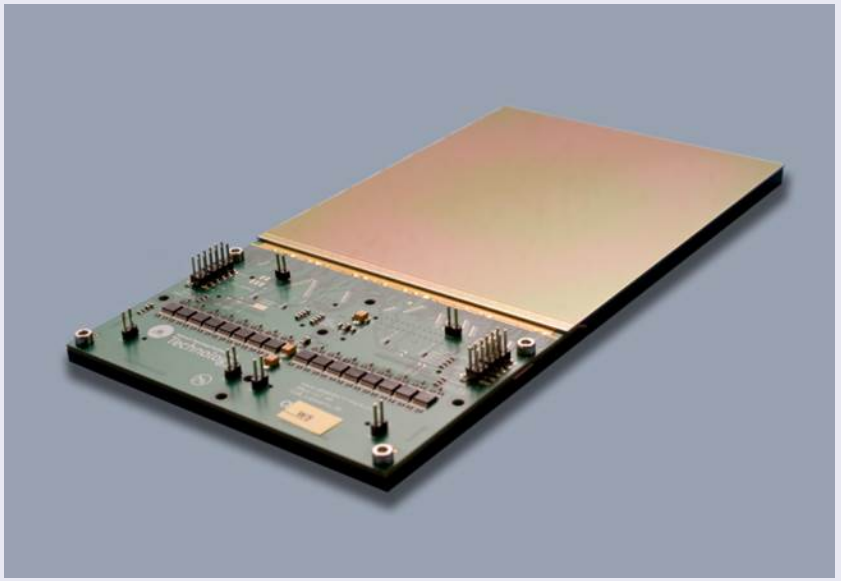
Transmission Electron Microscope

- 4096 x 4096 14 μm pixels
- Sensor Size: 61 mm x 63 mm
- Analogue output, 40 fps.
- Radiation Hard to 20 Mrad.



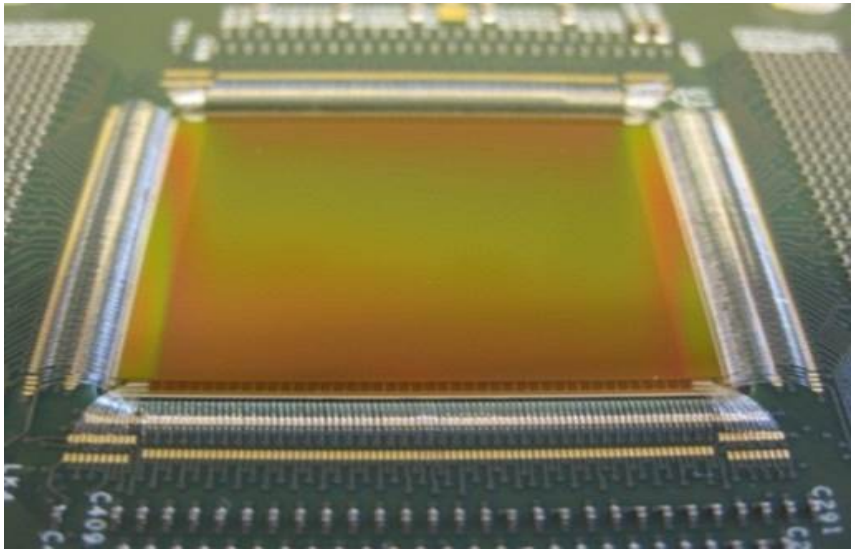
X-ray Imaging

- 2800 x 2400 50 μm pixels.
- 139.2 mm $\times$ 120 mm.
- Analogue output, 30 fps.
- 3-side buttable with minimal dead space.



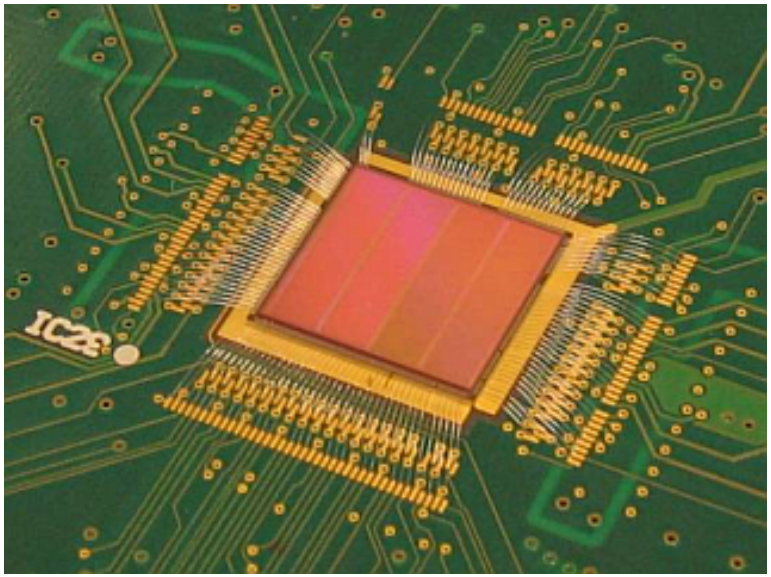
Kirana - Ultra High Speed Imaging Sensor

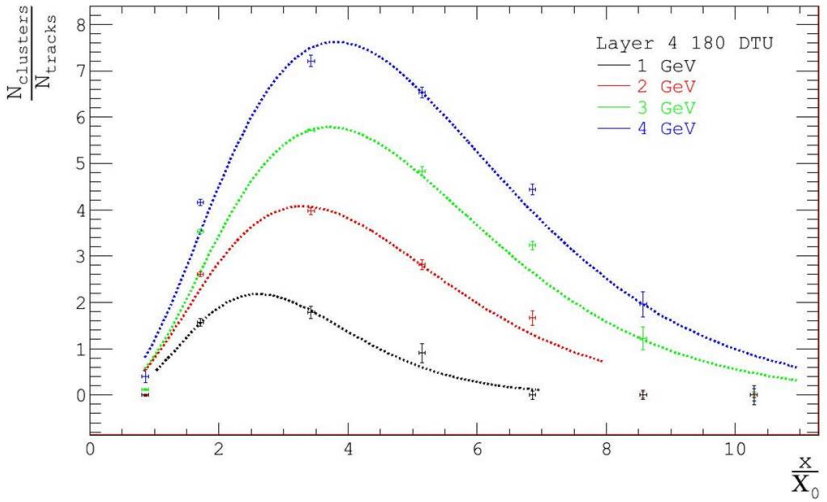
- 924×768, $30\,\mu\mathrm{m}$ pixels.
- Die size: $32.5 \times 25.5\,\mathrm{mm}$.
- CDS, in-pixel storage.
- Continuous readout at 1,180 fps.
- Burst mode: 180 frames at $2\,\mathrm{MHz}$ (but sensor will work at $5\,\mathrm{MHz}$).
- Gain: $80\mu V/e^-$.
- Full well: $11{,}700e^-$.
- Commercialised (Specialised Imaging).



Tera-Pixel Active Calorimeter Sensor (TPAC)

- 168×168 $50\,\mu\mathrm{m}$ pixels, $1 \times 1\,\mathrm{cm}^2$.
- $0.18\,\mu\mathrm{m}$ process, deep p-well, 3T structures only.
- 4 test structures designed + 5 or $12\,\mu\mathrm{m}$ epitaxial layer.
- Per pixel trim (4 bits), mask (1-bit) and comparator.
- Only hits above threshold stored (zero-suppression).
- $400\,\mathrm{ns}$ timestamp with readout every 8192 timestamps (bunch train).





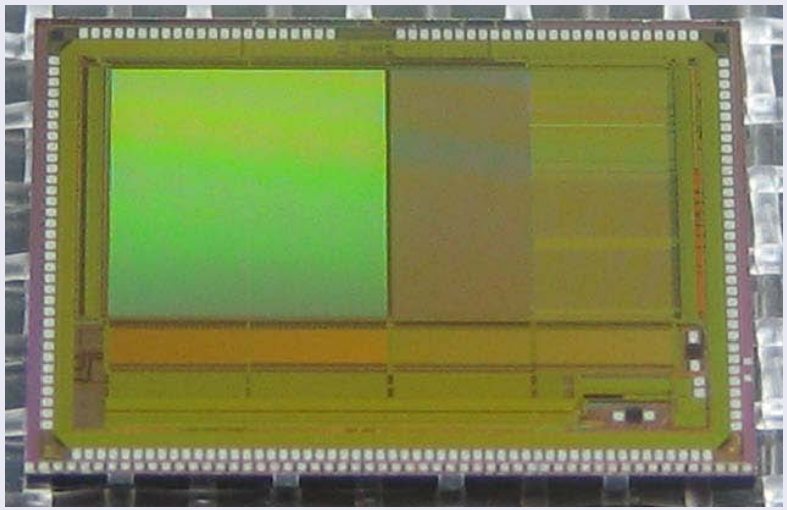
Cherwell 1 - Calorimetry/Tracking/Vertexing

4 test structures on 3 different epitaxial layers

1. DECAL 25: 48×96 $25\,\mu\mathrm{m}$ pixels with 2×2 summing.
2. DECAL 50: 24×48 $50\,\mu\mathrm{m}$ pixels.
3. Reference: 48×96 $25\,\mu\mathrm{m}$ pixels with ADC at column base.
4. Strixel: 48×96 $25\,\mu\mathrm{m}$ pixels with ADC embedded in pixel.

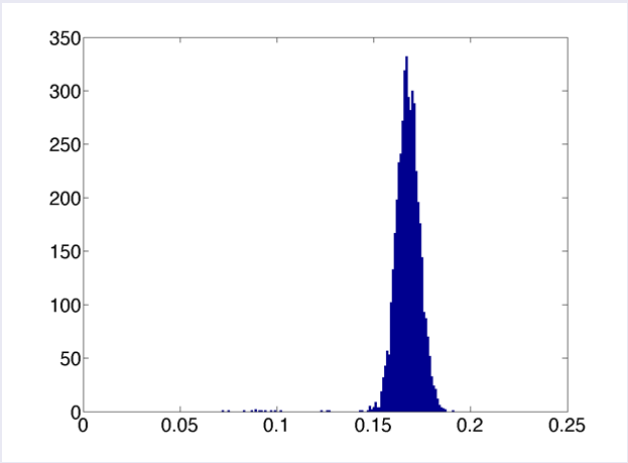
Additional features (in most variants)

- $0.5 \times 0.5\,\mathrm{cm}^2$, digital readout.
- $0.18\,\mu\mathrm{m}$ process, 4T structures, CDS.
- 12-bit ADC, rolling shutter, stores 10 time slices.
- Global shutter for DECAL.
- Supports power pulsing.

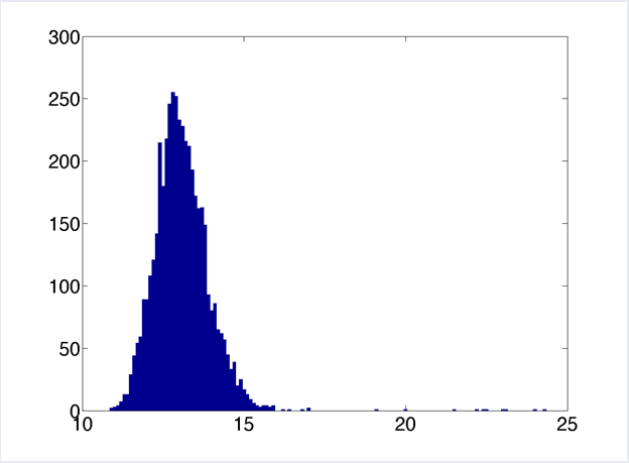


Cherwell 1 - Recent characterization work

Gain (ADC counts/e^-)



Noise (ADC counts)

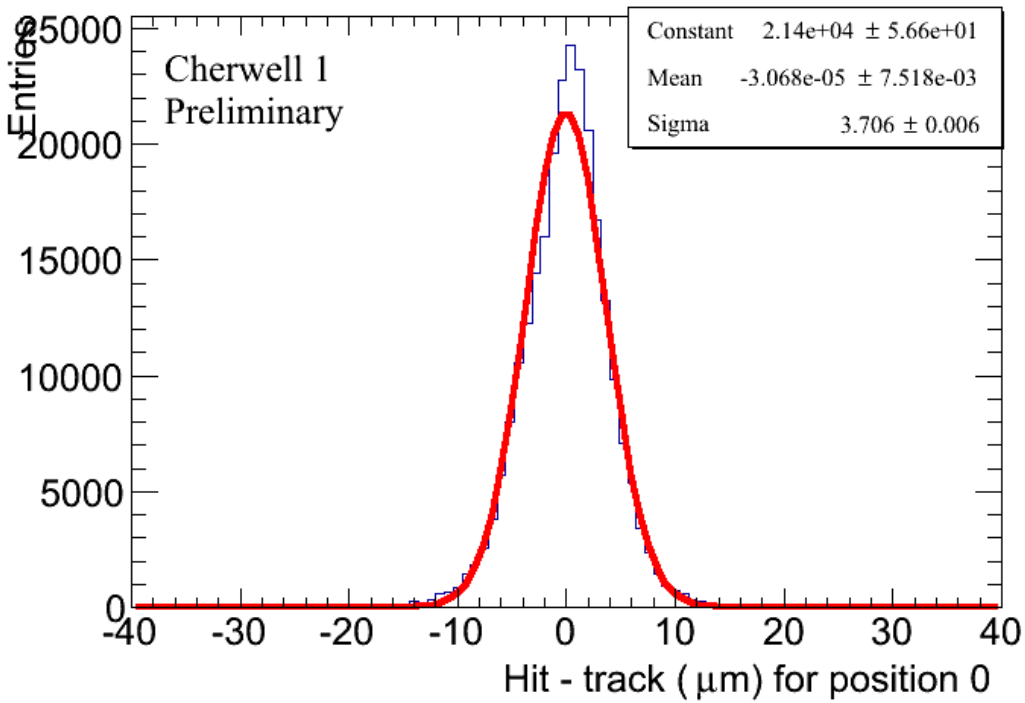


Preliminary results (May 2013)

- Noise 8-12 e^- rms depending on epitaxial layer.
- Gain 0.17 ADCs/e^- or 51$\mu V/e^-$.
- Full well 14700 e^-.
- Gain Stability $< 0.1\%/^oC$ between -50 to 50 ^oC.
- Signal-to-Noise > 130.

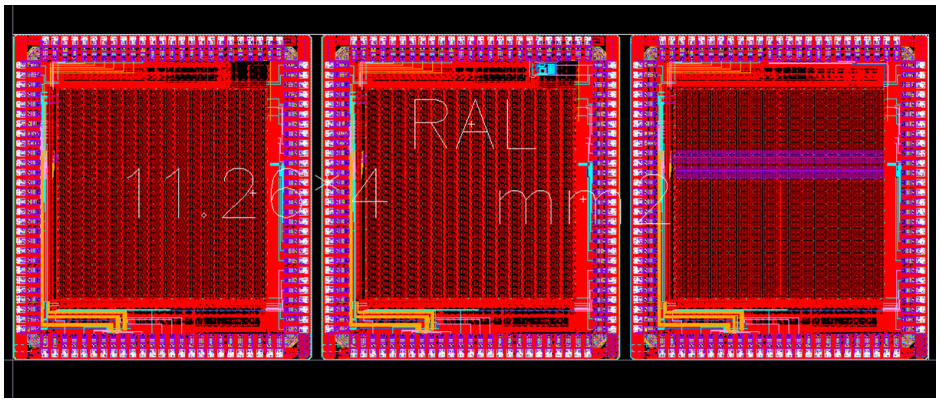
Hit Efficiency and Resolution from CERN test beam

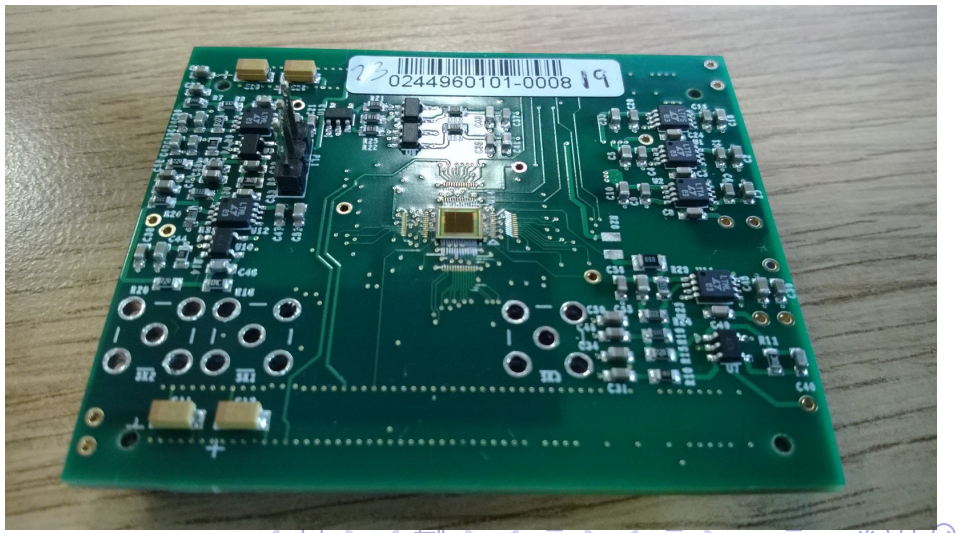
- SVD fit to clusters along a road without sensor under consideration.
- No corrections for non-linear charge sharing ($< 1.5\,\mu\mathrm{m}$); multiple scattering ($< 0.5\,\mu\mathrm{m}$); and tracking resolution ($\sim 1 - 2\,\mu\mathrm{m}$).
- Hit efficiency $\gtrsim 99.7\%$.
- Hit resolution $3.7\,\mu\mathrm{m}$ without corrections achieved.



Cherwell 2 - ALICE Inner Tracker System prototype

- Based on Cherwell 1 experience.
- 3 variants, (2 x all digital, 1 x analogue FE).
- In-pixel circuitry, 128×128 pixels.
- Gain $38 \mu V/e^-$, full well 18,000 e^-, dynamic range 2,900.
- Power 11 mW/cm^2.
- Rolling Shutter, Frame rate 21.76 μs.
- Readout speed $\gtrsim$ 500 Mbit/sec.
- About to be characterized before going to test beam.
- Will test at DESY in November.





Conclusion and Future

Cherwell 1 - Linear Collider

- Initial results have met or exceeded the original design goal.
- Hit efficiency ($\gtrsim 99.7\%$) and resolution ($3.7\,\mu\mathrm{m}$) looking good for future vertex and tracking devices.

Cherwell 2 - ALICE

- Sensor currently on test bench and being integrated into r/o system.
- Aim to characterize (PTC scans) in next few weeks.
- Test beam at DESY planned for mid-November. ALICE technology choice in 2014.
- Cherwell 3 : New features and upgrades being designed for production and testing in 2014.

Plans for the Future

- Cherwell 1: Publish first results (2013/14).
- DECAL and Strixel: These blocks of the Cherwell 1 sensor will be re-characterized; hope to go to DESY next year and re-test (Jan 2014).
- UK-MAPS: If get money, will characterise Lassena sensor for LC (2014-2015).
- ALICE ITS: Hope our MAPS design will be chosen (2014-2018).
- HV-CMOS: ATLAS are intested in HV-CMOS for tracking in LHC Phase II (2014-2023).
- Looking at getting involved in LC - perhaps simulation of pixel tracker.