Silicon Detectors: R&D and applications

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HEP Meeting 24

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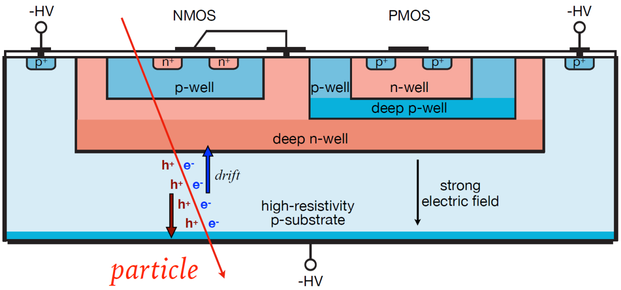
CV

- BSc and MSc at Heidelberg University
- Worked on HV-CMOS prototypes for Mu3e (MuPix)
- PhD with Eva on generic HV-CMOS R&D (RD50+UKRI) and LHCb Mighty Tracker

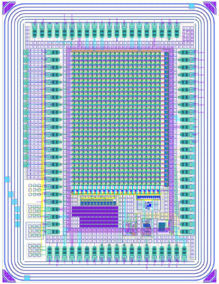
Reminder: HV-CMOS

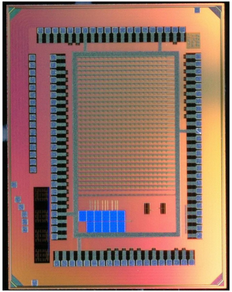
- Fast charge collection and readout in a single silicon chip
- Can be made very thin (50 µm)
- Cheap due to commercial process
- Drift times $\mathcal{O}(1\,\text{ns})$
- Radiation hard $\mathcal{O}(1 \times 10^{15}\,1\,\text{MeV}\,\text{n}_{\text{eq}}/\text{cm}^2)$
- Liverpool currently uses the LFoundry 150nm HV-CMOS node



New Prototypes

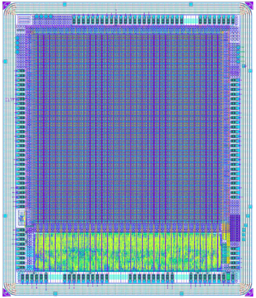
UKRI-MPW1

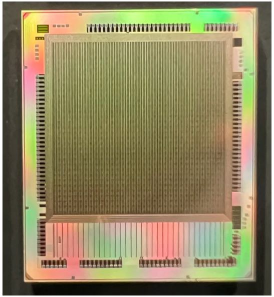




- Optimised for backside bias with high breakdown voltage
- Address issues with UKRI-MPW0
- 2.85 mm × 3.75 mm

RD50-MPW4

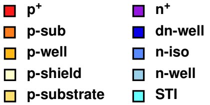


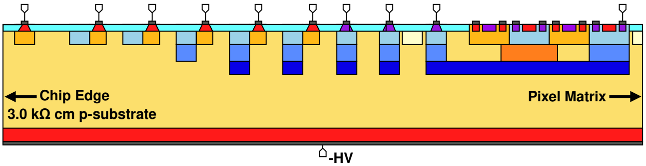


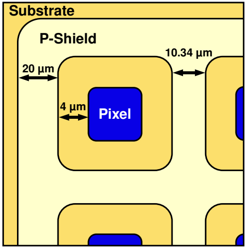
- Integrated readout
- Fix noise issue seen with RD50-MPW3
- 5.35 mm × 6.3 mm

UKRI-MPW1

- Developed new P-Shield layer with LFoundry to interrupt channel between pixels
- New guard ring scheme from RD50/Bonn to reduce current on the dicing edge
- Characterisation ongoing
- See Ben's presentation for more information





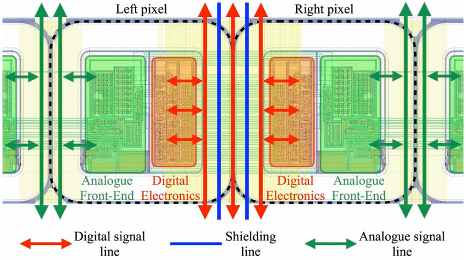


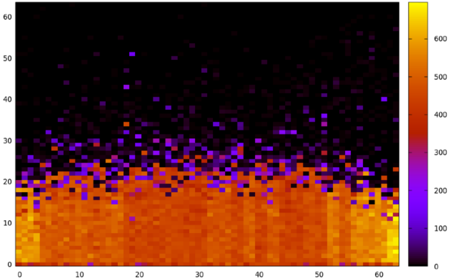
RD50-MPW4

- MPW3 had advanced readout scheme
- Neighbouring pixels share bus lines to save space and allow for shielding
- Digital power domain of pixels and periphery was shared

→ Noise injection into pixels ($\mathcal{O}(2\,ke)$)

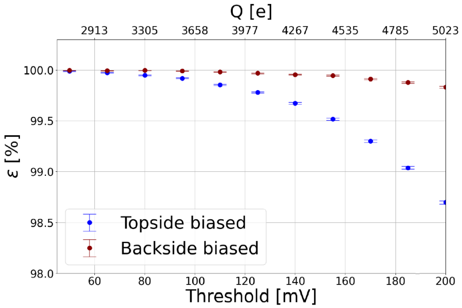
- Fixed for MPW4
- New guard ring scheme for higher breakdown (same as UKRI-MPW0)
- Test topside vs backside bias



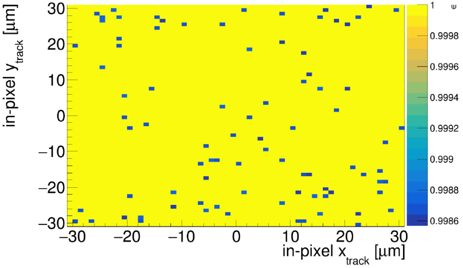



Hochspannung
Danger
High voltage!

RD50-MPW4 Testbeam Results + Future



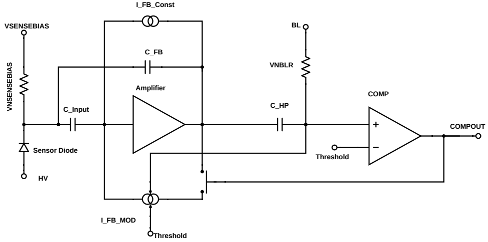
- Testbeam end of April at DESY
- Analysis ongoing
- Noise gone!
- Very high efficiency!
- 1TB of data

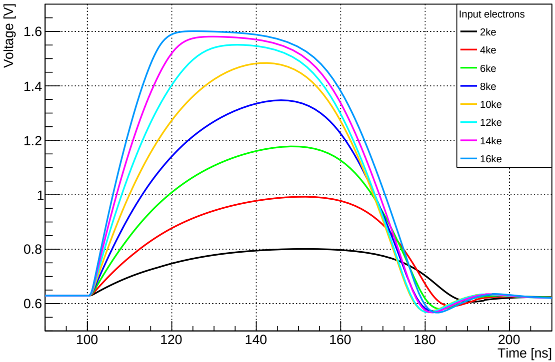


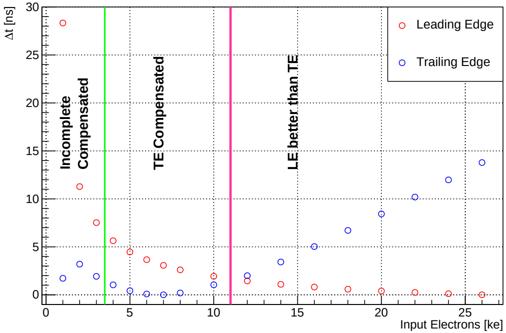
- RD50 is no longer with us
- R&D will continue within DRD3
- RD50-MPW4 and UKRI-MPW1 irradiated up to $3 \times 10^{16}\,1\,\text{MeV}\,n_{eq}/cm^2$
- Investigating to use RD50-MPW4 as basis for new Mighty Tracker sensor

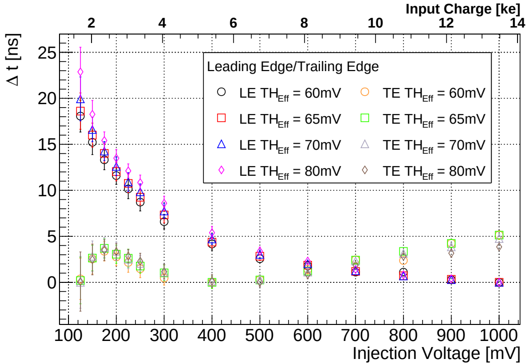
UKRI-MPW0 Timing Pixel

- Developed in my PhD
- Analogue time walk compensation for the trailing edge of the amplifier pulse
- Implemented in UKRI-MPW0





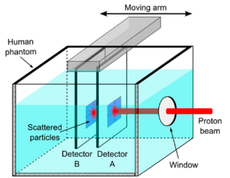




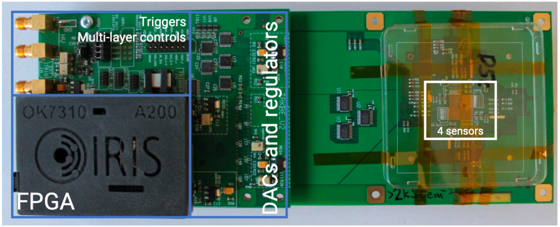
- Actually works!
- Significant reduction of time walk within the dynamic range
- Needs more measurements and improvements
- Filed a patent
- Looking for applications and partners to develop this idea further

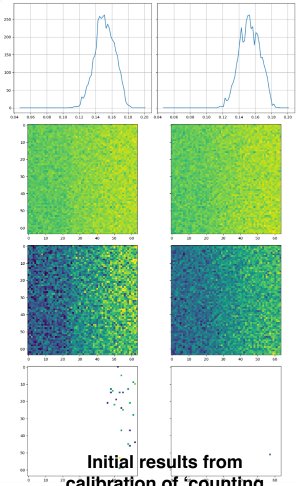
HVTrack: a novel HV-CMOS sensor for particle therapy

- HVTrack is a novel HV-CMOS chip designed by FBK in LFoundry 150nm CMOS for measuring clinical beams from an accelerator known as the IBA Proteus One
- The chip can be operated in 4 modes: counting, timing, energy, energy+counting, each pixel is 83um x 83um and contains two memories to allow high occupancy
- HVTrack modules comprising 4 chips to cover a 1cm^2 area assembled and wire bonded in the cleanroom
- Pairs of detector modules will be parylene coated and deployed in a water tank (phantom) for clinical beam characterisation



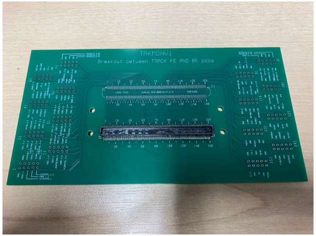
HVTrack system with two PCBs, on the left the controlling board and sensing PCB on the right

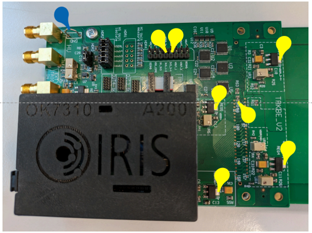


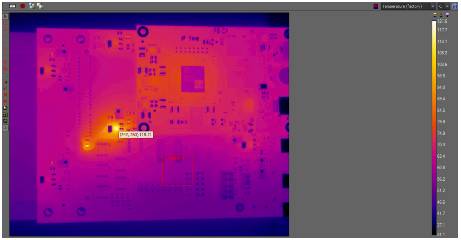


Initial results from calibration of 'counting mode'

HVTrack chip and PCB testing





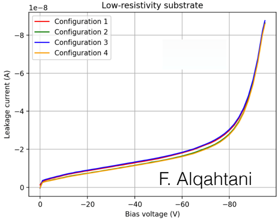


- Firmware optimisation ongoing at FBK to enable characterisation of the 4 different modes of HVTrack
- Problems encountered with long multi-pin connectors mounted on PCBs and difficult to check all pins for opens / shorts as many don't have access at both ends. Faults have been diagnosed with the aid of x-ray scans to look for poor solder joints under the connectors that appear good when checked by eye
- Thermal imaging used as an additional diagnostic to look for shorts or problematic regulators
- New 'interposer' PCB recently designed and fabricated to help monitoring of all pins on the chip and FPGA for better debug of PCB and characterisation of the different modes of the chip

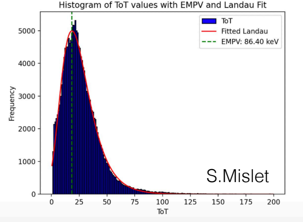
Measurements and simulations

- Development of an AllPix² monte carlo simulation based on GEANT4 to model the chip characteristics as well as radiation transport
- Probe station measurements of HVtrack chips to compare with spec and inform inputs to AllPix simulation
- Measurements with alternative pixel sensors with a similar pixel size (Timepix3) and resolution to test out calibration procedures using radioactive sources (laser measurements are also planned)

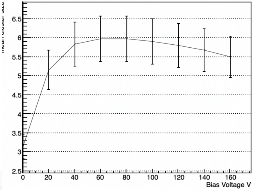
HVTrack IV curve



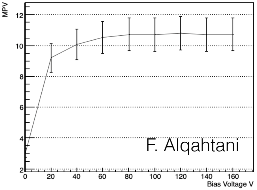
Timepix3 Sr90 charge collection



Allpix2 cluster size vs Bias voltage

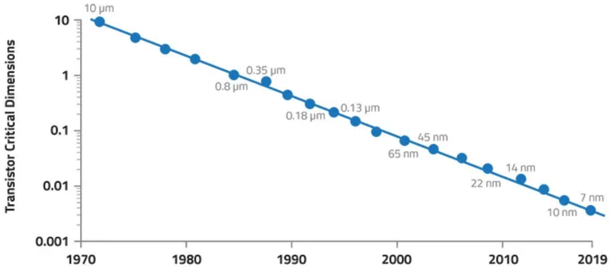


Allpix2 charge deposition vs Bias voltage



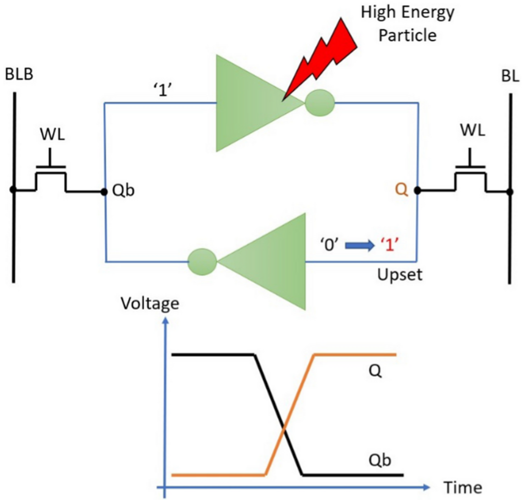
What is Particam?

- Adoption of smaller feature sizes for particle physics has slowed down over the last years
- More expensive and complex
- Limitations due to bump bonds and transistor size for analogue circuits
- Need a new concept for further miniaturisation



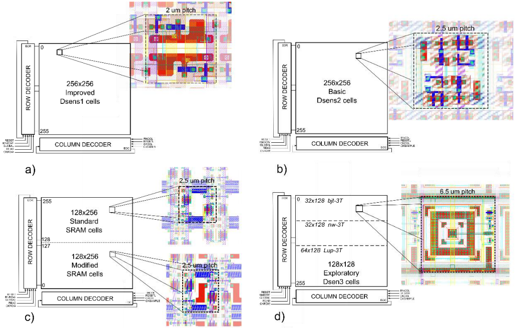
What is Particam? II

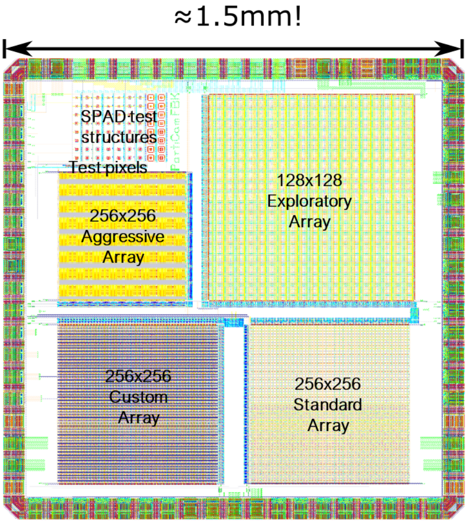
- Enter the Single Event Upset (SEU)!
- Ionising radiation can flip the content of memory cells
- Normally bad because it can break the configuration of the ASIC
- Much effort is spent minimising the rate and effects of SEUs
- What if we can harness the lightning?



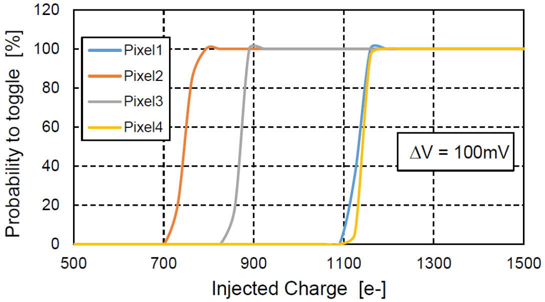
Particam1

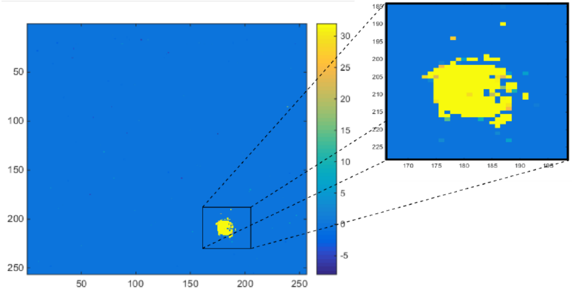
- Demonstrator in UMC 65nm node designed by FBK
- Many different RAM cell designs
- Smallest pixel has 4 transistors and a 2 µm pitch!





Particam1 II





- Optimised pixels only need $\mathcal{O}(1\,ke)$ to flip
- Sensitive to laser light

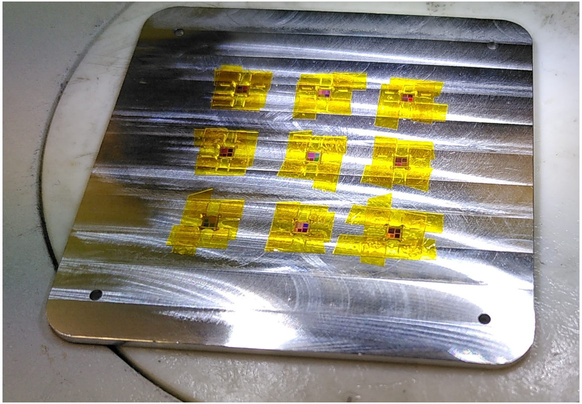
- No deep junctions used

$\rightarrow$ Poor charge collection

- Only some flavours are sensitive to alphas

Particam Future

- Particam2 should arrive in June
- Particam1 setup now in Liverpool
- Test of Particam1 with converter as neutron detector at PSI
- PhD student and 2nd PostDoc joining soon
- Investigating smaller process nodes
- Always looking for applications



Teams

HV-CMOS

- **Eva Vilella**
- Jan Hammerich
- Sam Powell
- Sigrid Scherl
- Ben Wade
- Chenfan Zhang
- New PhD student!

Apologies if I have forgotten anyone!

Proton Therapy

- **Jon Taylor**
- Fajer Alqahtani
- Gianluigi Casse
- Carlos Chavez
- Shaikah Mislet
- Tony Smith
- Alan Taylor
- New PhD student planned

FBK

- Nicola Massari
- Luca Parmesan

Particam

- **Gianluigi Casse**
- Jan Hammerich
- Eva Vilella
- New PhD student!
- New PostDoc

FBK

- Nicola Massari
- Massimo Gottardi
- Luca Parmesan

Acknowledgements

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