Science & Technology Facilities Council

MAPS Technology for Vertexing, Tracking, and Calorimetry

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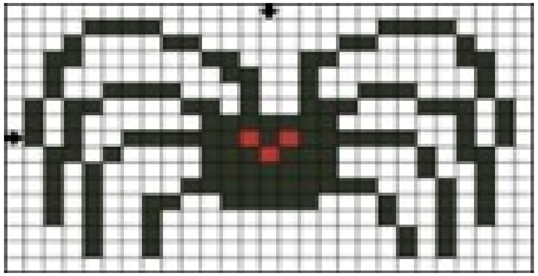
TiPP 2011 13th June 2011

University of Birmingham

University of Oxford



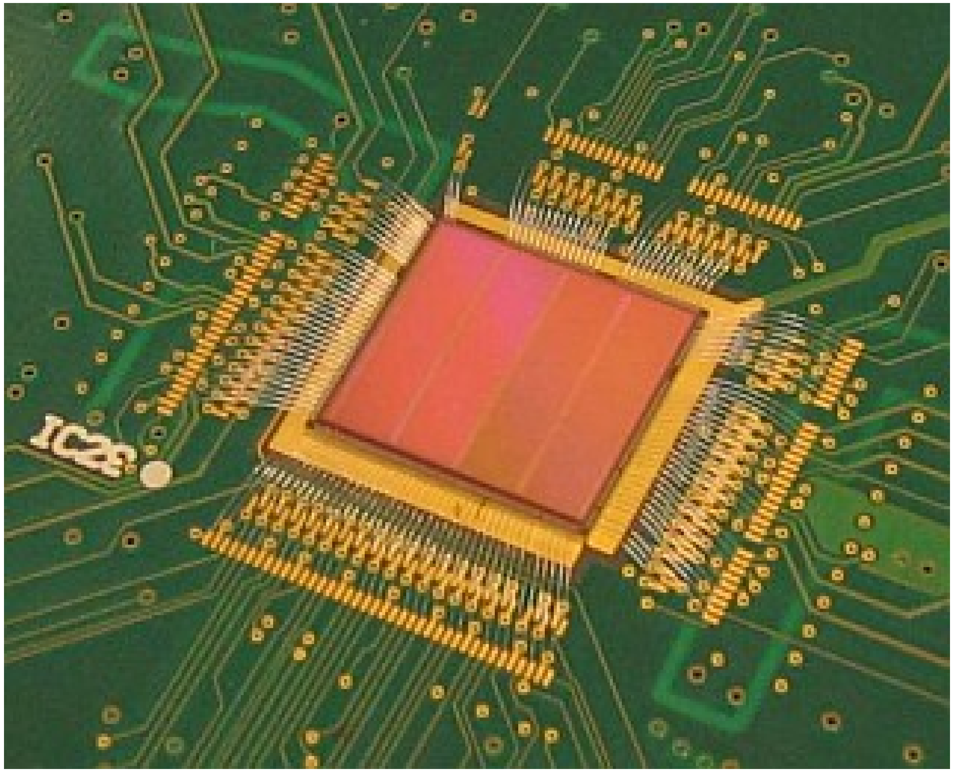
SPiDeR

Imperial College London

University of Bristol

Overview

- Who Are We?
- What Do We Do?
- INMAPS Process
- TPAC Sensor
- Test Beam Results
- TPAC Irradiations



TPAC 1.2 Sensor

Who Are We?

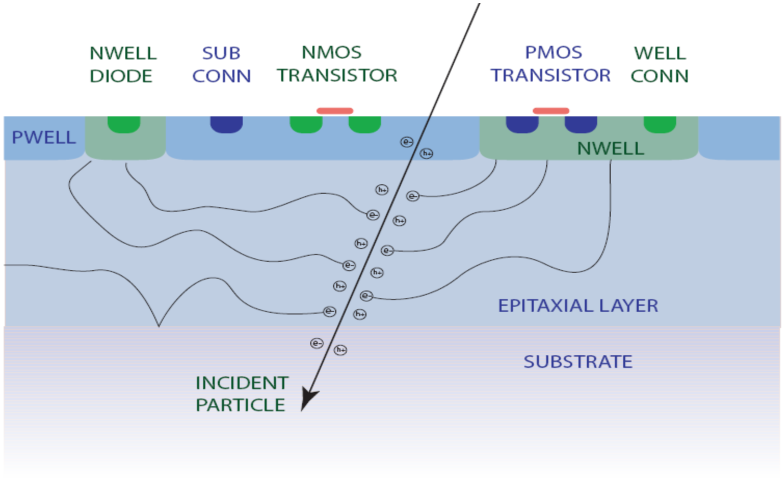
- **SPiDeR** – **S**ilicon **Pi**xel **De**tector **R**&D
- Generic Pixel R&D for particle physics applications using CMOS sensors
- Members from
  - Imperial College London
  - Rutherford Appleton Laboratory / STFC
  - University of Birmingham
  - University of Bristol
  - University of Oxford
  - Queen Mary University of London

What Do We Do?

- FORTIS (**FO**u**R** **T**ransistor **I**maging **S**ensor)
  - Designed for tracking
  - Signal to Noise ratio > 100
- TPAC (**T**era**P**ixel Active **C**alorimeter)
  - Digital sensor
  - Designed for Digital ECAL at future Linear Collider
  - Various designs
    - standard
    - deep p-well
    - hi-resistivity
  - Useful for vertex trackers (ALICE and SuperB)

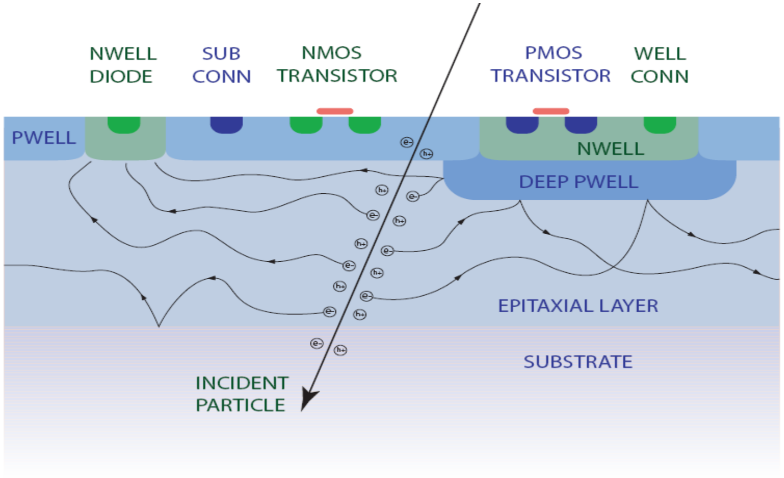
Both utilise INMAPS technology

INMAPS Technology



Standard CMOS

- Charge collected by diffusion (t~100 ns)
- Parasitic charge collection at n-wells (cannot use PMOS)



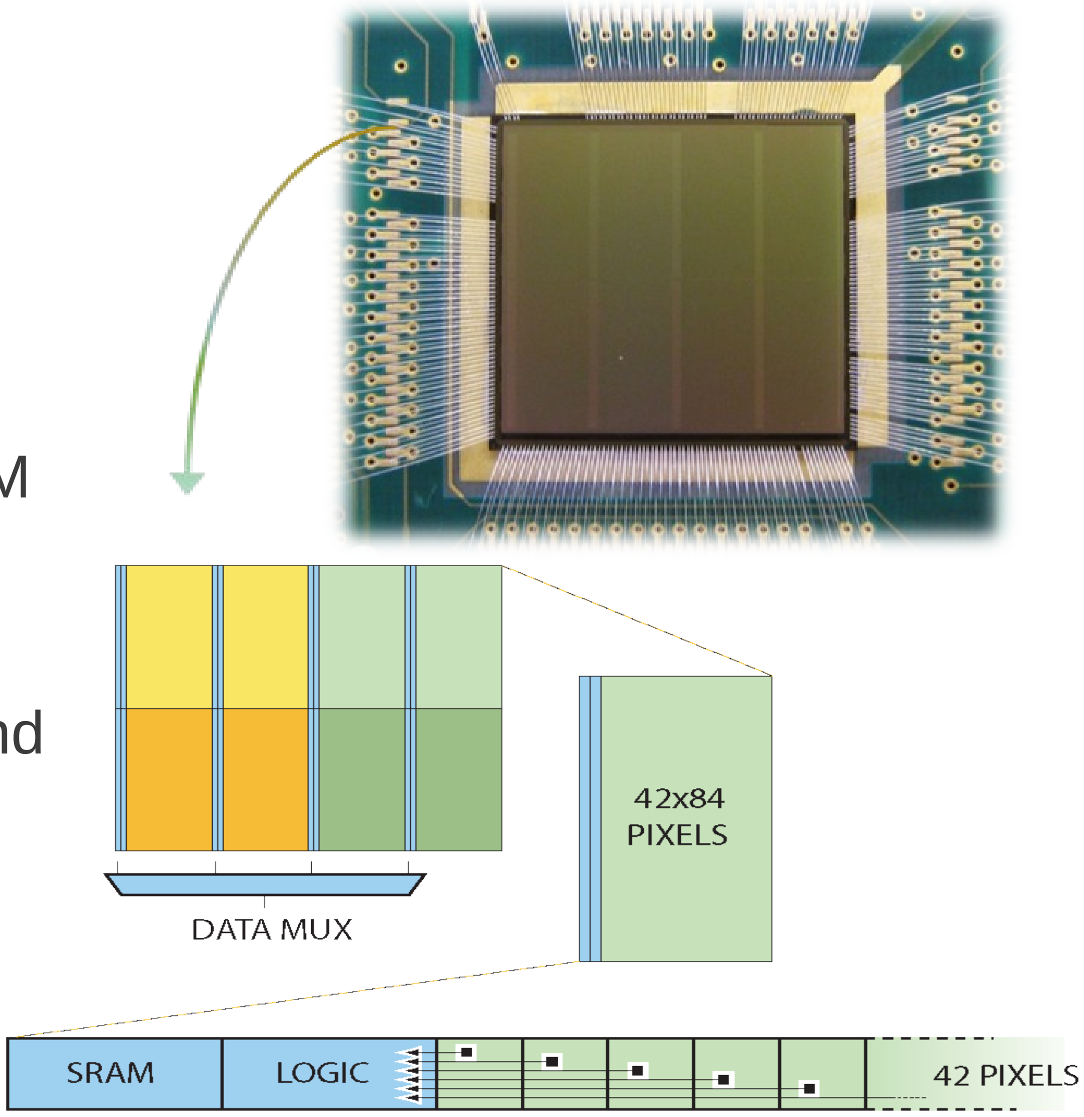
INMAPS CMOS

- Developed deep p-well to shield the n-well
- Allows full CMOS
- TPAC first to use technology
- Benefits demonstrated
- High resistivity epitaxial possible

TPAC Sensors

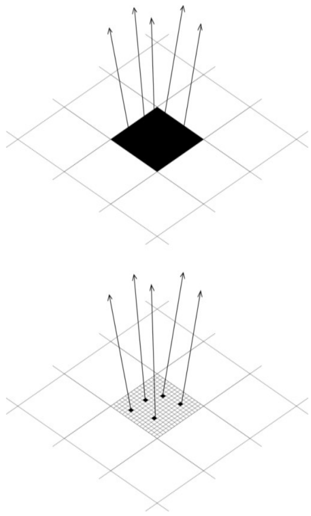
- 3 iterations 1.0, 1.1 & 1.2
- 168x168 pixel grid
- 50x50 μm^2 pixel size
- 1x1 cm^2 total sensor size
- Four columns of logic & SRAM
- Each logic column serves 42 pixels
- Hits and time stamp stored and readout after data acquisition

arXiv:0807.2920 arXiv:1103.4265

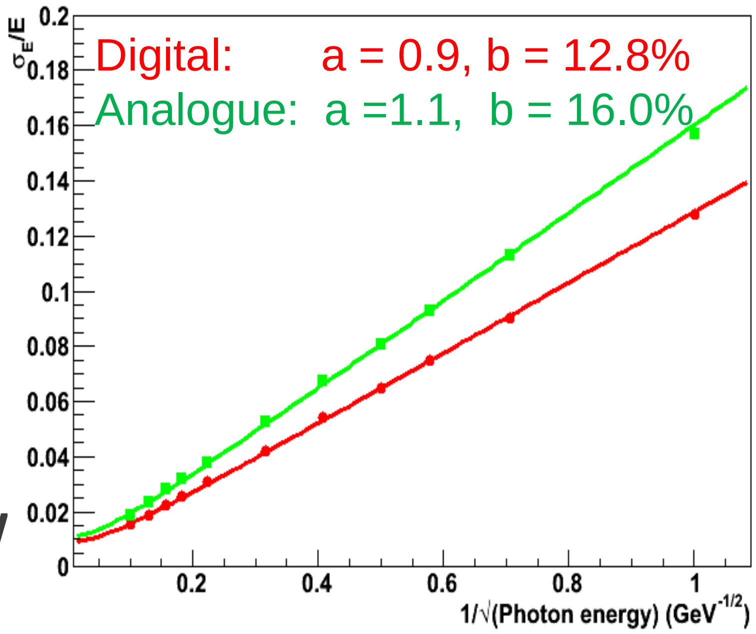


Digital ECAL

Digital ECAL is finely segmented and counts the number of particles not their energy



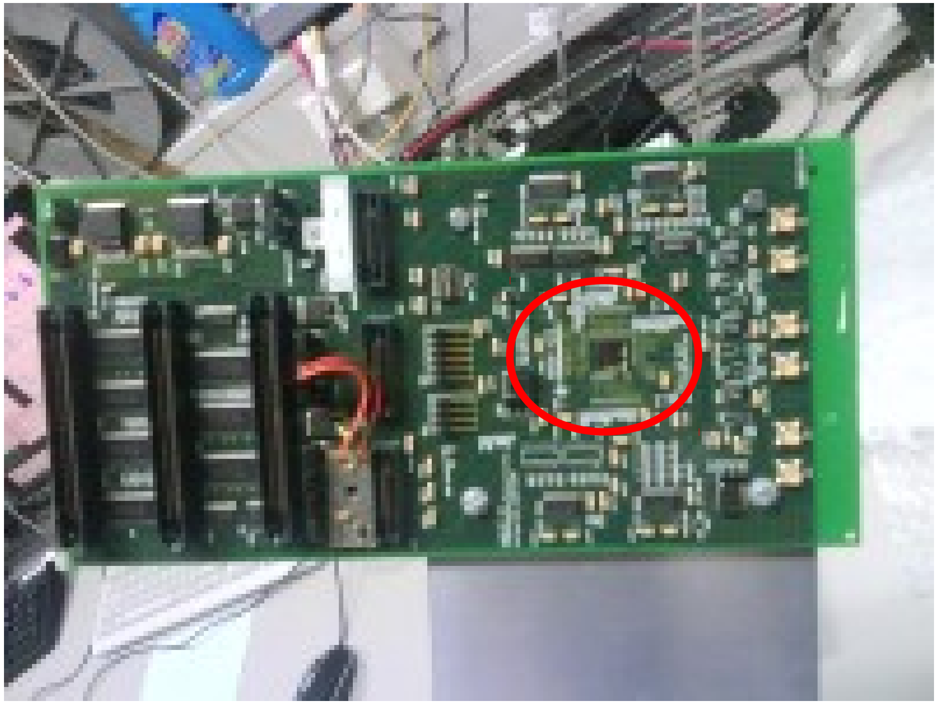
- $\frac{dE}{dt} \propto N$
- Removes landau fluctuations in shower
- High granularity allows Particle Flow Algorithms (PFA)



20 layers $0.6X_0$ & 10 layers $1.2X_0$

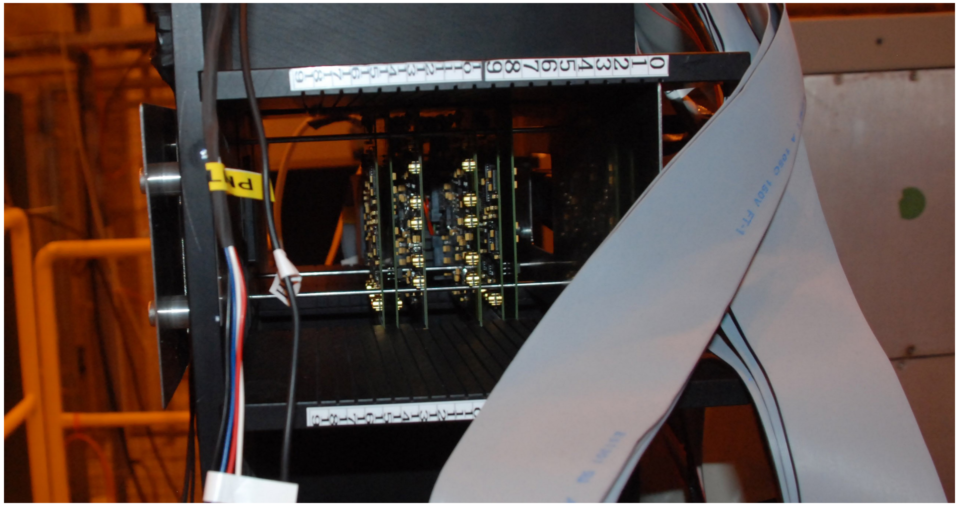
Test Beams

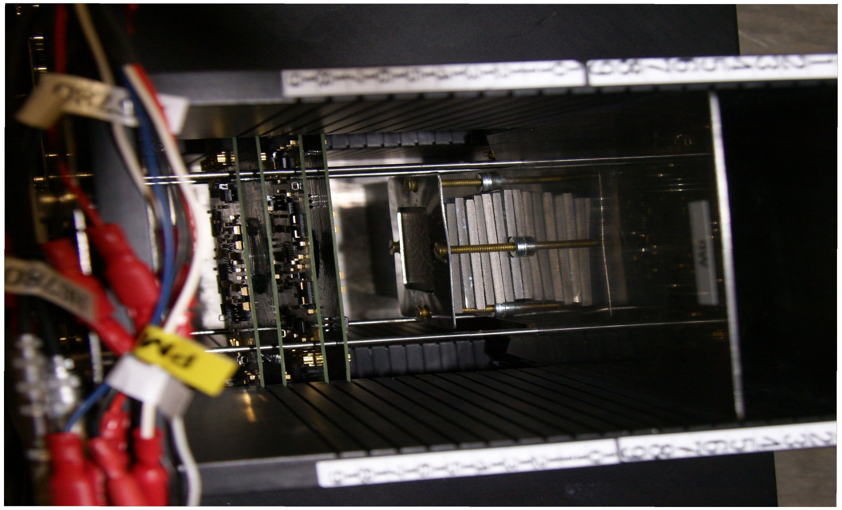
- FORTIS & TPAC combined test beams
  - CERN August '09 (pions 20-120 GeV)
  - DESY March '10 (e^+ 1-5 GeV)
- Studies
  - MIP efficiencies
  - Particle shower response

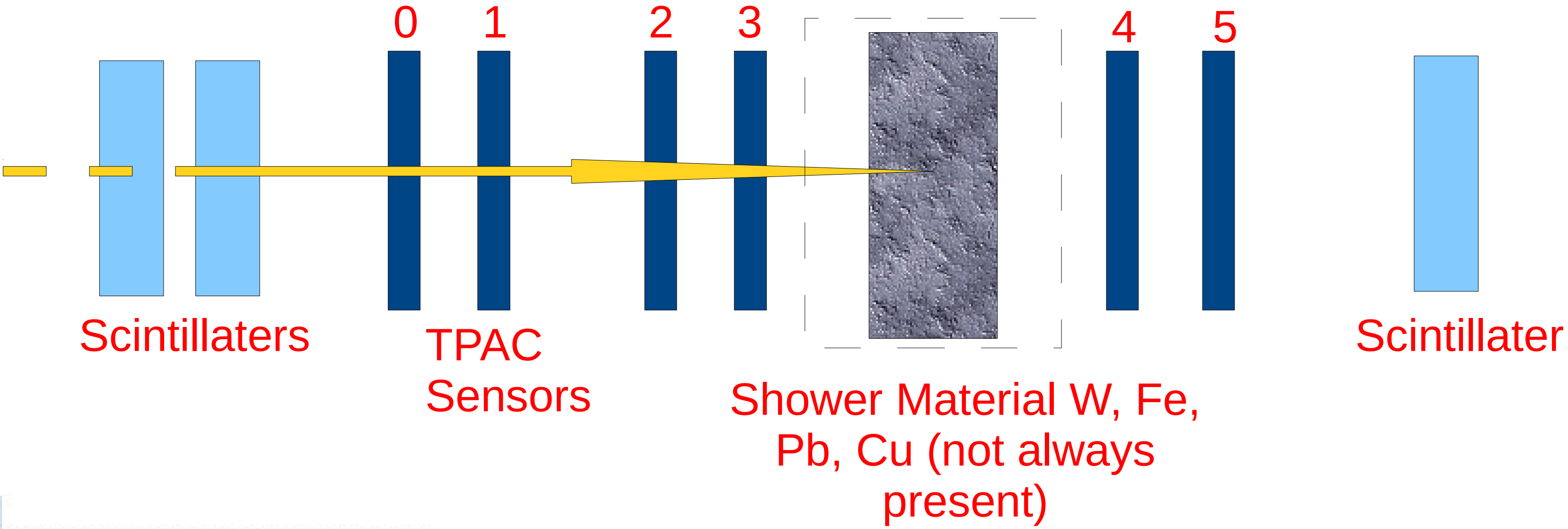


TPAC 1.2 bonded onto a PCB

Test Beam



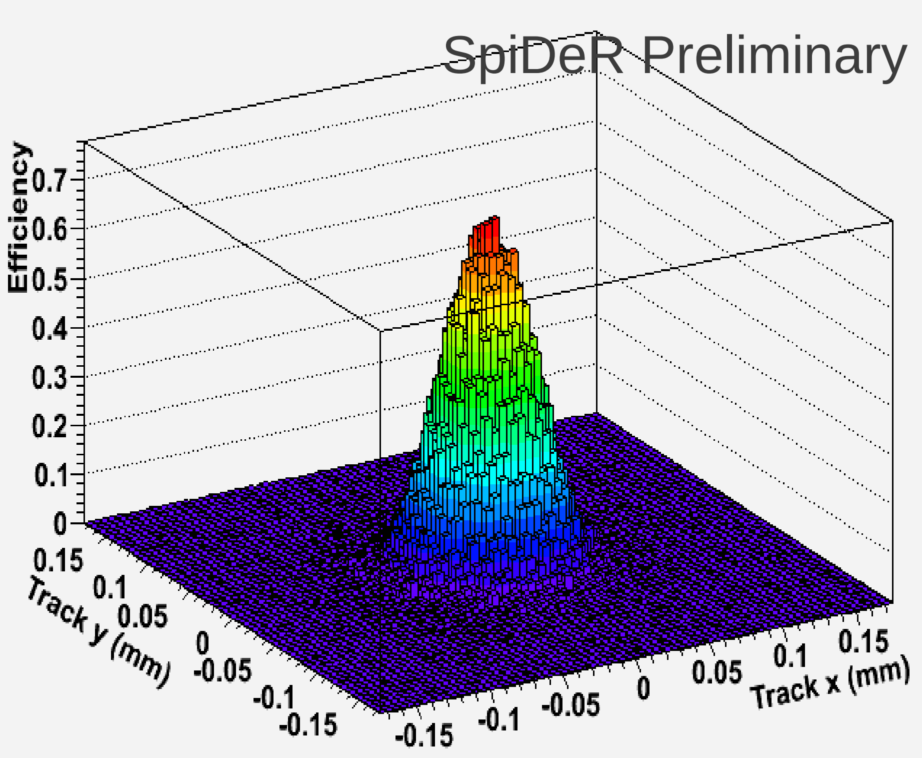



0
1
2
3
4
5
Scintillaters
TPAC Sensors
Shower Material W, Fe, Pb, Cu (not always present)
Scintillater

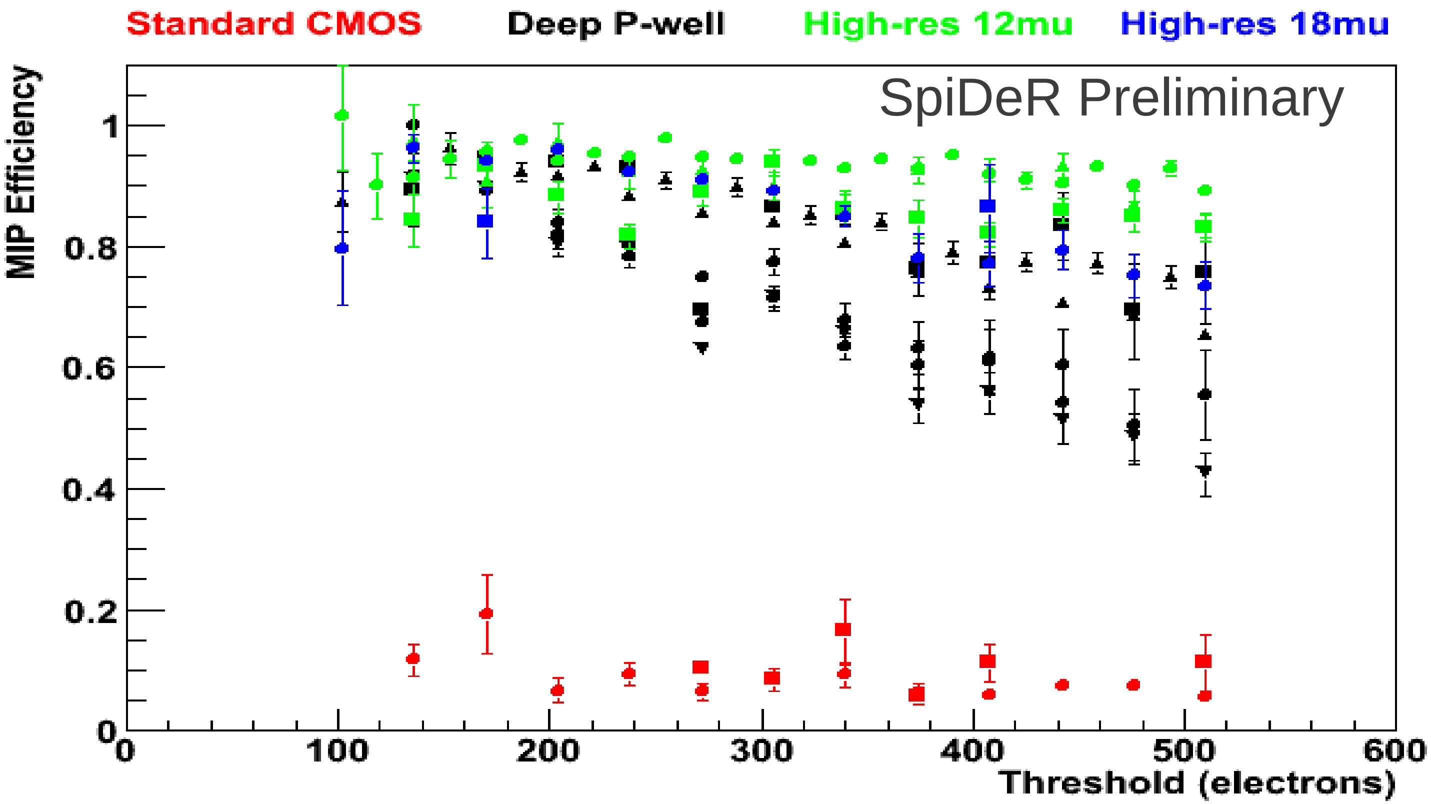
MIP Efficiencies

Studies conducted for pions and positrons

- Form tracks
- Project the tracks into single sensors
- Search for hit probability around the projection
- Fit distribution with a flat top convoluted with gaussian for track resolution to determine efficiency
- Track resolution ~ pixel size



MIP Efficiencies (II)



Significant improvement in efficiencies with deep p-well over standard sensor

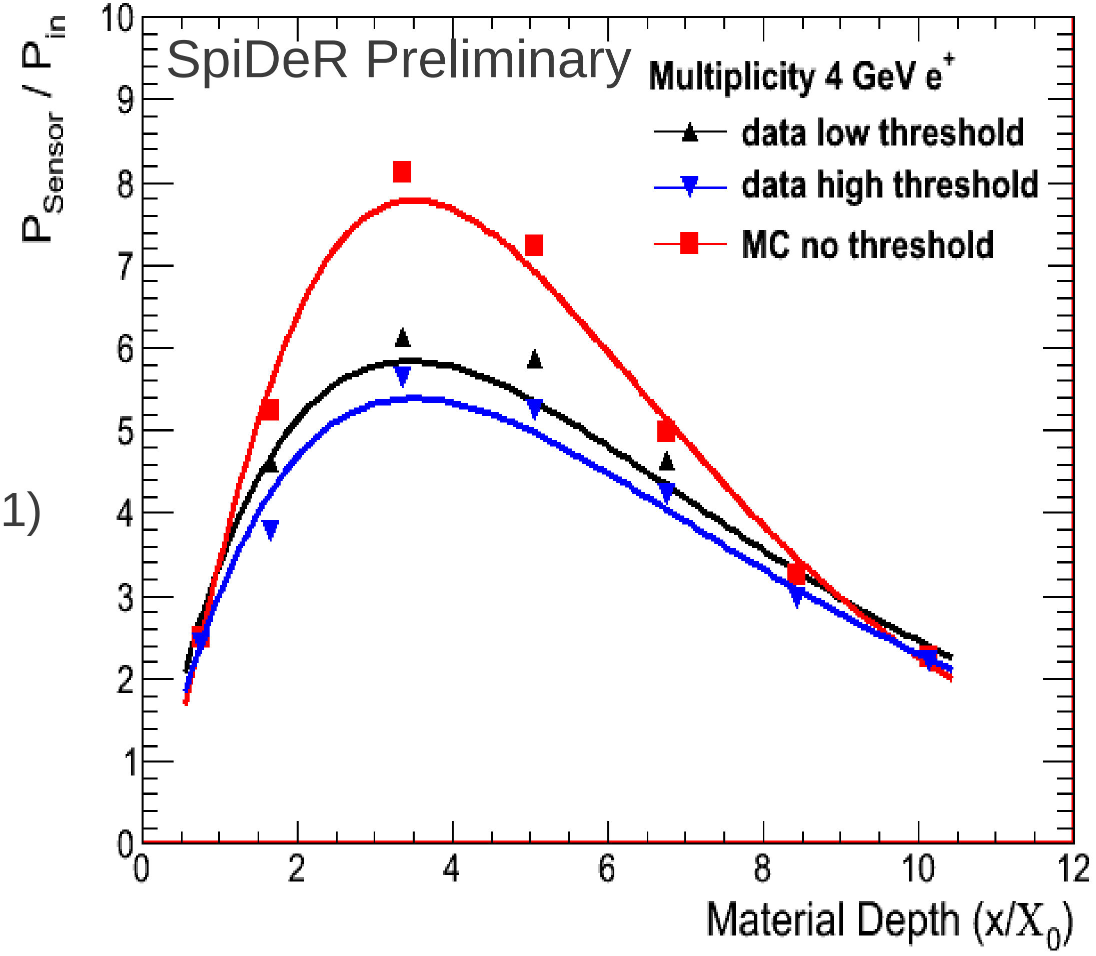
Further improvement using high resistivity epi layer

TPAC EM Shower Response

P_{in} = Number of tracks
P_{sensor} = Number of hits detected in layer

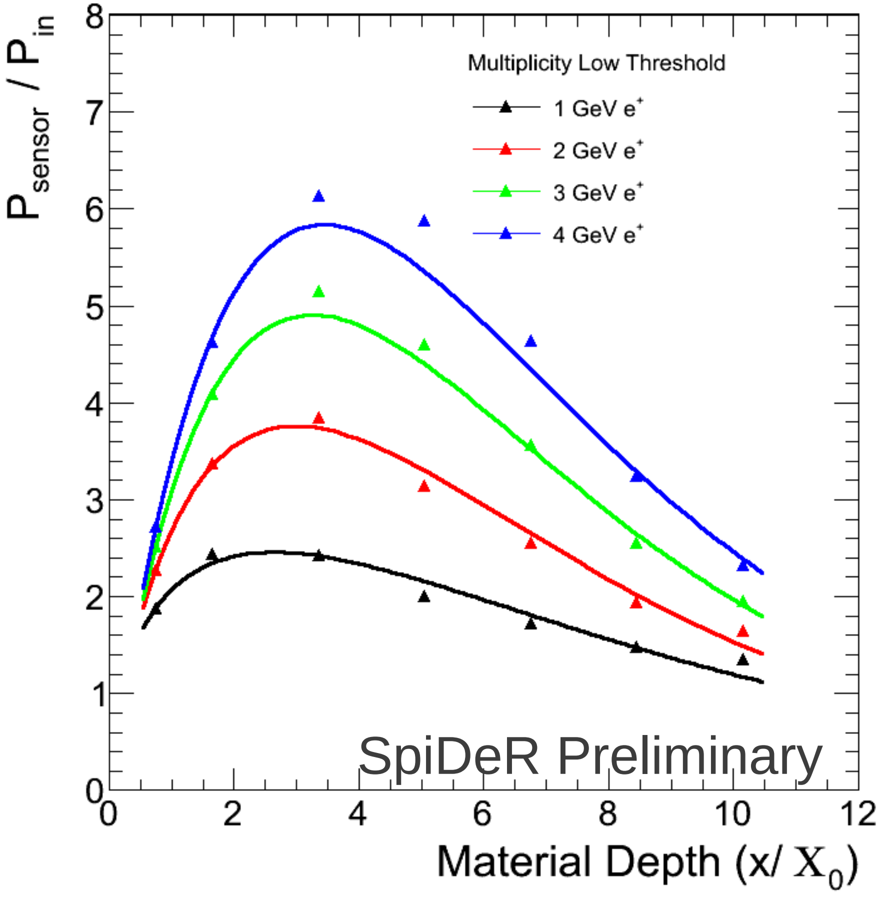
$$\frac{dE}{dt}=E_0 b \frac{(bt)^{a-1}\exp(-bt)}{\Gamma(a)} \quad (1)$$

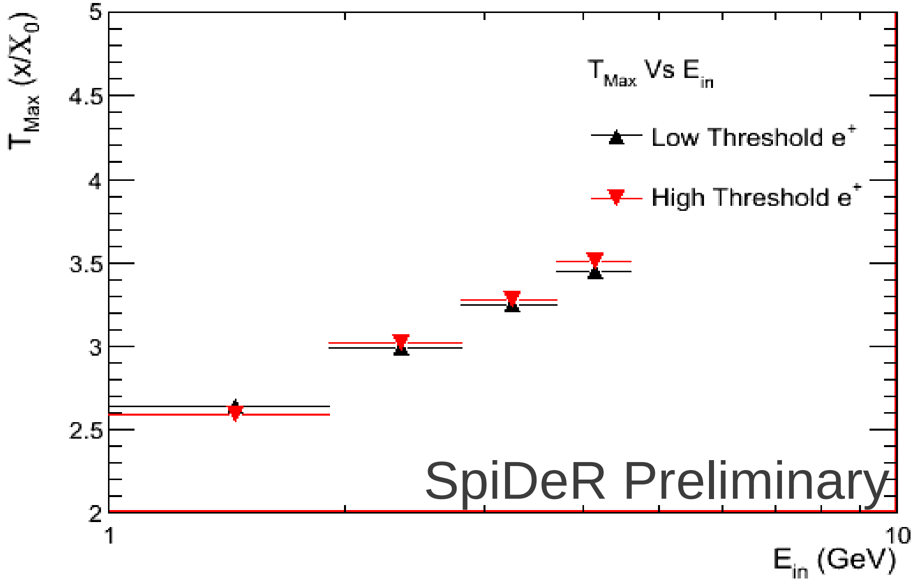
Cannot compare MC yet as not fully digitised



(1) http://pdg.lbl.gov/2010/reviews/rpp2010-rev-passage-particles-matter.pdf

TPAC EM Shower Response (II)





$$t_{Max} = \frac{(a-1)}{b} = \ln(y) + 0.5$$

Multiplicity increases with energy
excellent for DECAL concept

Increases linearly with natural log
energy as predicted

Vertexing With INMAPS Technology

Potential use of sensors using INMAPS for vertex and tracking detectors

- SuperB
- ALICE ITS upgrade

Vertex detectors need to be radiation hard to survive in the harsh environments close to beam line

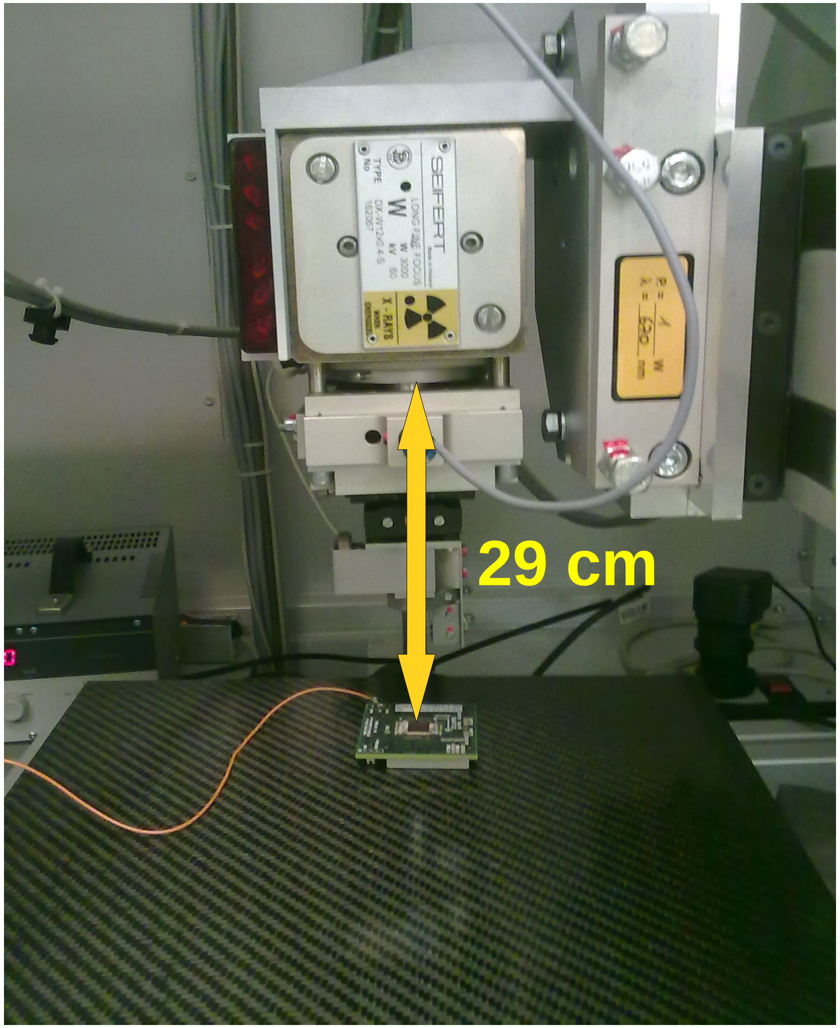
Studies of radiation hardness using x-rays are under way using TPAC

Needs modifications e.g analogue readout

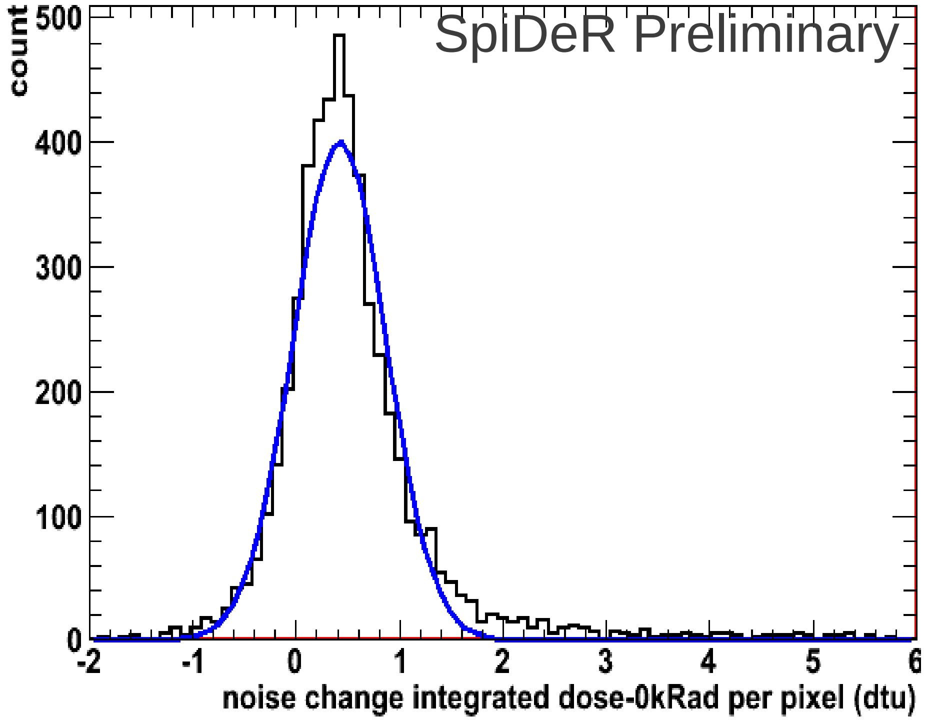
TPAC Irradiations

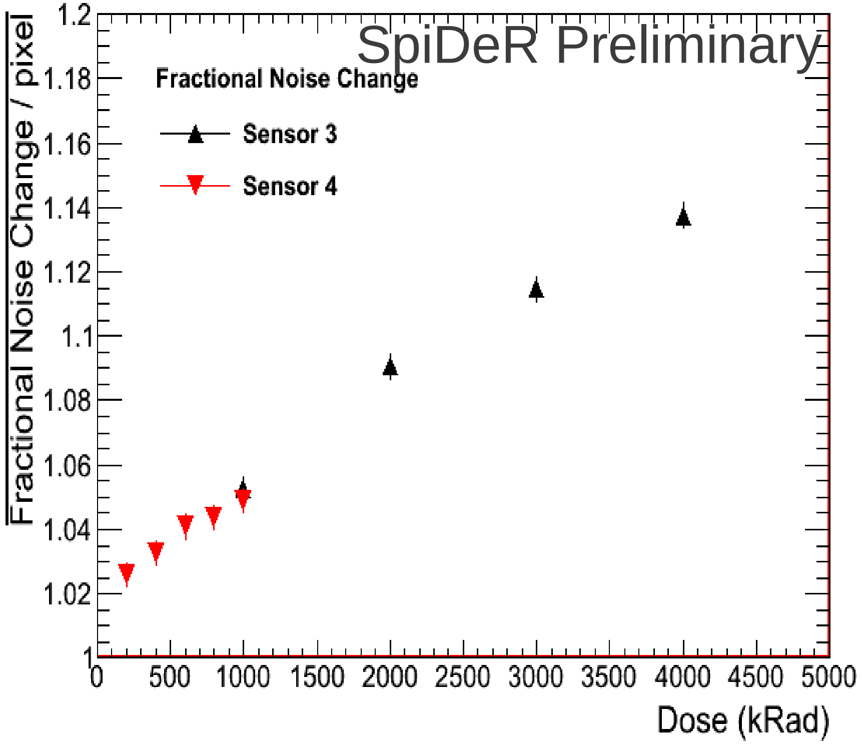
X-ray tube Set-up

- Bremsstralung beam V=50kV I=50mA
- Distance = 29 cm
- Target = Tungsten
- Dose Rate = 60 Rad/s in 12µm Si
- Sensor held at 0 V



Noise Changes With Dose





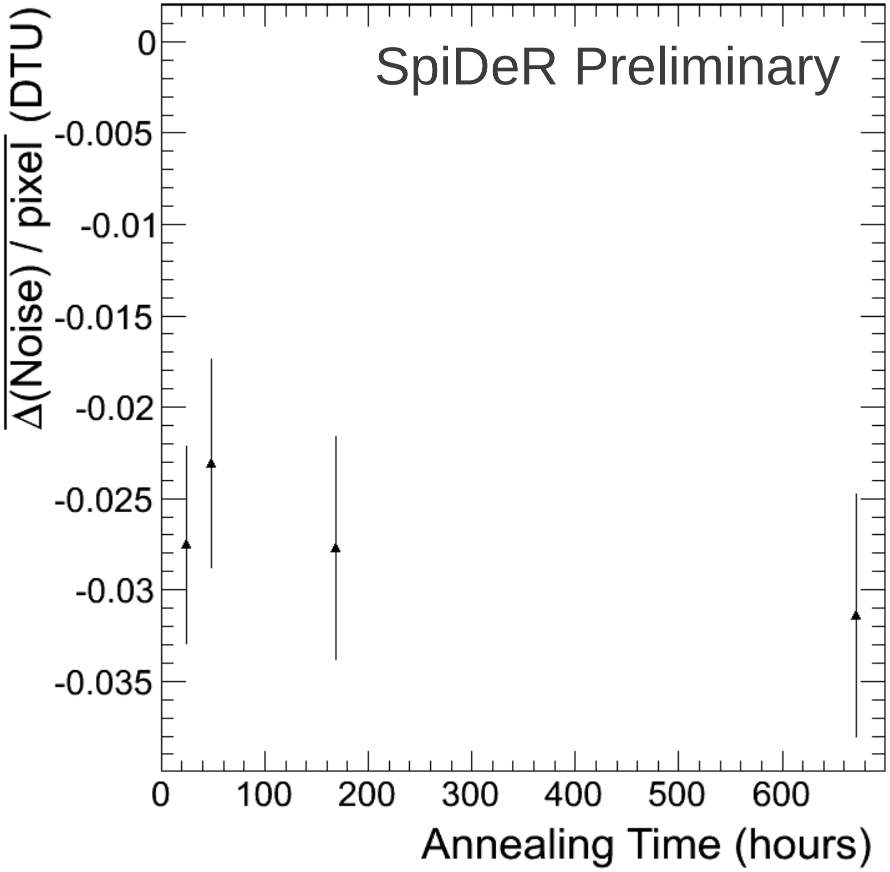
Noise compared pixel by pixel after each irradiation

Results of these then put in histogram and fitted (example left)

Fit results are then plotted Vs dose (right)

Noise Changes Vs Annealing

- After exposure how quickly does the sensor recover?
- 5 MRad dose allowed to anneal held at 0 V for
  - 24 hours
  - 48 hours
  - 168 hours
  - 672 hours
- @ 5Mrad Δ(noise) ~ 1 DTU



Over 672 hours only recovers 0.03 DTU and most of this occurs in first 24 hours

Summary

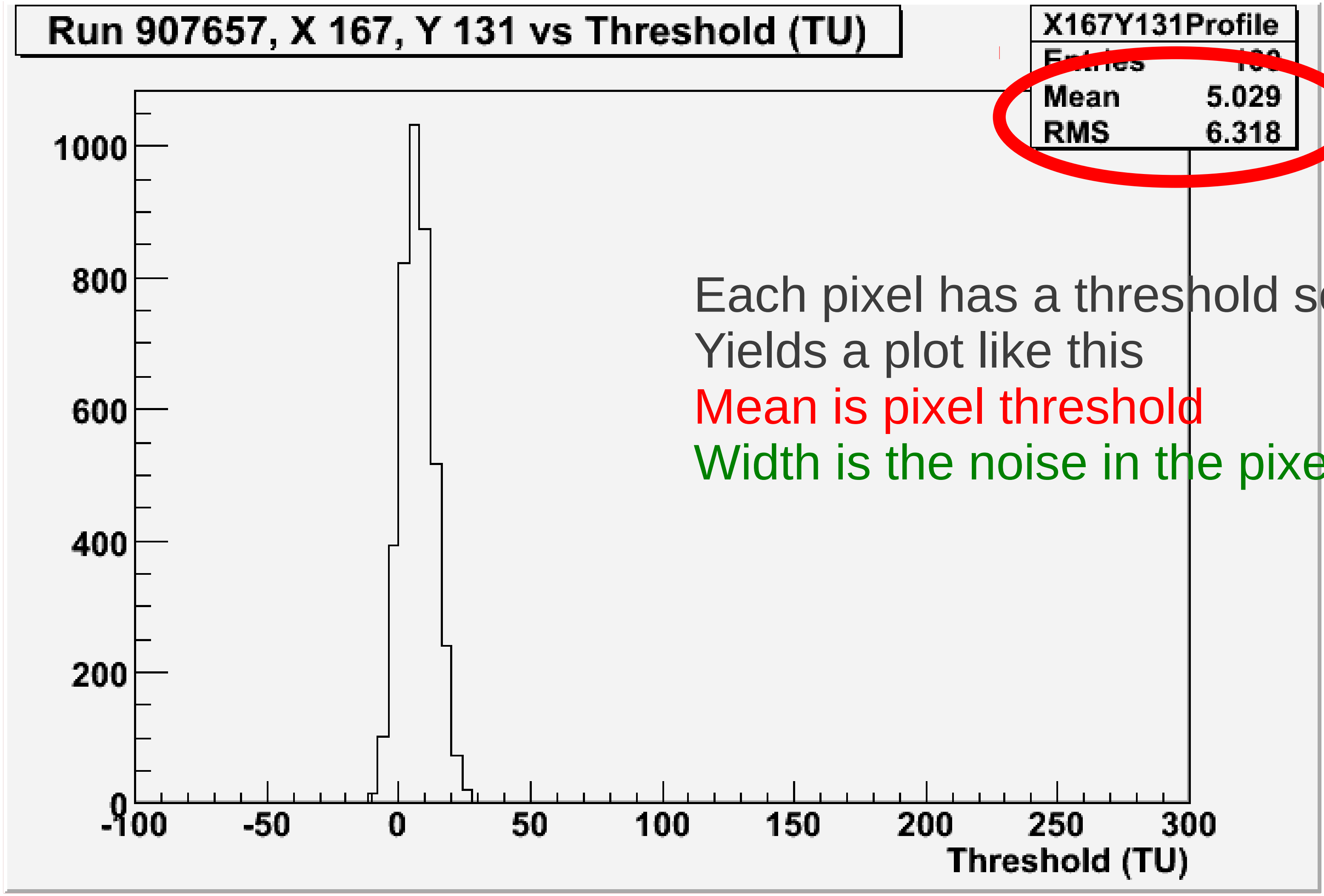
- INMAPS technology gives x5 efficiency improvement over standard CMOS sensors
- Have demonstrated higher E_{in} yields greater shower particles
- Dose of 1 MRad give noise increase of ~ 5%, 4 MRad increase of 14%
- Future work
  - Improve the fit for shower multiplicities
  - Move on from shower multiplicities to shower densities
    - Have another beam test using EUDET Telescope to analyse alongside these studies
  - Continue irradiations with
    - different sensor types at different bias
    - Different sources of radiation (p in Birmingham?, ions with ALICE ITS??)

Two papers published on TPAC 1.0 sensors and the INMAPS process

- arXiv:1103.4265
- arXiv:0807.2920v1

Back-up Slides

Threshold / Noise scan



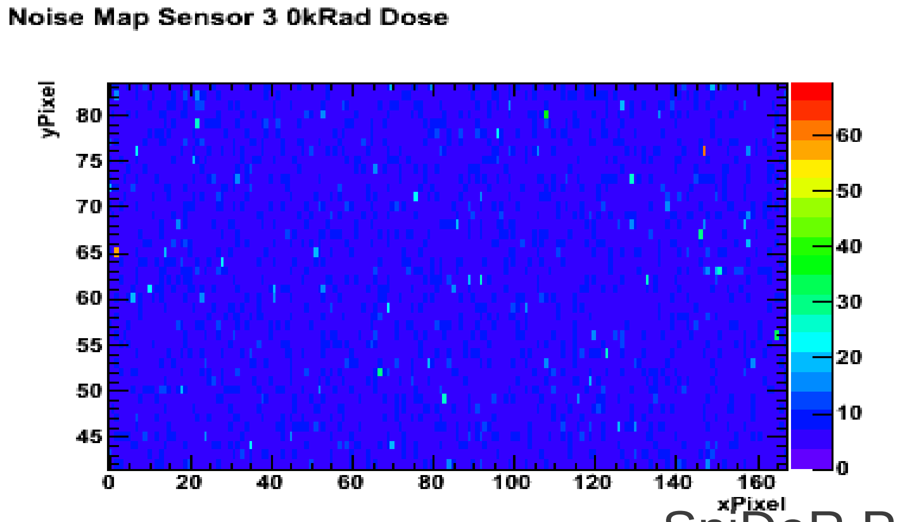
Each pixel has a threshold scan

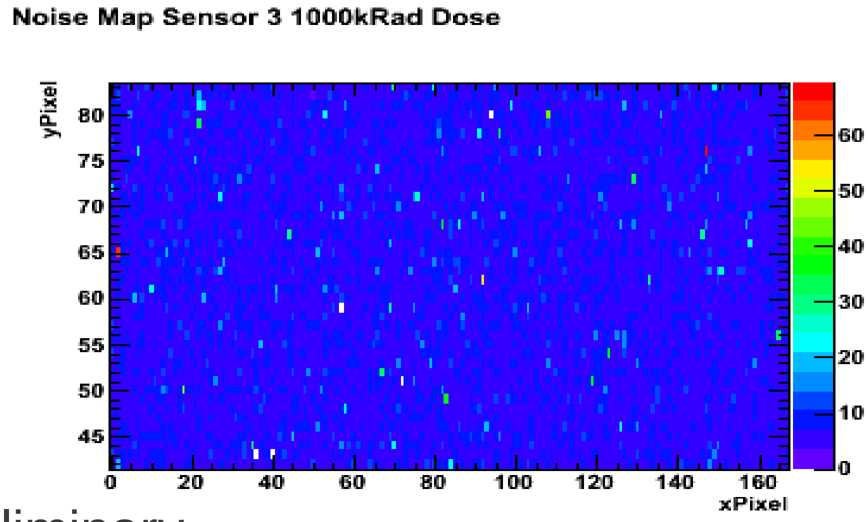
Yields a plot like this

Mean is pixel threshold

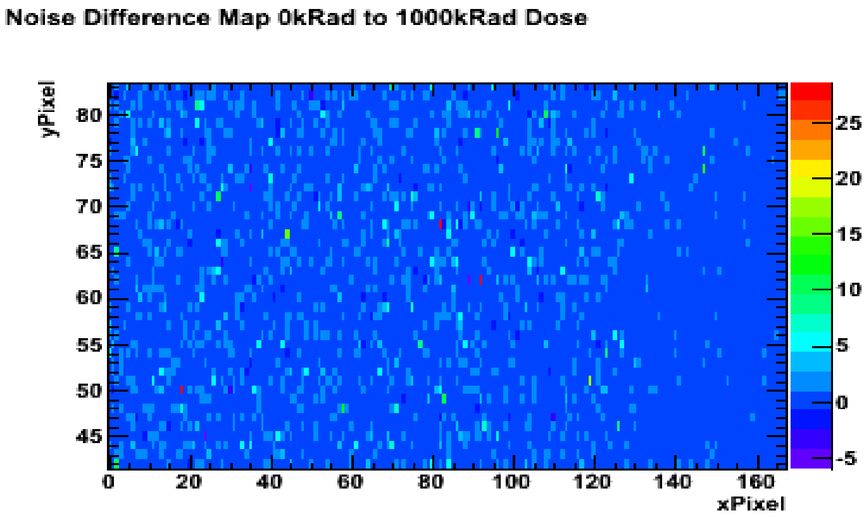
Width is the noise in the pixel

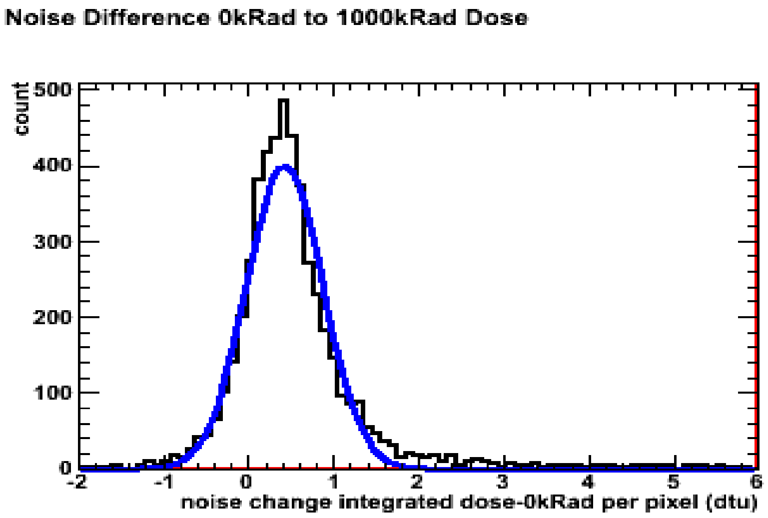
Noise Change Method


Noise Map Sensor 3 0kRad Dose

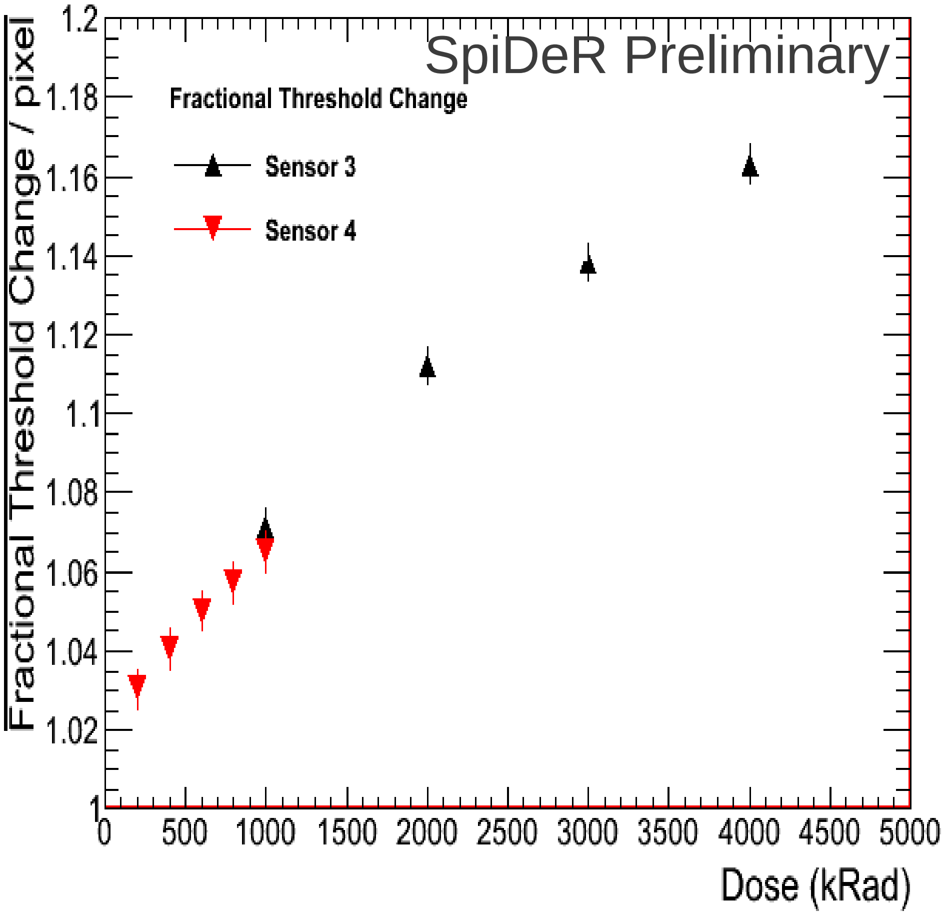

Noise Map Sensor 3 1000kRad Dose

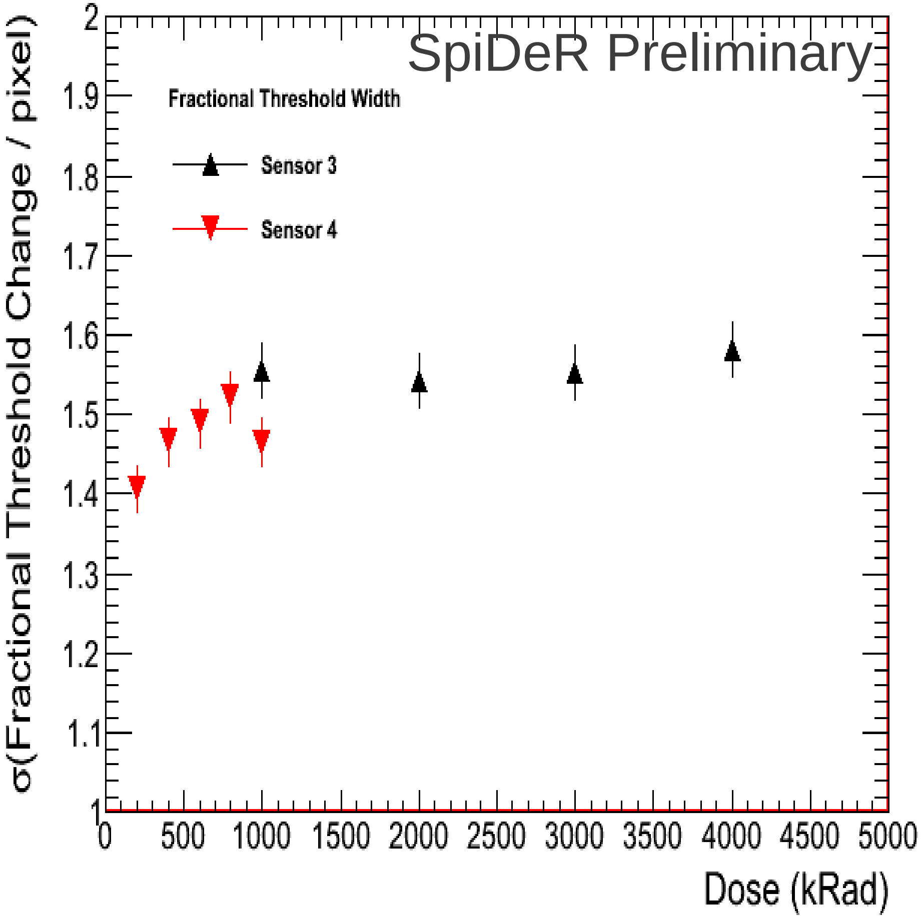
SpiDeR Preliminary


Noise Difference Map 0kRad to 1000kRad Dose

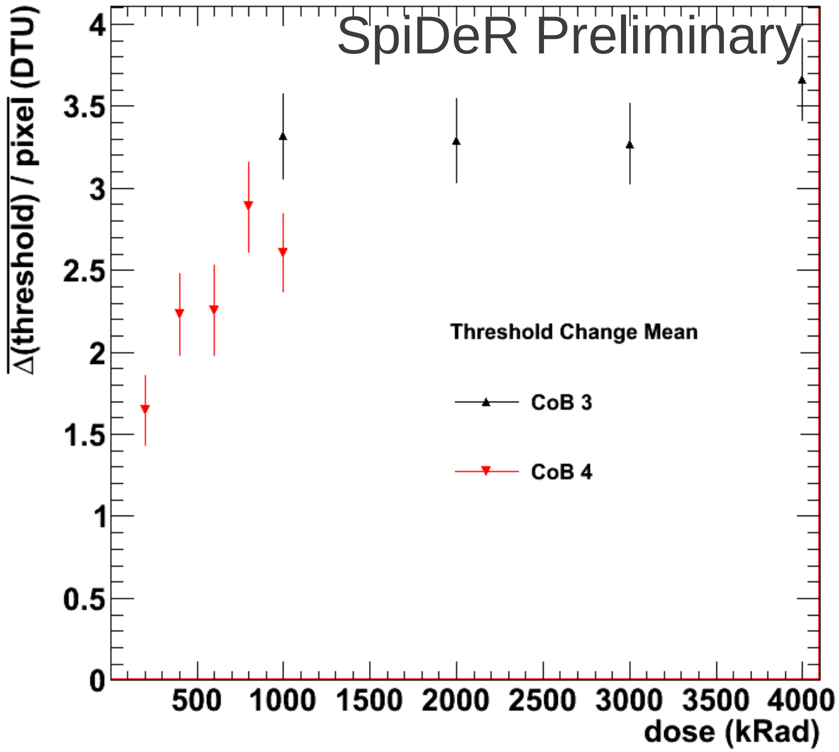

Noise Difference 0kRad to 1000kRad Dose

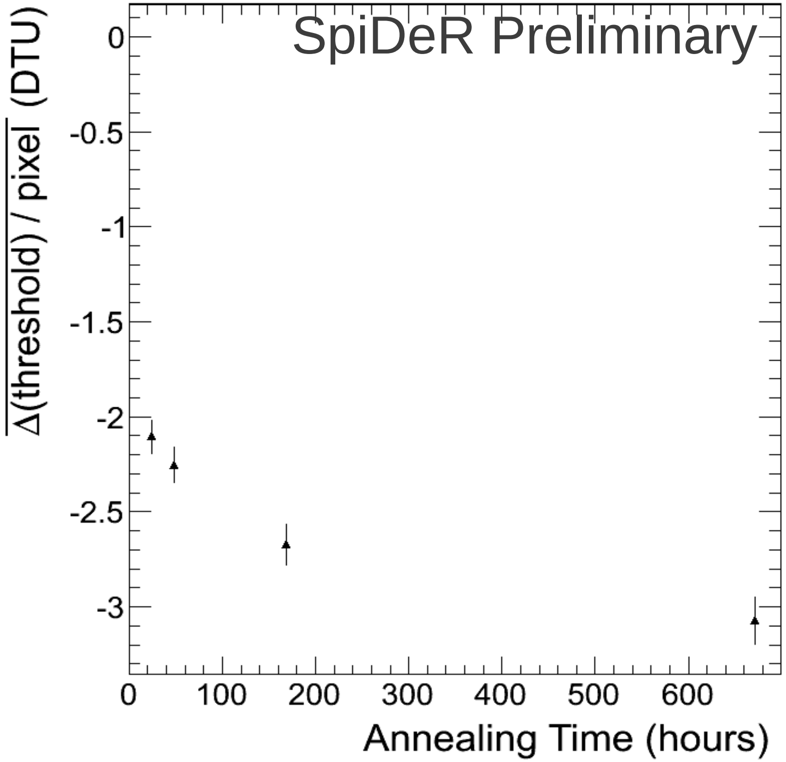
Fractional Pedestal Changes





Pedestal Changes





Can see pedestal shift with dose up to ~ 1MRad

60% this shift anneals away in just 24 hours at ground and 85% after 672 hours