DECAL using MAPS technology: Beam test results

Tony Price [1]

University of Birmingham

txp@hep.ph.bham.ac.uk

24$^{\text{th}}$ October 2012

[1] on behalf of the SPiDeR Collaboration

Overview

SPiDeR Collaboration

Who Are We?

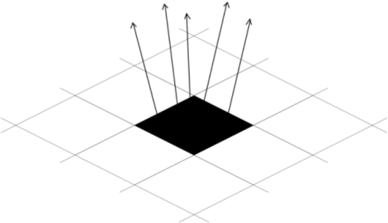
- **SPiDeR** - **S**ilicon **Pi**xel **De**tector **R**&D
- Generic Pixel R&D for particle physics applications using CMOS sensors
- Members from
  - Imperial College London
  - Rutherford Appleton Laboratory / STFC
  - University of Birmingham
  - University of Bristol
  - University of Oxford
  - Queen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

Digital ECAL
The Concept

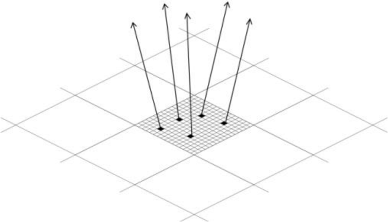
- Make a pixellated calorimeter to count the particles in each sampling layer
- Digital readout
- Ensure the pixels are small enough to avoid multiple particles passing through a single pixel
  - Avoid undercounting and non-linearity in higher particle density environments
- Max density of 100 $particles/mm^2$ leads to pixel sizes of 50 μm^2
- Digital variant of an ECAL at the ILC would need 10^{12} channels!!
- Dead area and power consumption per channel must be kept to a minimum

Digital ECAL

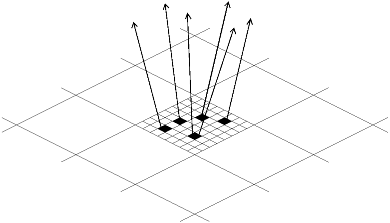
The Concept



Analogue ECAL



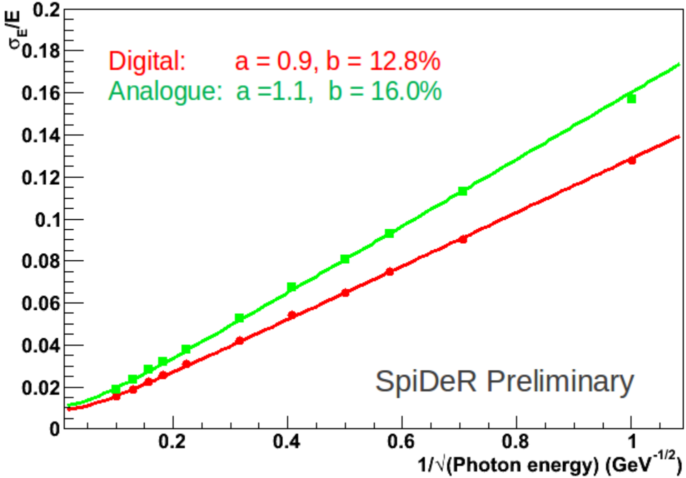
DECAL $N_{pixels} = N_{particles}$



DECAL $N_{pixels} \leq N_{particles}$

Digital ECAL

Energy Resolution Vs analogue ECAL



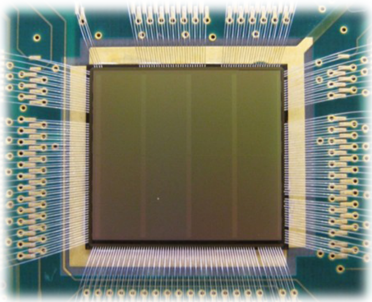
Simulation: 20 layers 0.6 X_0 & 10 layers 1.2 X_0

TPAC Sensor

TeraPixel Active Calorimeter Sensor

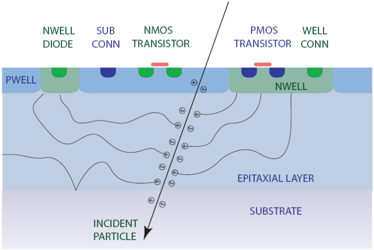
CMOS sensor designed with the DECAL requirements in mind

- 168×168 pixel grid
- 50×50 μm^2 pixel size
- Digital readout
- Low noise
- Utilise INMAPS process
- 42 pixels served by one strip of SRAM and logic
- Charge collected by diffusion to signal diodes
- Sensor sampled every 400 ns (timestamp)
- Sensor readout every 8000 timestamps (bunch train)

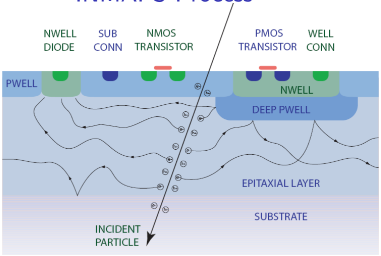


TPAC Sensor

TPAC Sensor



INMAPS Process



CMOS architecture causes parasitic charge collection at the N-wells reducing the pixel efficiency. INMAPS technology uses a **deep P-well** which inhibits the parasitic collection increasing the signal at the diodes. Allows use of standard full CMOS

- lower cost fabrication at multiple foundaries
- allows different resitivity epitaxial layers
  - 12 μm standard INMAPS (standard sensor)
  - 12/18 μm high resistivity INMAPS

Beam Test

Overview

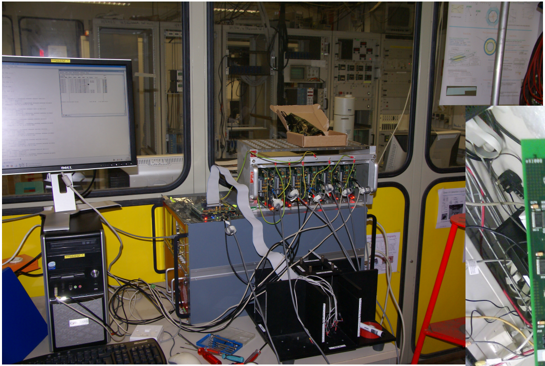
Beam tests of TPAC sensors conducted at

- CERN 20-120 GeV pions
- DESY 1-5 GeV electrons

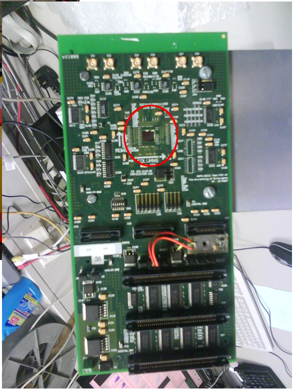
to study the sensor response to Minimum Ionising Particles (MIPs) and particle showers

Beam Test

Overview



Complete set-up at beam test

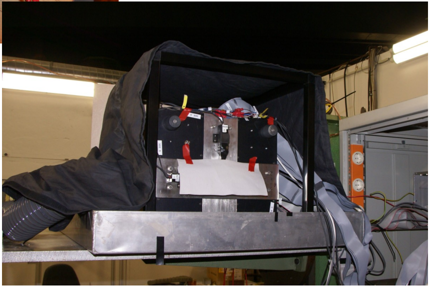


Bonded sensor

Beam Test

Setup - PMT Triggers

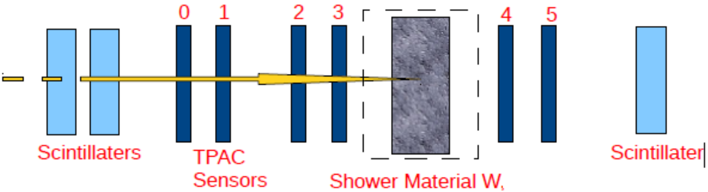
2 in front



1 behind

Beam Test

Setup

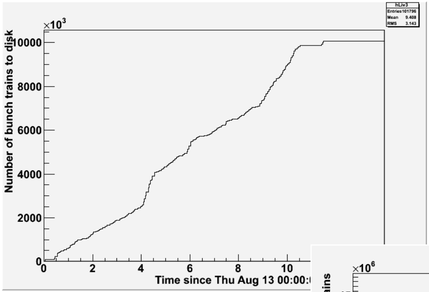


TPAC stack operated in two modes:

1. Tracking: Tracks were formed in sensors 0145 and projected into 34 to study properties of the sensor
2. Showering: Shower material placed between sensors 34, tracks formed in sensors 0123, shower studied in sensors 45

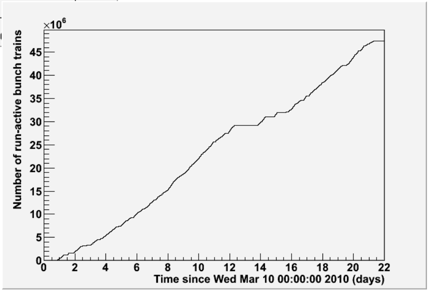
NB: Active area just 9×9 mm^2 so in *Showering* mode don't expect full containment. Repeated data taking runs with varying depth of shower material.

Data Checking



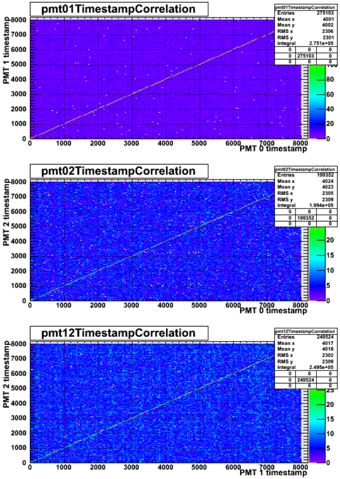
10M+ bunch trains written to disk at CERN

45M+ bunch train written to disk at DESY



Data Checking

PMT Correlations

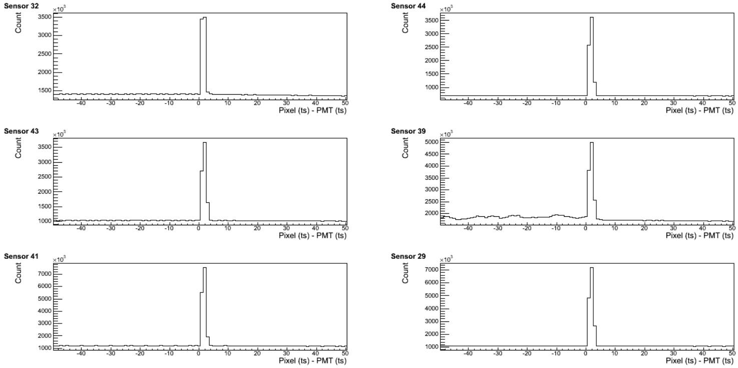


Clear correlations between the PMT triggers

Data Checking

Hit Timings

Plot the timestamp of all hits w.r.t PMT coincidence timestamps in all 6 sensors of an run.

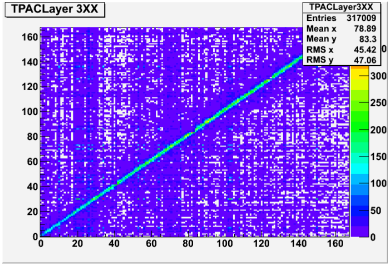


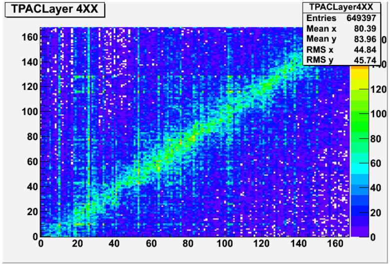
All genuine hits occur in an event window of $0<\Delta t<3$

Data Checking

Hit Correlations

Comparing all of the hits in time between sensors look for correlations between sensors to show alignment.



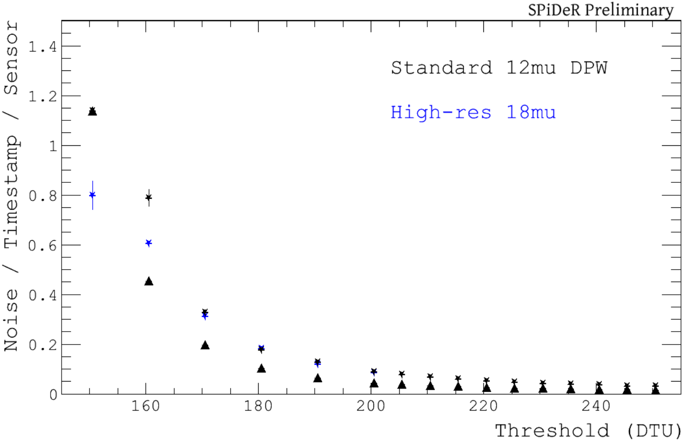


Can see clear correlations between layers before W

Correlations broader downstream due to showering

Noise Rate

Count number of pixels fired in events with no PMT coincidence

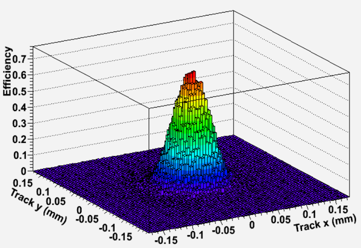


Noise rate for a complete threshold scan, NB rate independent of epi layer

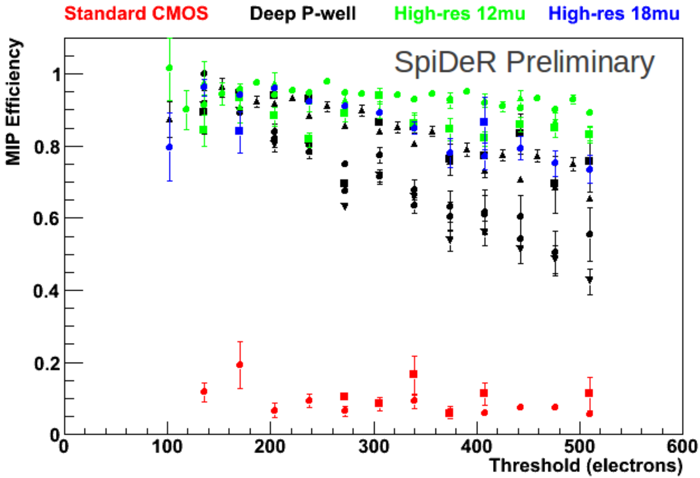
Pixel Efficiencies to MIPS

Studies conducted for both pions and electrons at CERN and DESY

- Formed a track in the event
- Project the track into sensor
- Look for hits around the projection and look for hit probability
- Fit the resulting distribution (right) to extract efficiency



Pixel Efficiencies to MIPS



Efficiency vastly increased using the INMAPS process over standard CMOS

Clusters

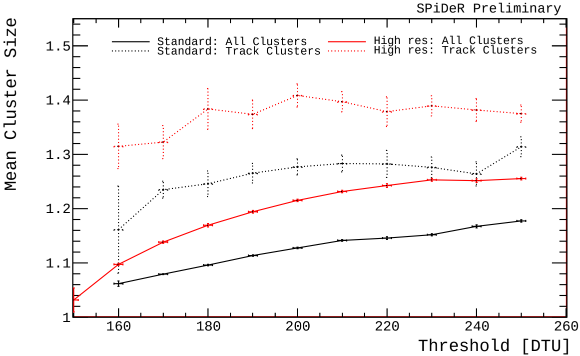
Algorithm

- Assume all hits within narrow event window occur at the same time
- Search hits for pixels which fire in multiple timestamps
- Find clusters using a seed pixel and searching nearest neighbours for hits
- Continue until all hits are formed into clusters

Types

- Single pixel clusters
- Single pixel clusters which fire in multiple timestamps
- Multiple pixel clusters

Clusters
Sizes

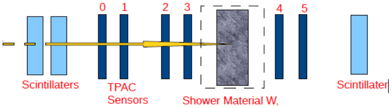


- High res yields larger cluster sizes due to increase charge collection eff
- Noise cluster size = 1, ∼1–2 clusters/event, low DTU noise rate high, mean cluster size ↑ as noise rate ↓
- Track associated cluster sizes stable with DTU

Shower Multiplicity

Event Selection

- Utilised DESY data with stack set in *Showering* mode.
- Found tracks in sensors 0123 ($\geq$3 hits)
- Demand a single track to avoid overlapping showers
- Track must go through central region of sensors 45
- Multiplicity $= \frac{N_{clusters}}{N_{tracks}}$



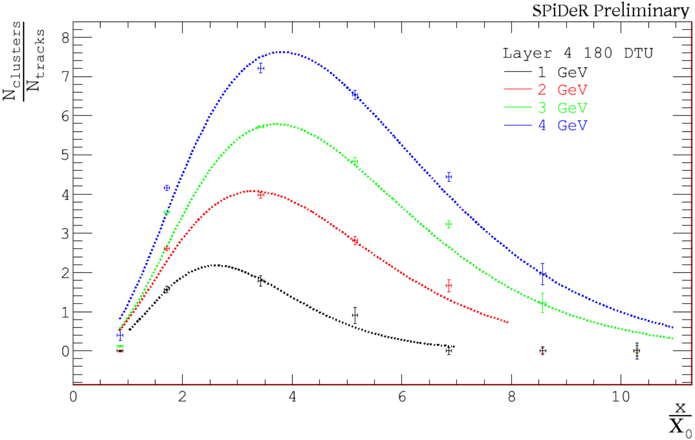
Fitting

- Plotted Mean Multiplicity Vs $\frac{x}{\chi 0}$
- $\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1}\exp(-bt)}{\Gamma(a)}$ [2]

[2] http://pdg.lbl.gov/2010/reviews/rpp2010-rev-passage-particles-matter.pdf

Shower Multiplicity

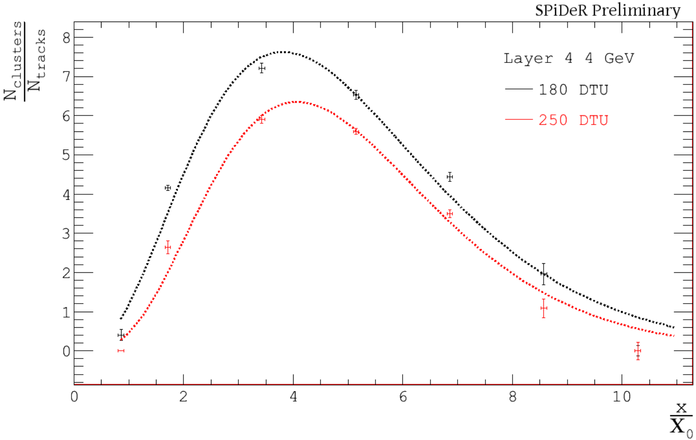
180 DTU Overlayed



Multiplicity increases with E_{in}
Demonstrates DECAL concept validity

Shower Multiplicity

Threshold Comparison



Threshold comparison shows reduction in efficiency as expected

Shower Density

Same event selection as shower multiplicity

Event Selection

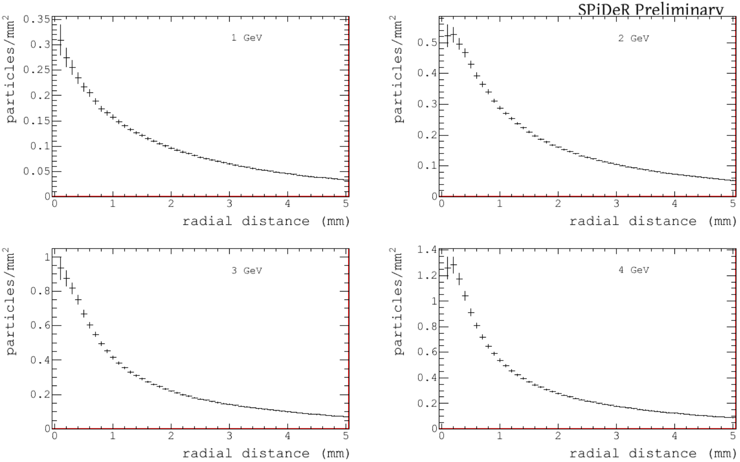
- Utilised DESY data with stack set in *Showering* mode.
- Found tracks in sensors 0123 ($\geq$3 hits)
- Demand a single track to avoid overlapping showers
- Track must go through central region of sensors 45

Core Density Calculation

- Take track projection as cone centre
- Scan out distances of r from centre
- Count number of particles within search area
- Calculate density within search area
- Create density profile for different radii

Shower Density

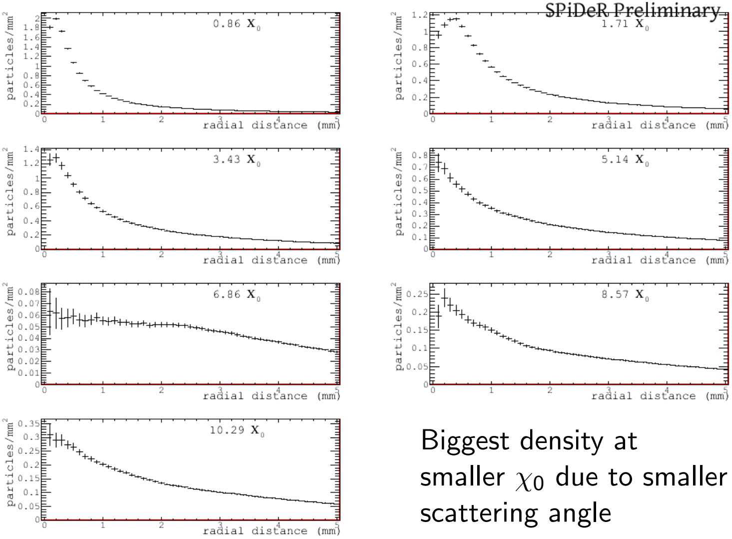
3.43 χ_0 tungsten



Core density increases with energy as expected (even if only by a small amount)

Shower Density

4 GeV Samples



Biggest density at smaller χ_0 due to smaller scattering angle

Conclusions

- TPAC sensor designed to meet the requirements of DECAL
- 2 beam tests completed with 55M+ bunchtrains written to disk
- Noise rate varies exponentially with DTU independent of epitaxial layer
- INMAPS process raises MIP efficiency by factor of ∼5
- Shower multiplicities increase with increasing energy demonstrating the DECAL concept to be valid
- More data is required at higher energies to study shower densities