MAPS Calorimetry at the ILC

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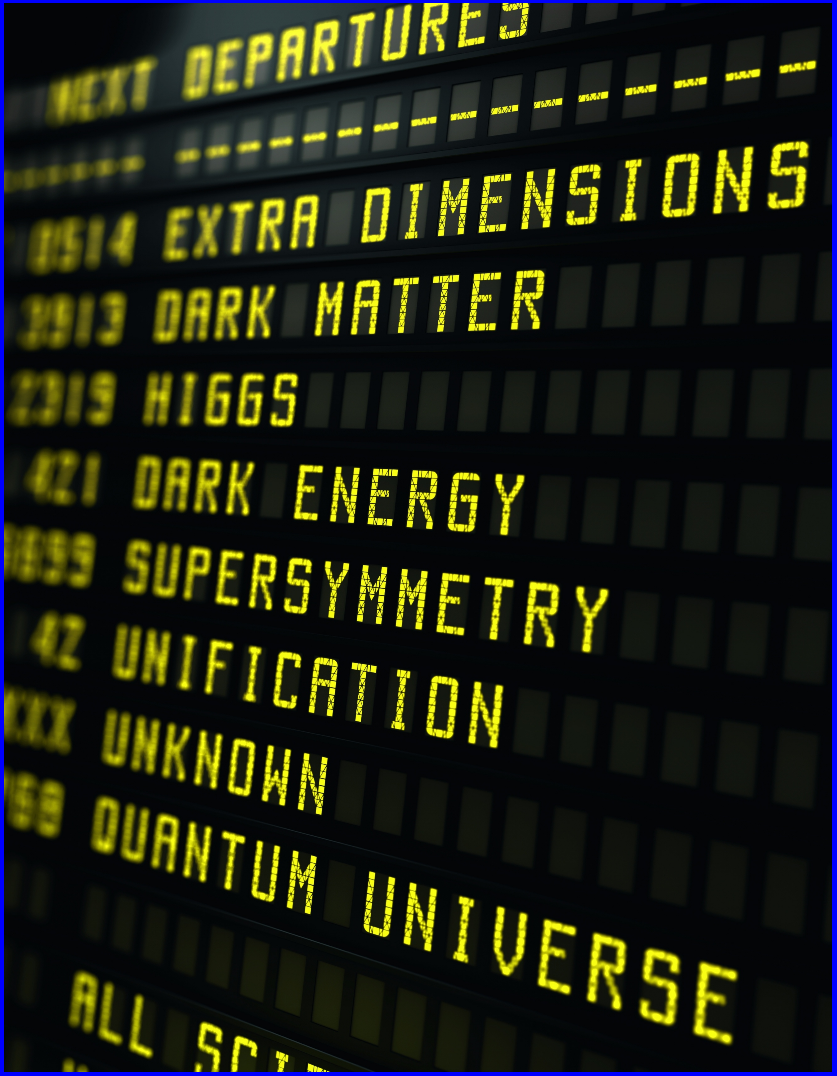
Introduction

- The aim of this talk is to provide an overview of MAPS (Monolithic Active Pixel Sensors), and its merits.
- In order to do that it is first necessary to establish what they are and what they will (hopefully) be used for.
- In this context they are a kind of E-M calorimeter (the technology behind a MAPS calorimeter does have other uses).
- They are being developed for the International Linear Collider (ILC).
- So, why is MAPS good for the ILC?
- To answer that question we have to cover what we want from the ILC, and how we're going to get it.
- Which brings us at last to the beginning ...

ILC Motivation

- The ILC will be a measurement machine, not a discovery machine.
- The ILC is intended to follow up on the results from the LHC.
- Specifically, once interesting events have been identified at the LHC, the ILC should be able to replicate these events repeatedly and unambiguously.
- So how do we intend to do that?

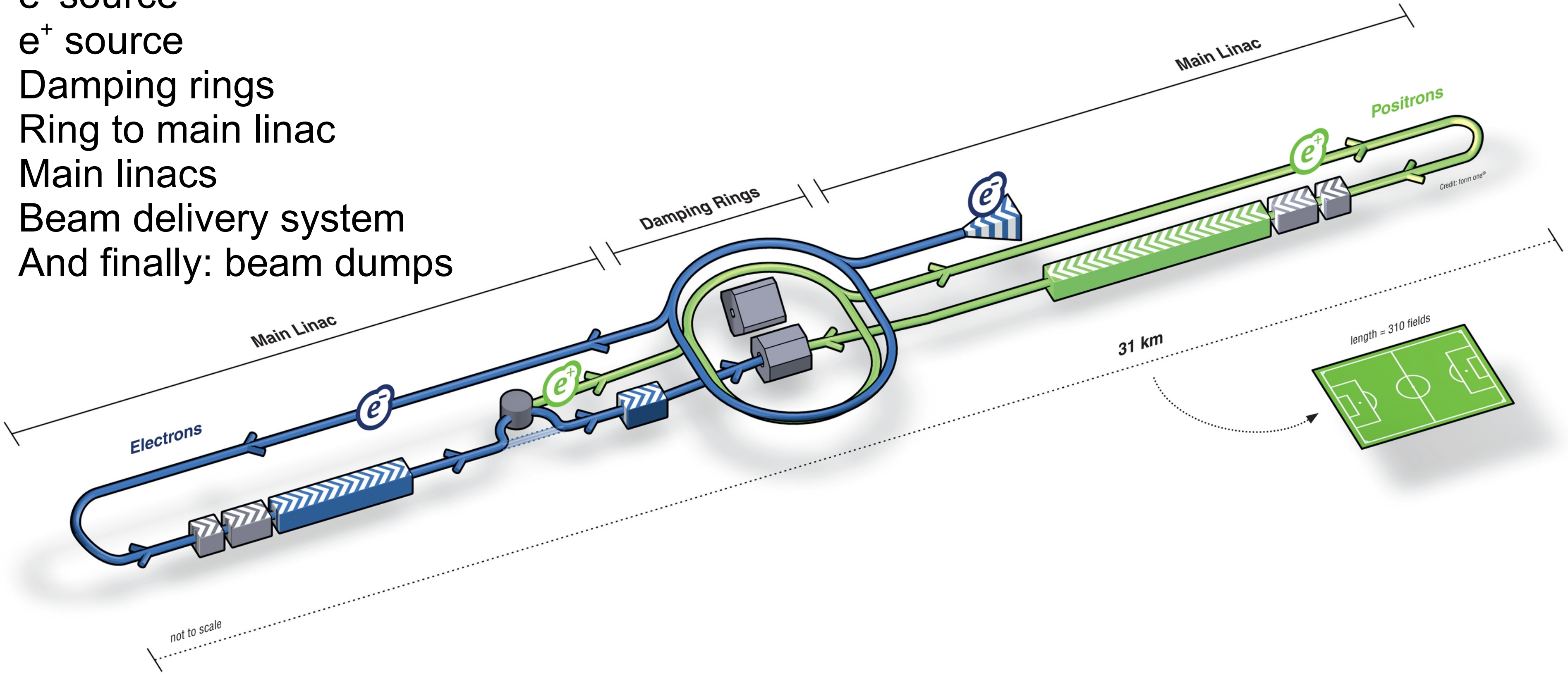


ILC Design:The Basics

- Starting design calls for two linear accelerators (combined length 31km), accelerating e^+/e^- beams with a centre of mass energy of 500GeV.
- ILC Upgrade will extend this to 50km, producing 1TeV centre of mass energy.
- Decisions on a 'minimal machine' in 2012.
- The current design calls for two detectors moved in and out of the beam line as needed (a push-pull system).

ILC Design: The Accelerator

- Consists of:
- e^- source
- e^+ source
- Damping rings
- Ring to main linac
- Main linacs
- Beam delivery system
- And finally: beam dumps



ILC Design: The Accelerator

- e^- beam produced by a photocathode DC gun.
- e^+ beam produced by taking a small number of electrons from the e^- beam in the main linac at around 150GeV.
- These electrons are then passed through a helical undulator to produce high energy photons.
- The resulting photons collide with a titanium alloy target to produce electron-positron pairs.

ILC Design: The Accelerator

- Once produced the beams are shaped, accelerated up to 5GeV, and injected into the damping rings.
- The damping rings serve to collimate the beams by causing the constituent particles to continuously lose kinetic energy via Bremsstrahlung radiation while continuously accelerating the beams along the beam line.
- The damping rings also allow bunches from the source so that pulse to pulse variations can be ironed out.
- Beams are then extracted from the damping rings and pass into the Ring To Main Linac (RTML) system.
- In addition to transporting the beams the RTML system also rotates the beam polarizations, removes the 'beam halo' created by the damping rings and compresses the bunch length by a factor of 30~45.

ILC Design: The Accelerator

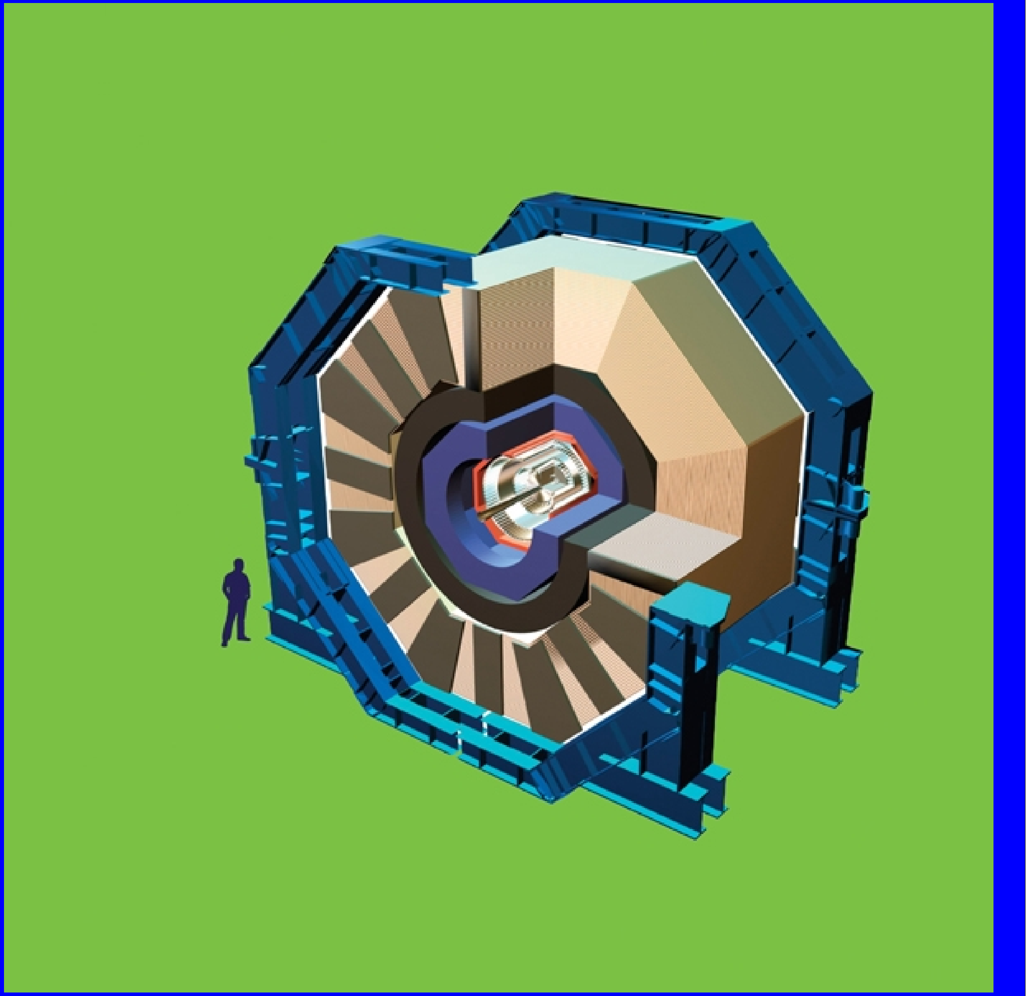
- The main linacs of the ILC will be based around superconducting RF cavities and will accelerate the beams from 15GeV in the RTML system to 250GeV (500GeV after upgrades).
- The detector ends of the main linacs feed into the Beam Delivery Systems (BDS) which focus and direct the beam while monitoring key beam parameters (e.g. energy and polarisation) before and after interactions.
- Passing through the interaction point (and the associated beam-beam interactions) tends to ruin the shape and cohesion of the beams, so any left overs finish their journey in the beam dumps.

ILC Design: The Detectors

- There are at present three concepts for the ILC detectors:
- SiD (Silicon Detector).
- 4th (named as such because the ILD used to be two separate concepts making this one the 4th concept).
- ILD (International Large Detector).

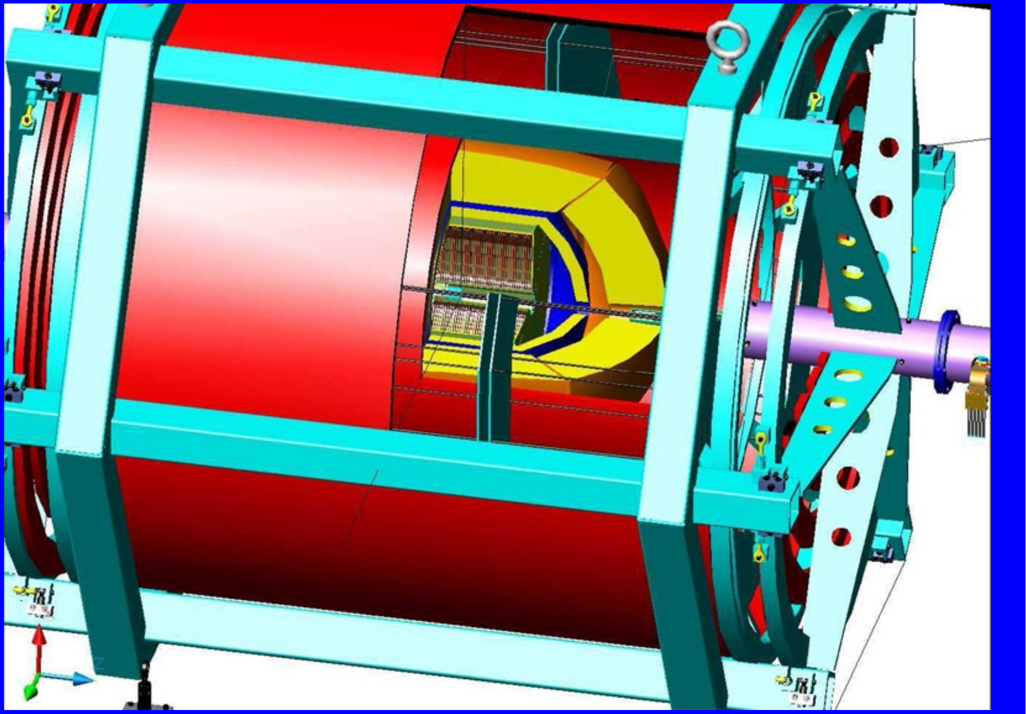
ILC Design: SiD

- Designed as a robust, general purpose detector.
- Based on mature technologies for reliability.
- Momentum measurement handled by a silicon strip momentum tracker.
- ECAL alternates layers of tungsten absorber with silicon diode detectors.
- HCAL alternates steel absorbers with resistive plate chambers.
- 5T B-field within the barrel.



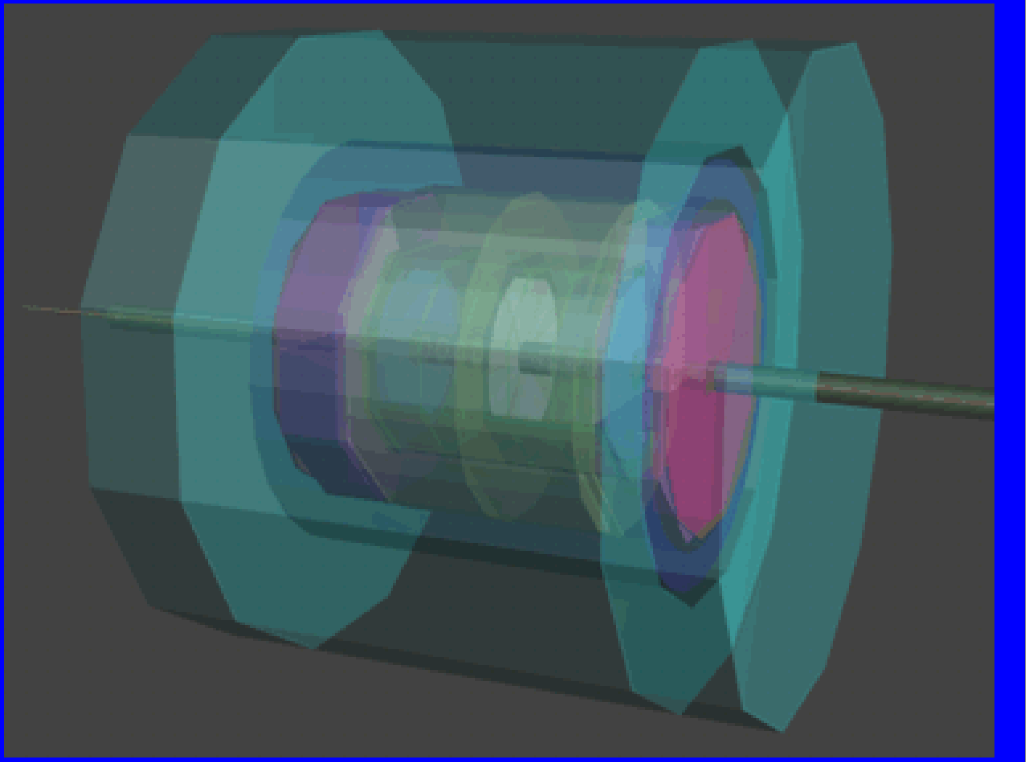
ILC Design: 4th

- Designed for high performance, intended to have a simple versatile design.
- Momentum measurement handled by a TPC.
- Both HCAL and ECAL both designed around the same technology:
- Calorimeters will use quartz fibre components sensitive to scintillation and Cerenkov light.
- Dual solenoid which should aid with muon tracking while providing a b-field in the main barrel



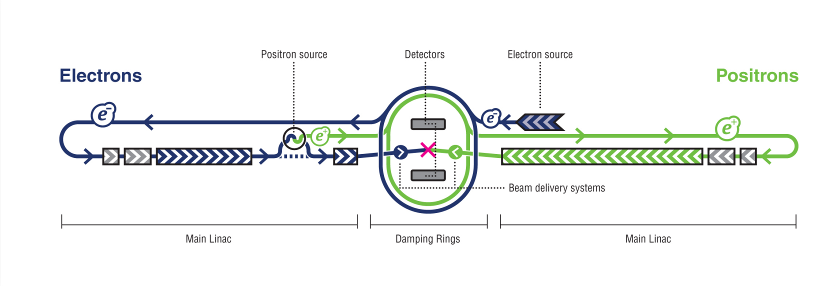
ILC Design: ILD

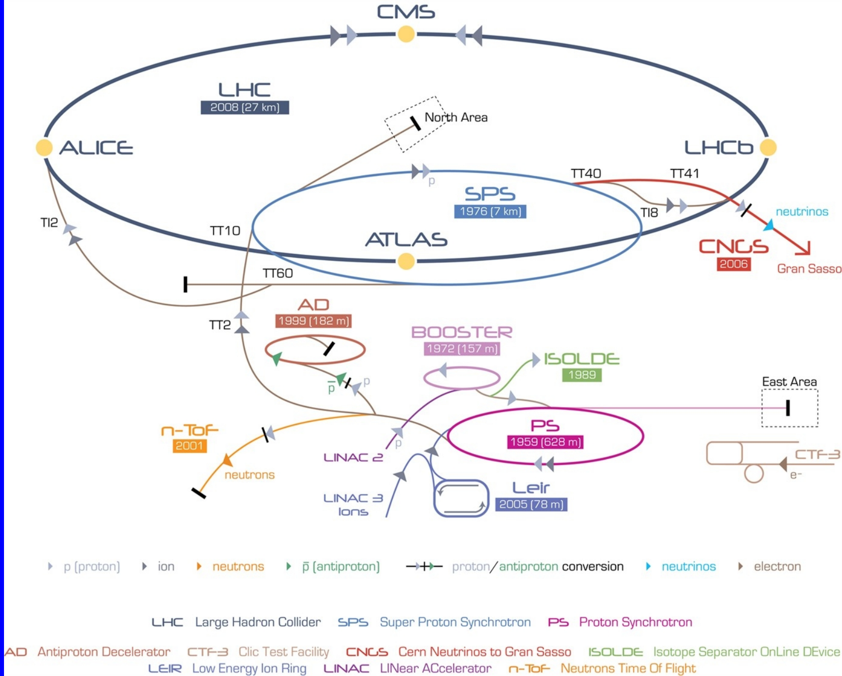
- Intended to be a high performance/efficiency system with extensive redundancy.
- Momentum measurements are handled by a TPC supplemented by silicon strip detectors.
- ECAL will either be a silicon-tungsten detector, or a scintillator-tungsten detector.
- HCAL will either be a steel-scintillator or a steel-gas detector.
- Solenoid produces 4T in the barrel.



ILC Design: LHC comparison

- Beams:
- Luminosity and interaction energy are highly comparable.
- ILC beam energy width is significantly smaller than the LHC.
- ILC beams will be polarized to select specific event types.
- Detectors:
- ILC detectors tend to require a higher energy resolution than their LHC counterparts.



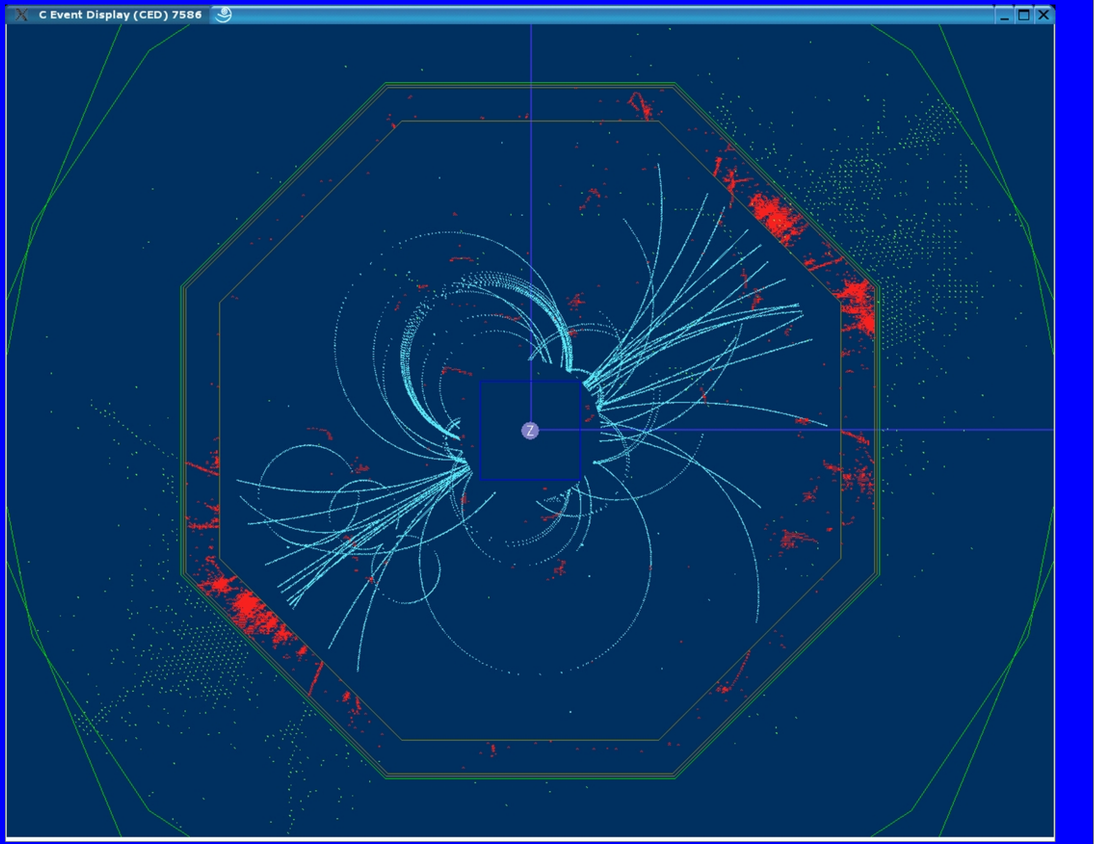


MAPS in theory: Context

- So ILC detectors will need good energy resolution from their detectors.
- As you can see from the earlier detector slides a popular response to this requirement is a Si-W calorimeter, unfortunately these tend to be expensive.
- Current estimates for the ILD place the cost of a Si-W detector at $112 million (in 2006 USD), this is over a quarter of the proposed detector cost.
- There is therefore a certain amount of appetite for cheaper alternatives.

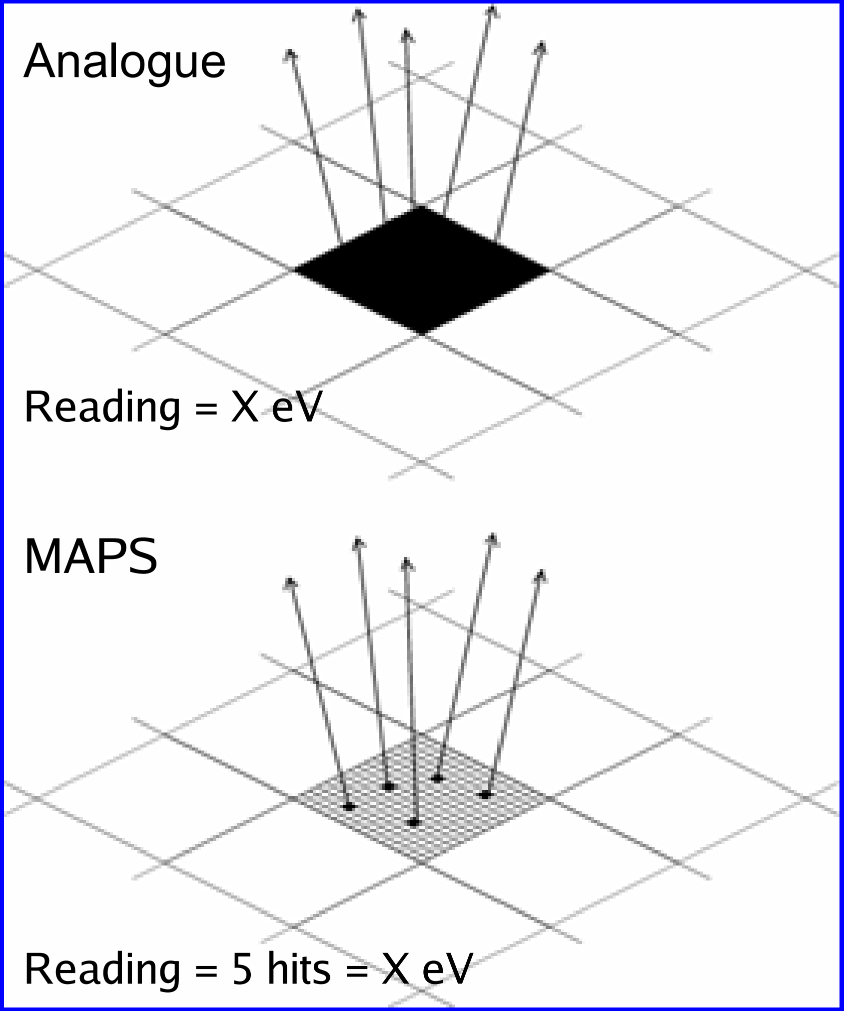
MAPS in theory: Context

- Even putting cost to one side the energy resolution requirements for an ILC detector will be hard to meet.
- In order to meet these requirements the detector components must not only work well, they must work well together.
- For an ECAL this means that the sensor must be highly granular.



MAPS in theory: How it works

- MAPS works by shower particle counting.
- Individual pixels do not measure deposited energy, they only record whether or not they were hit.
- Particle density at the core of a shower ~100/mm^2, therefore pixels must be smaller than 100µm * 100µm to have a reasonable chance of counting all hits.
- A MAPS ECAL will have an area of 50µm * 50µm per pixel.



MAPS in theory: Advantages

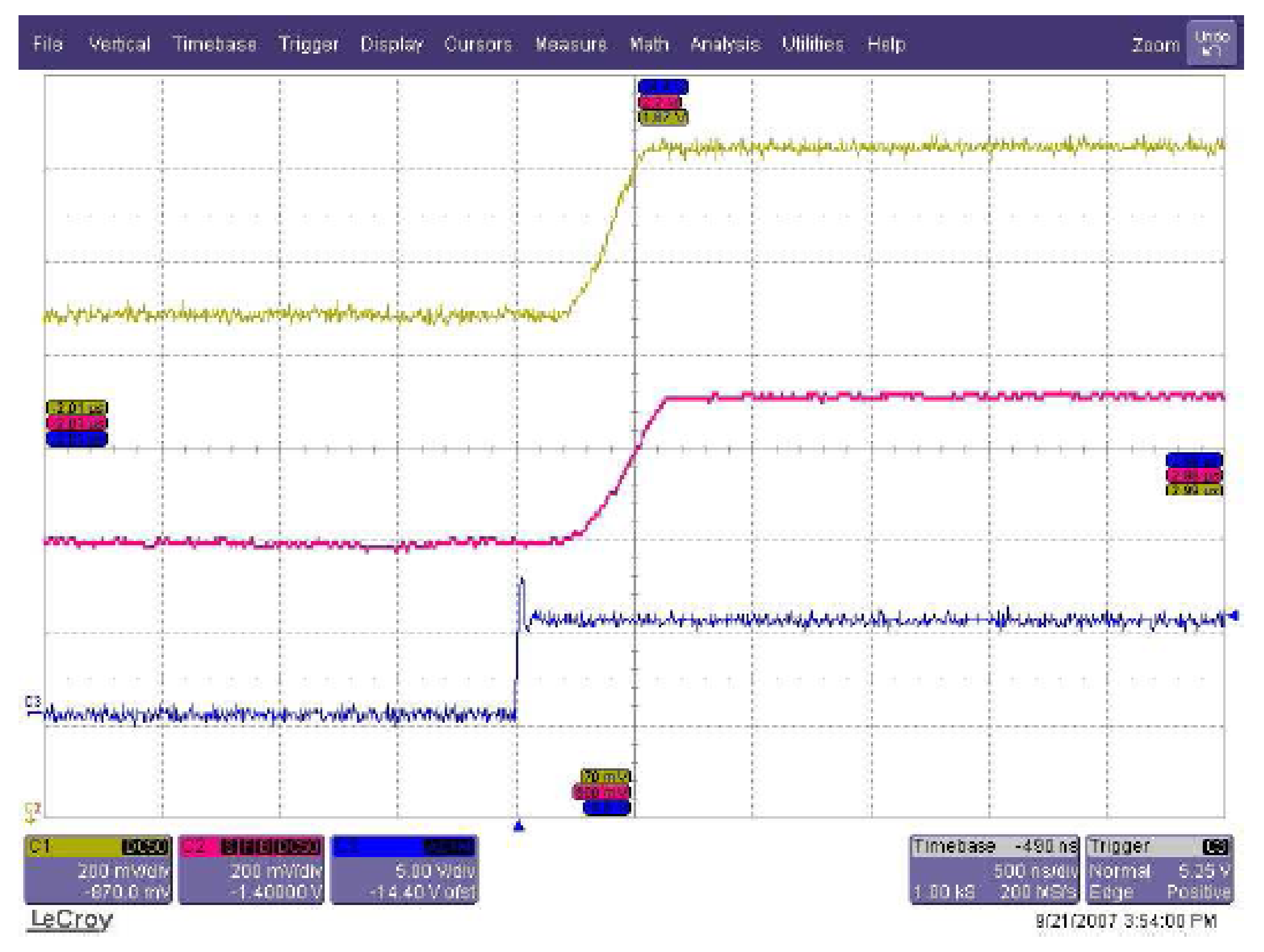
- MAPS is based on well established CMOS technology which should (hopefully) make large scale fabrication relatively economical.
- Combined with the reduced quantities of silicon required, a MAPS ECAL might be only half the cost of a more conventional Si-W ECAL.
- MAPS allows (and in fact requires) the detector to have much smaller pixels, improving the granularity of the detector.

MAPS in practice: Challenges

- To make a viable MAPS ECAL the following requirements must be met:
  1. Viable binary ECAL pixels with an area less than 50µm * 50µm.
  2. A large number of those pixels must work together as a single sensor.
  3. When completed, a MAPS ECAL must produce reliable and high resolution energy readings.

MAPS in practice: Individual Pixels

- Proof of life studies with MAPS pixels, analogue readout.
- Pixel response on y-axis, time on x-axis (yellow and pink).
- Laser output on y-axis, time on x-axis (blue).



C1 DC50 200 mV/div -670.0 mV

C2 200 mV/div -1.40000 V

C3 5.00 V/div -14.40 V ofst

Timebase -490 ns 500 ns/div 1.00 kS 200 MS/s

Trigger C3 Normal 5.25 V Edge Positive

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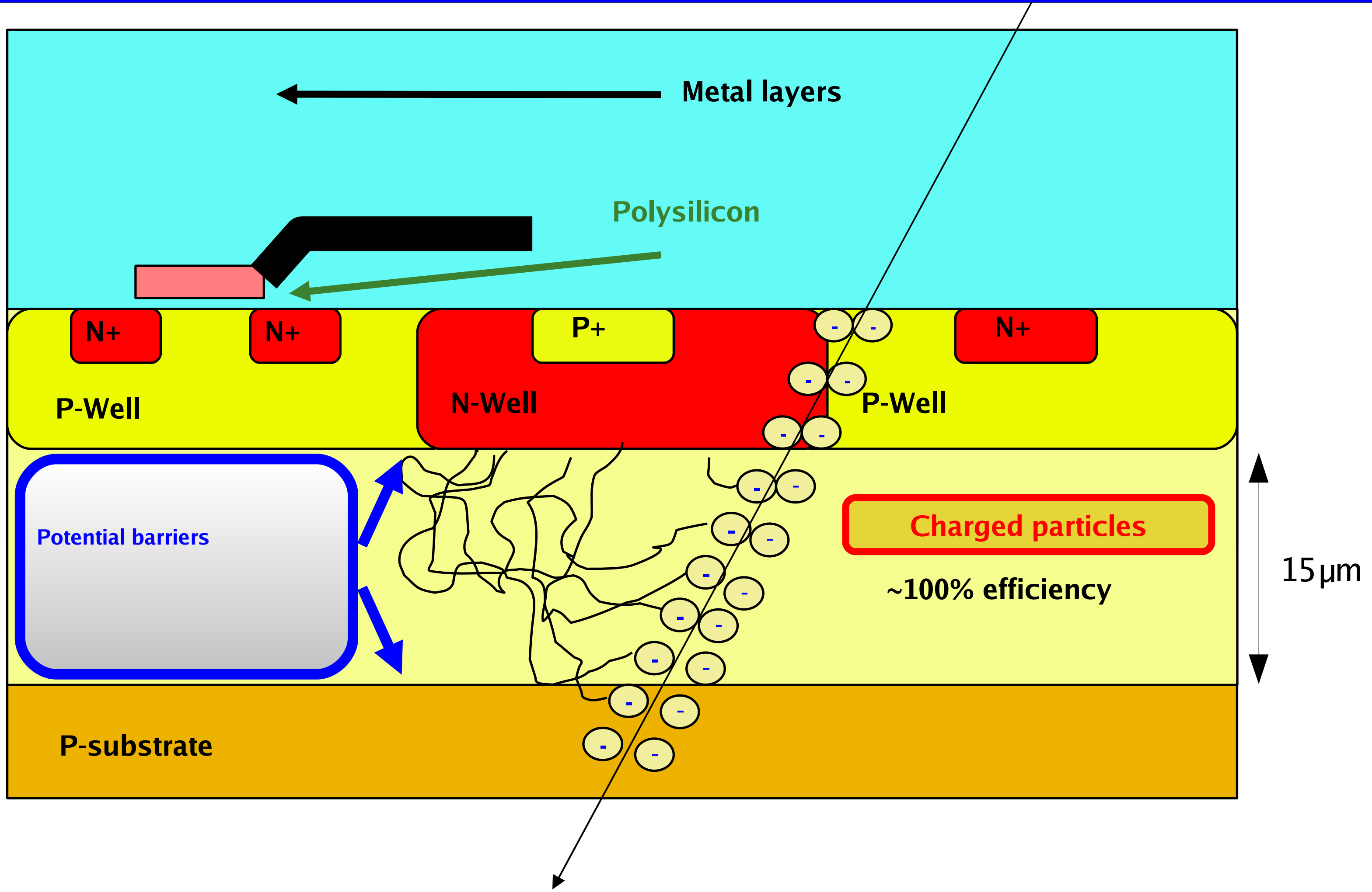
MAPS in practice: Individual pixels



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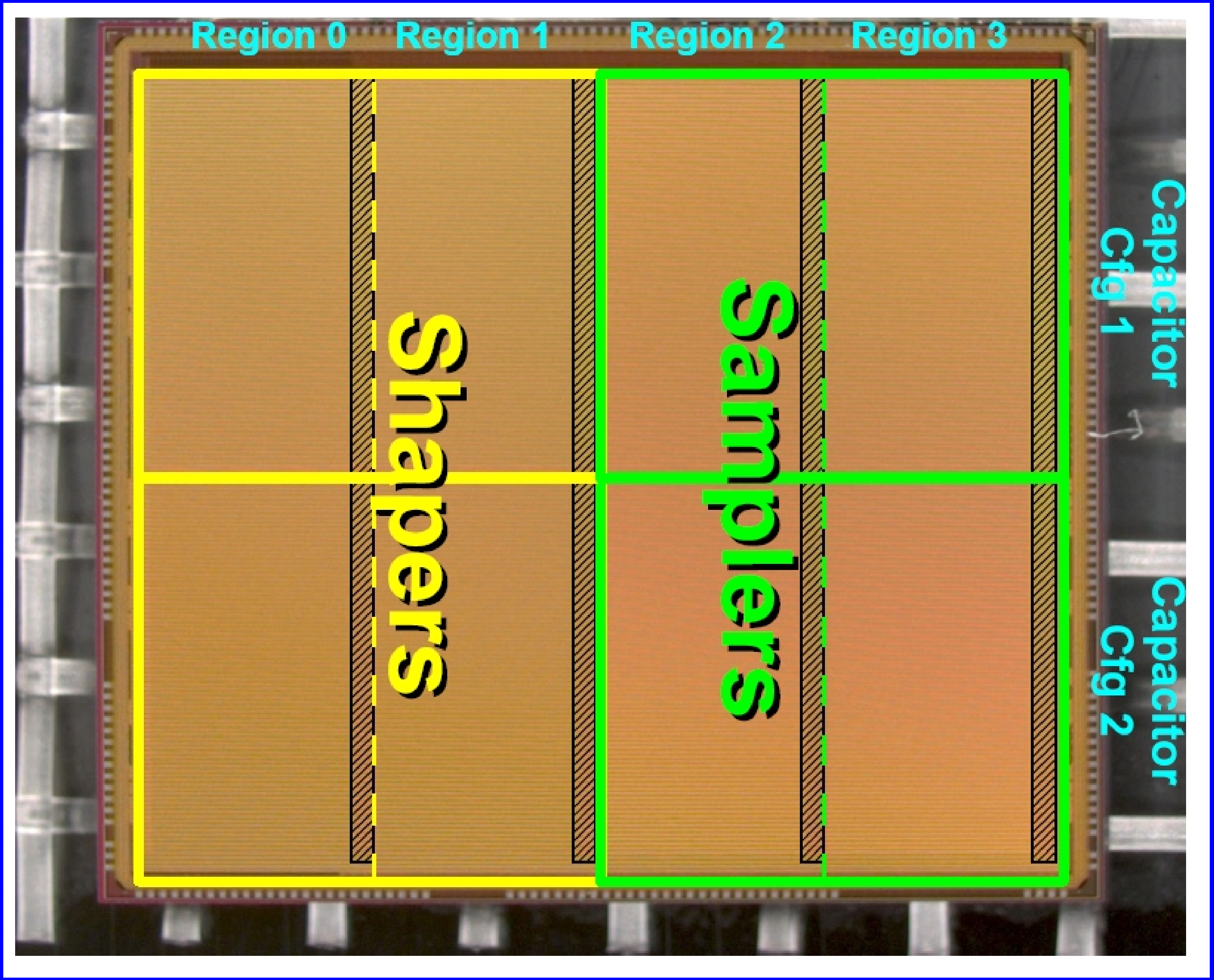
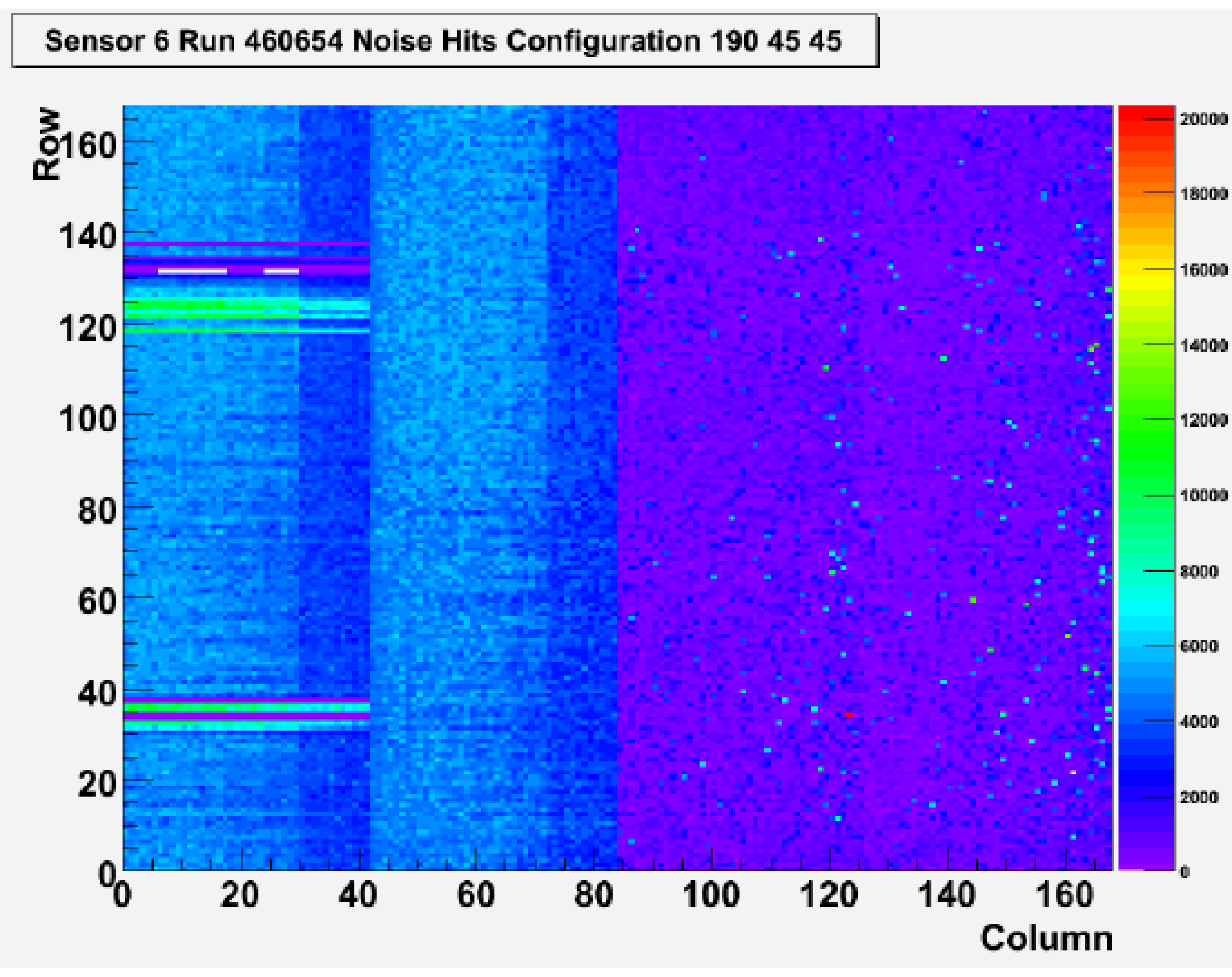
MAPS in practice: Test Sensor

- First test sensors constructed in 2007 (TPAC 1.0).
- TPAC 1.0 used a mixture of different pixel designs.
- TPAC 1.0 has been tested extensively and findings have been used to design TPAC 1.1 and TPAC 1.2.

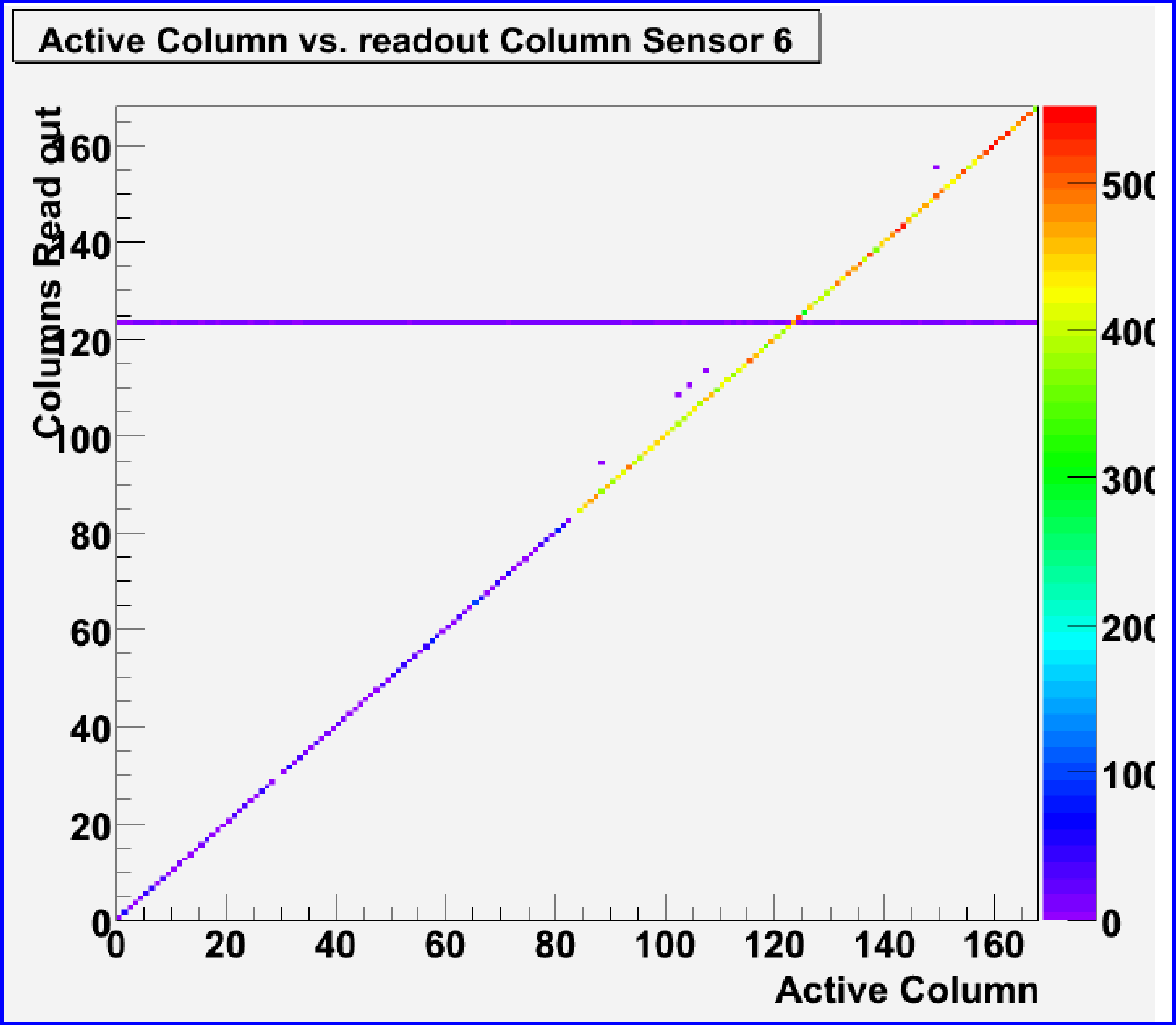


MAPS in practice: Test Sensor

- What you see here is the result of:
  1. Variable pixel thresholds.
  2. Pixel cross-talk.



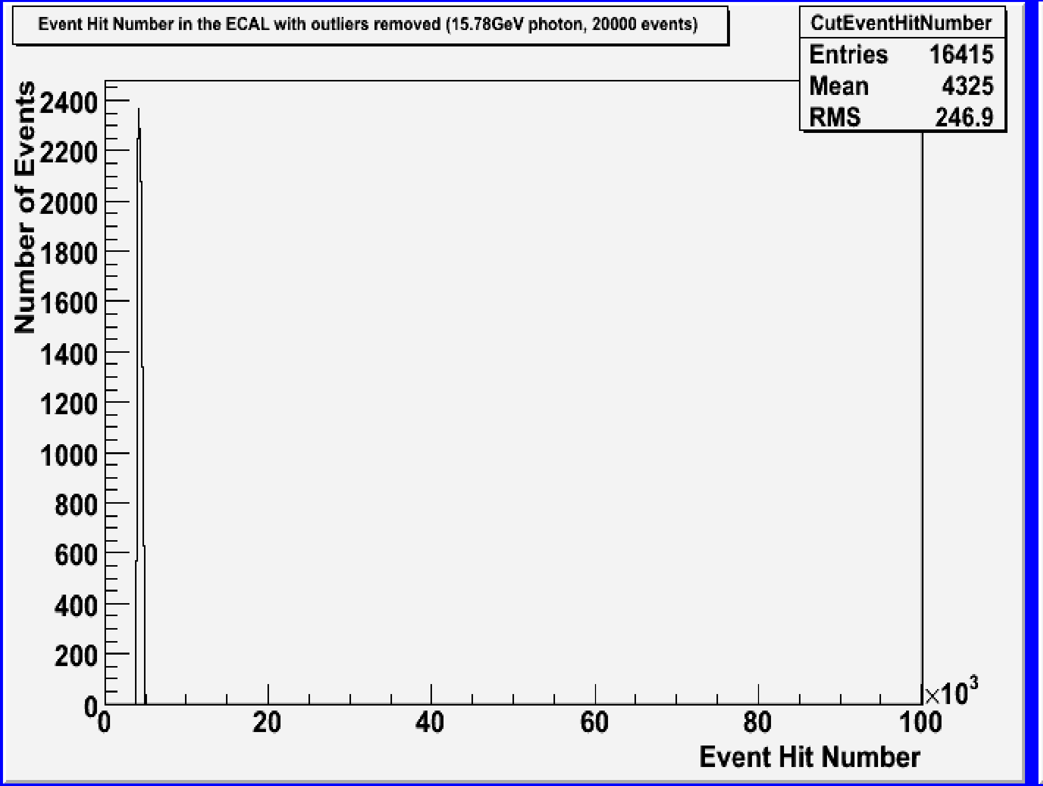
MAPS in practice: Test Sensor

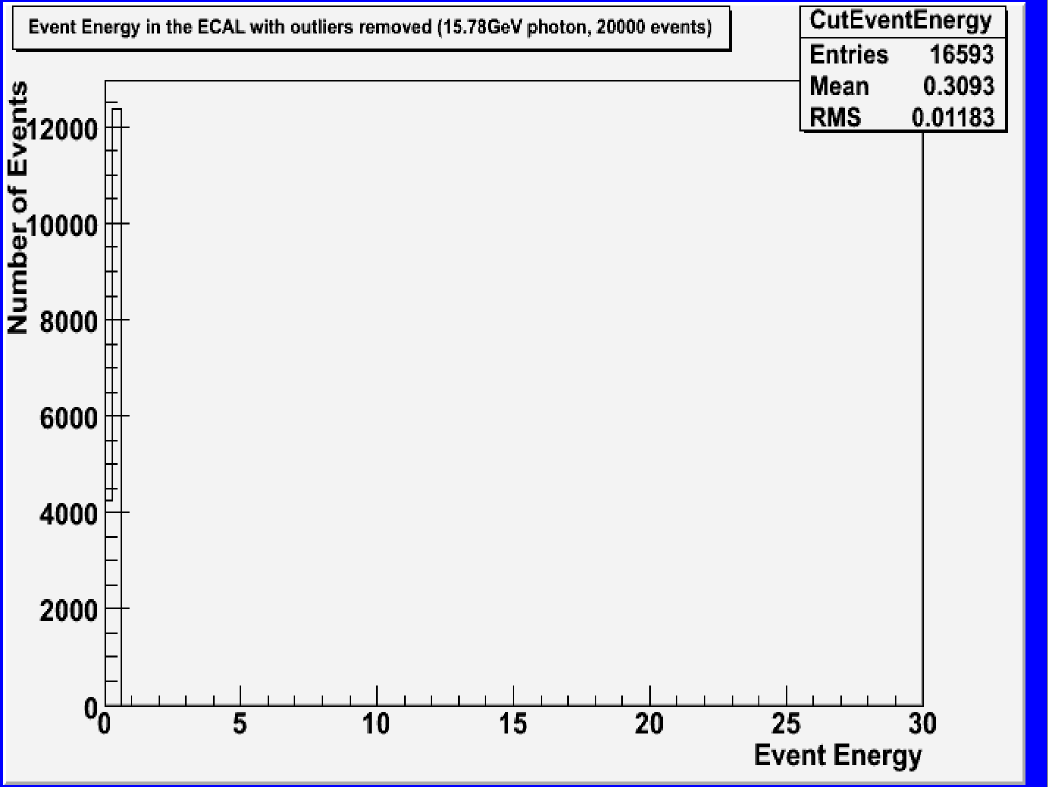


MAPS in practice: Simulated ECAL

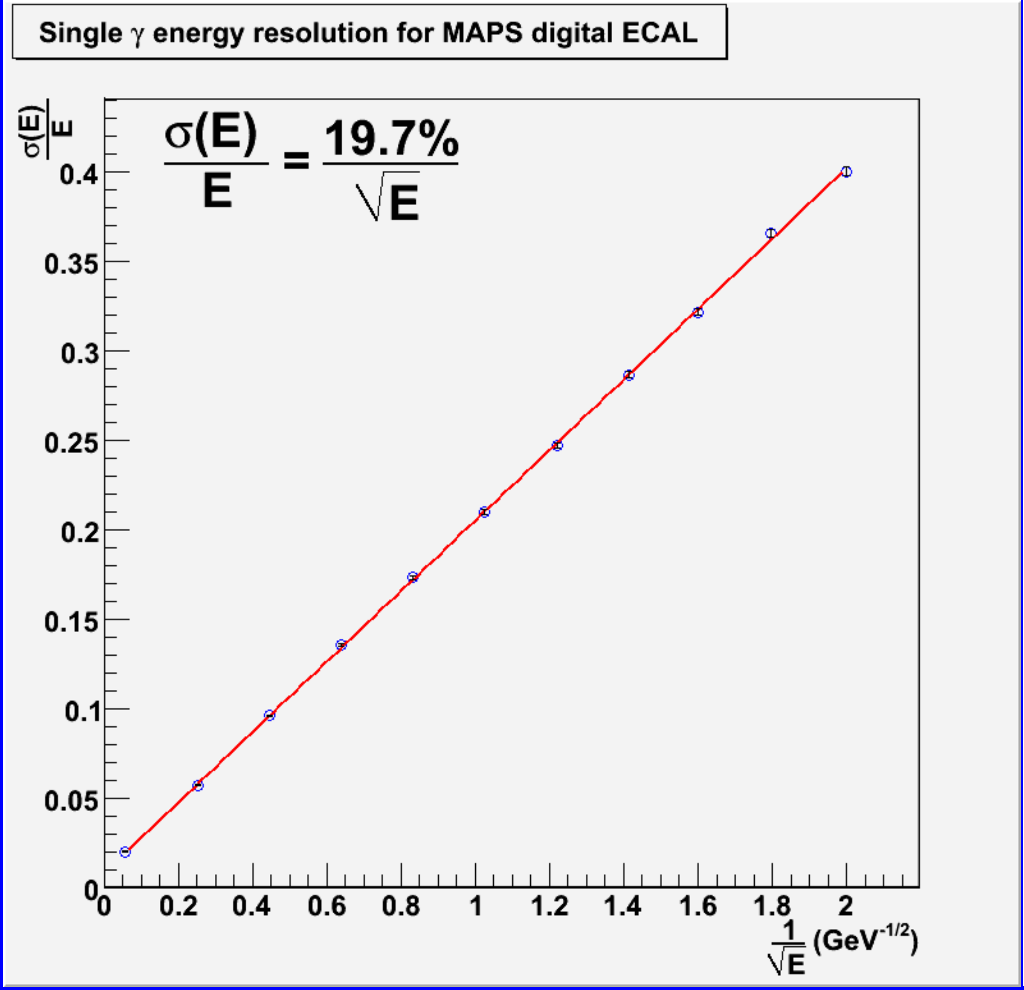
MAPS

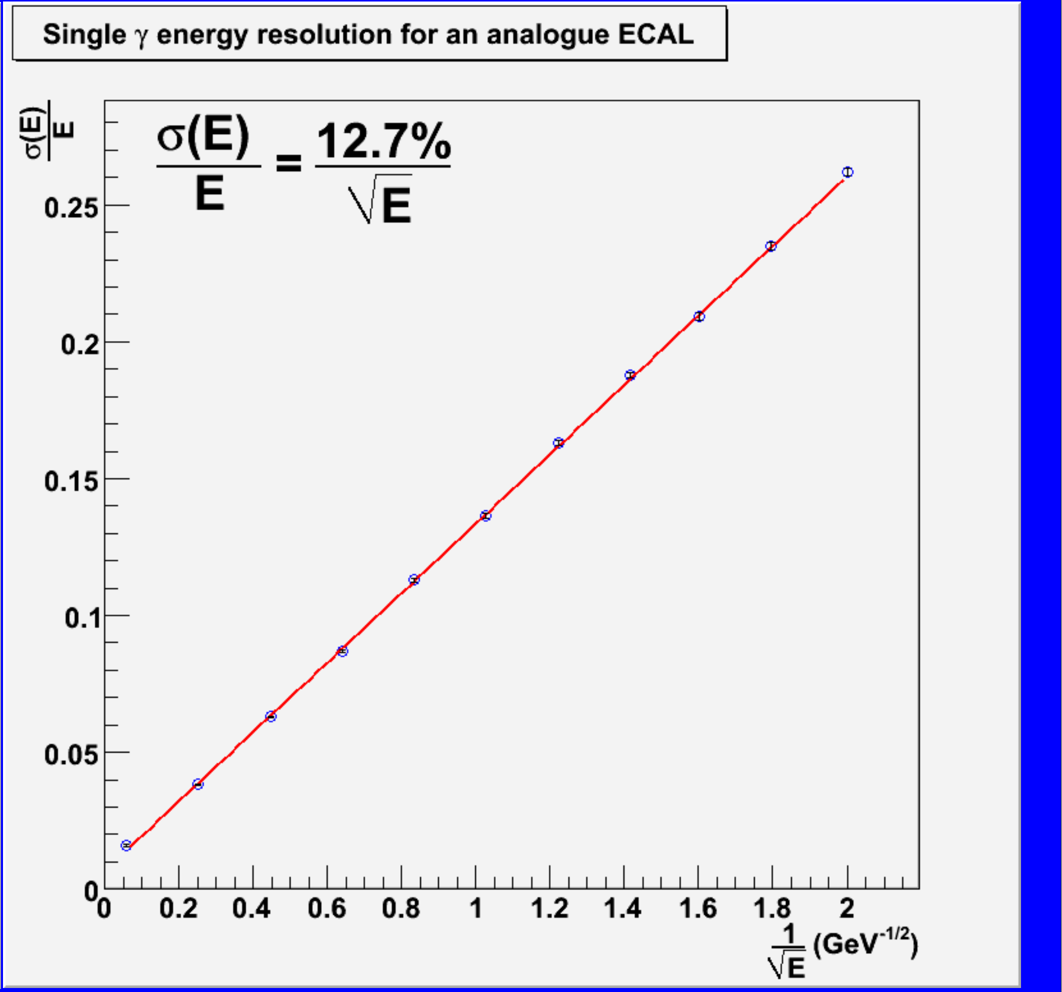
Analogue





MAPS in practice: Simulated ECAL





Future Outlook

- TPAC 1.2 sensors have recently been produced and are undergoing testing. TPAC 1.2 incorporates the following new features:
- Single pixel design throughout the sensor (shapers)
- Larger number of 'trim bits' to fine tune pixel thresholds
- TPAC 1.2 will undergo test beam studies at CERN this summer.
- Once testing with our 0.9cm * 0.9cm test sensor is complete CALICE MAPS will move on to larger sensors, specifically 2.5cm * 2.5cm sensors which can be placed in 16 sensor stacks to permit ECAL testing.
- Hopefully all of this will be working by some time in 2012 when decisions about the ILC 'minimal machine' will be made.

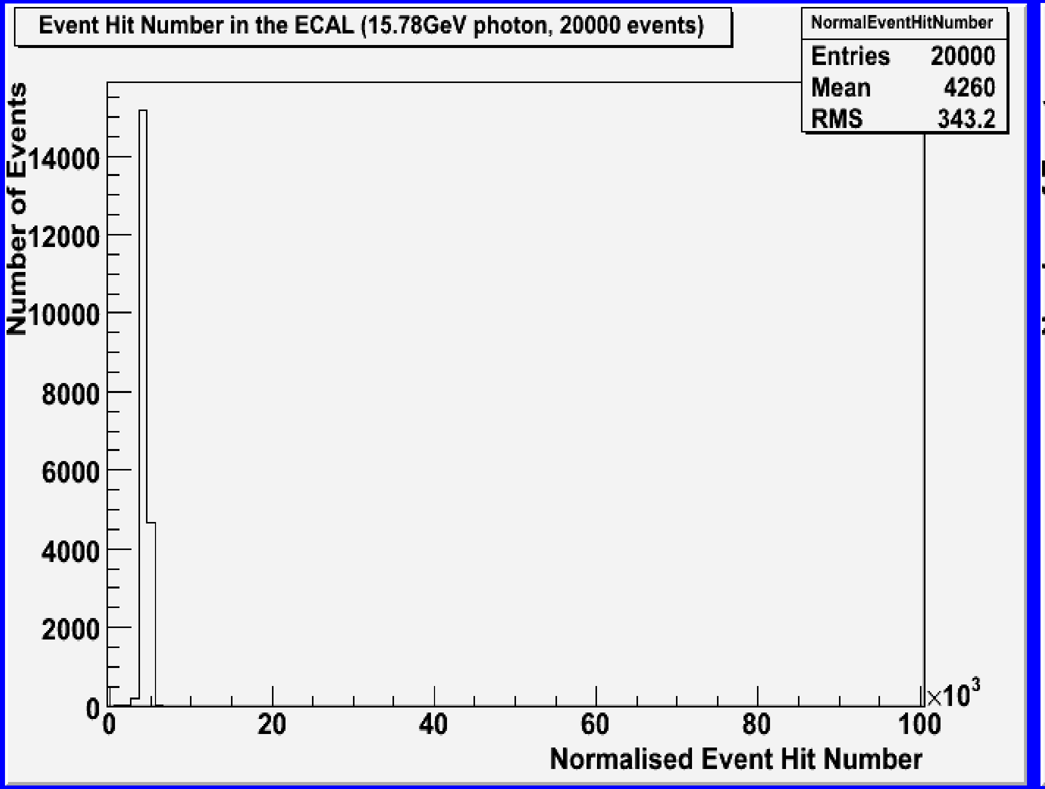
Conclusions

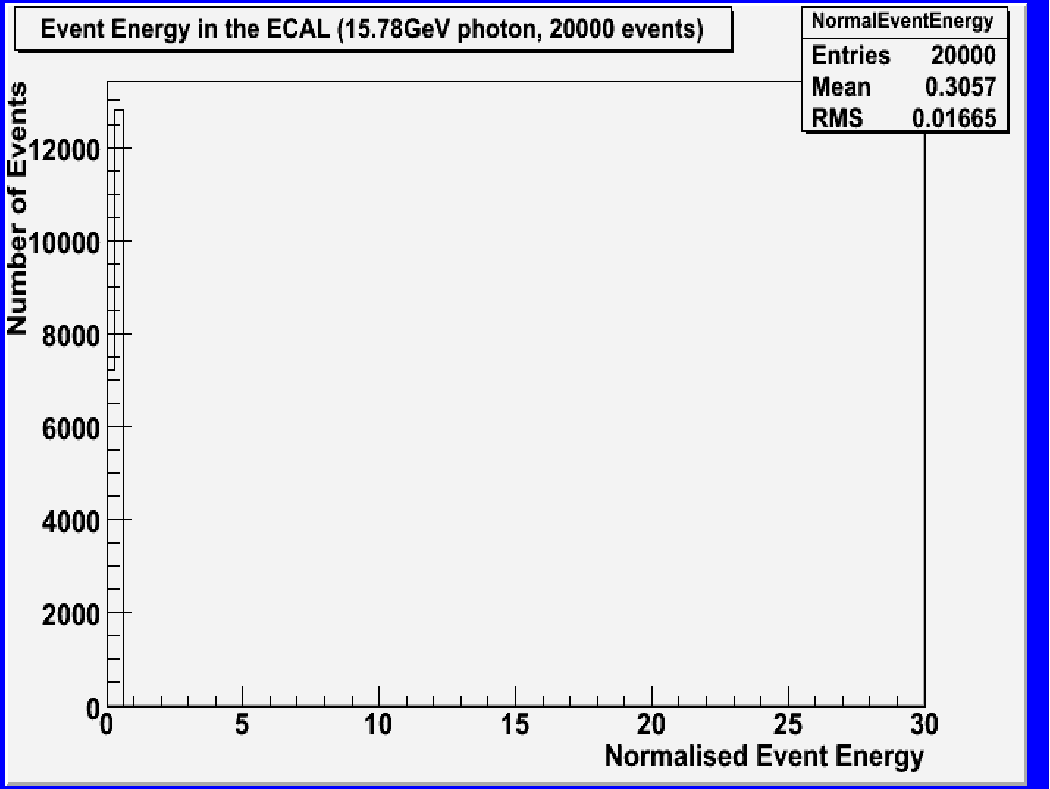
- MAPS provides performance comparable to an analogue ECAL, with significantly less highly processed silicon.
- Modifications made to the new test sensor should fix the current problems with TPAC 1.0, giving us a functioning MAPS system.
- MAPS should work well as a stand-alone ECAL, and it should work better as part of an integrated detector.
- By 2012 we should be able to demonstrate a working MAPS sensor, and hopefully a working MAPS ECAL

Simulated ECAL: Uncut data

MAPS

Analogue





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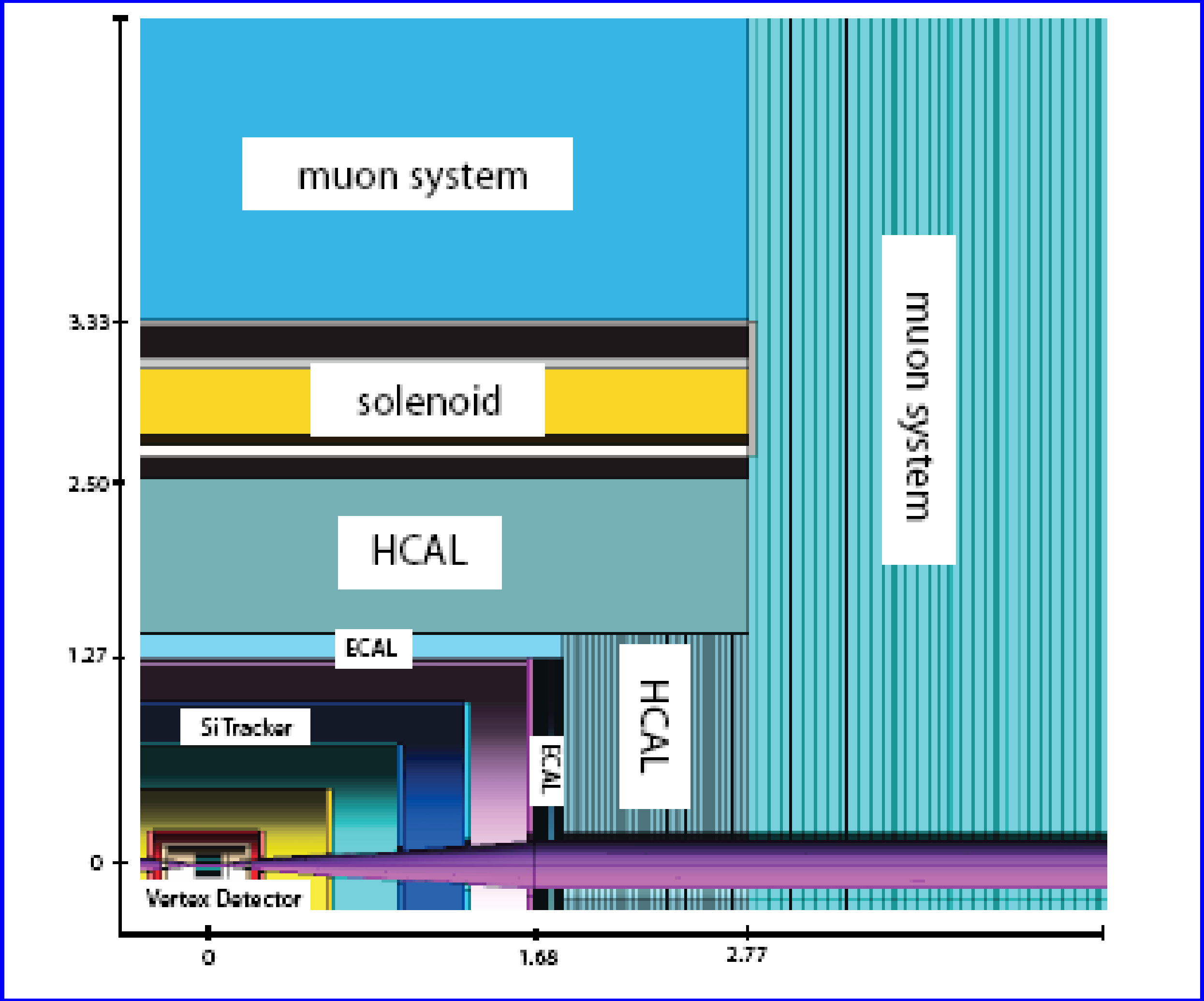
Detector Cross-section: SiD



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All distances in mm

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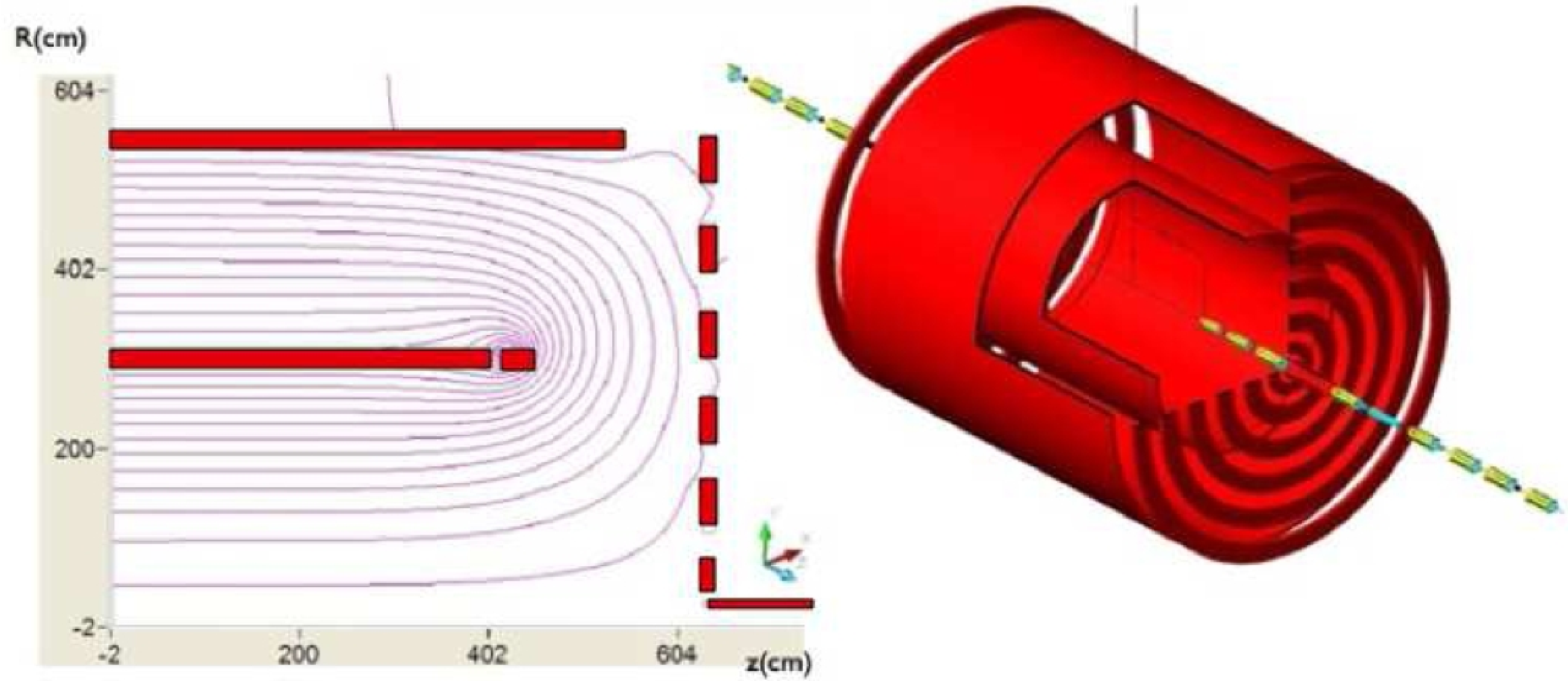
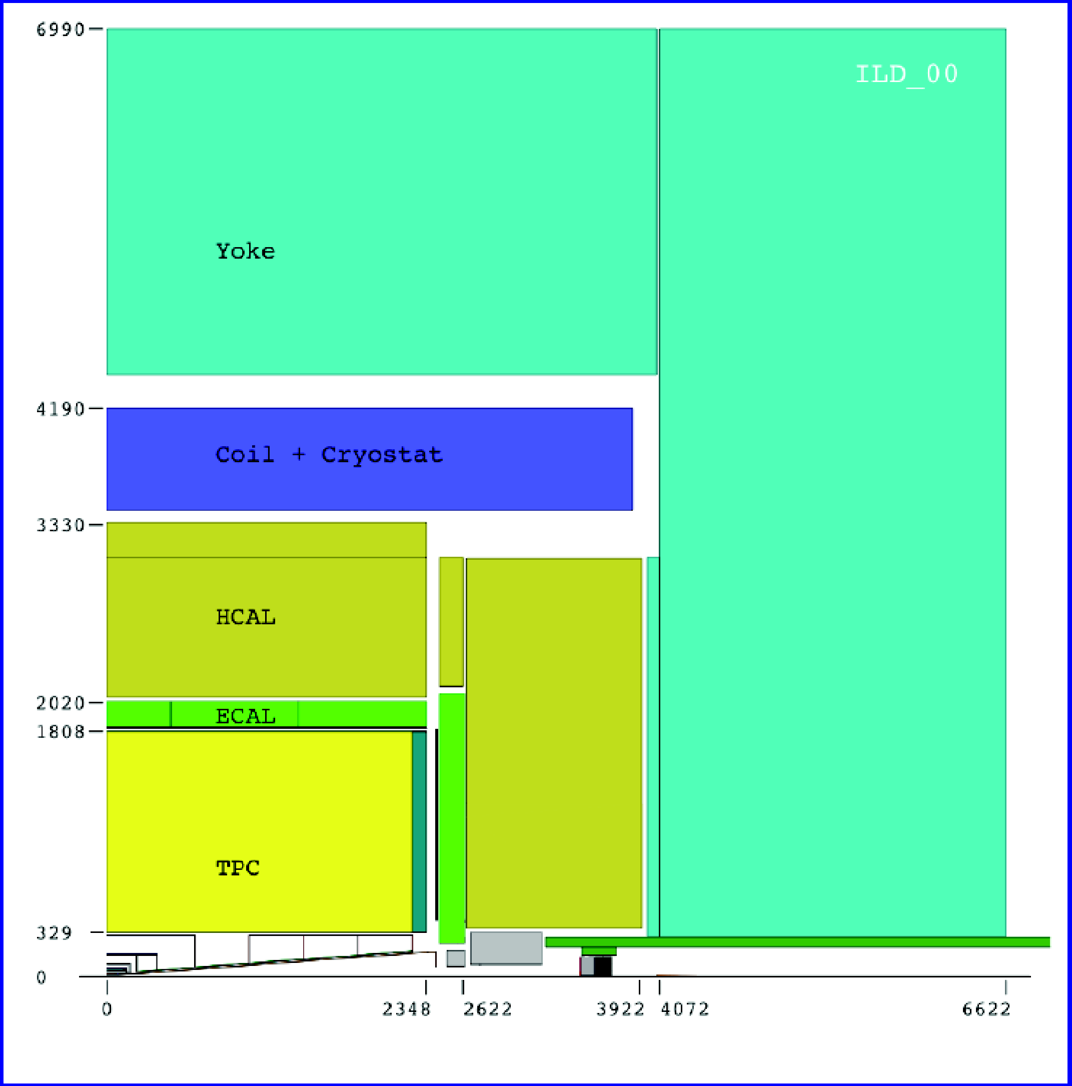
Detector Cross-section: 4th



Detector Cross-section: ILD



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All distances in mm

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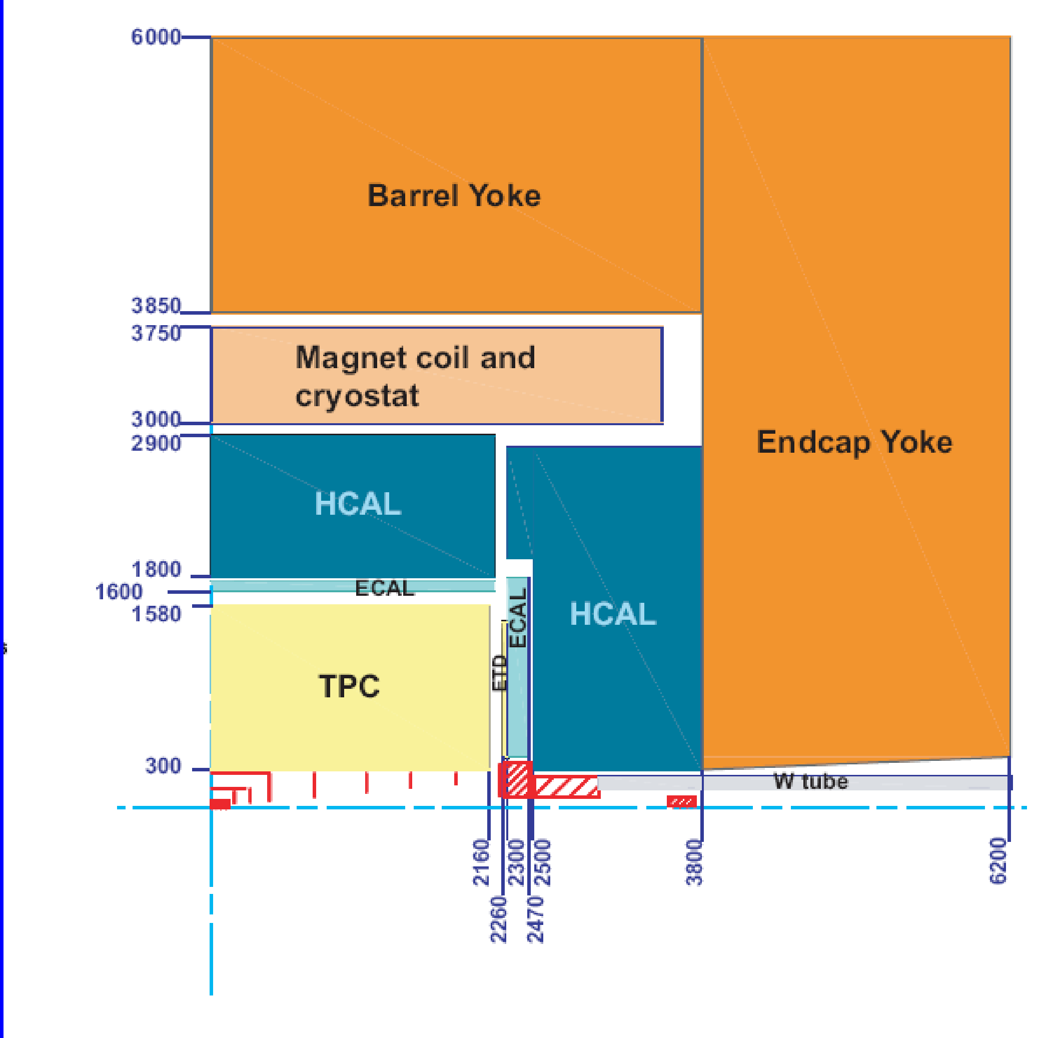
Detector Cross-section: LDC



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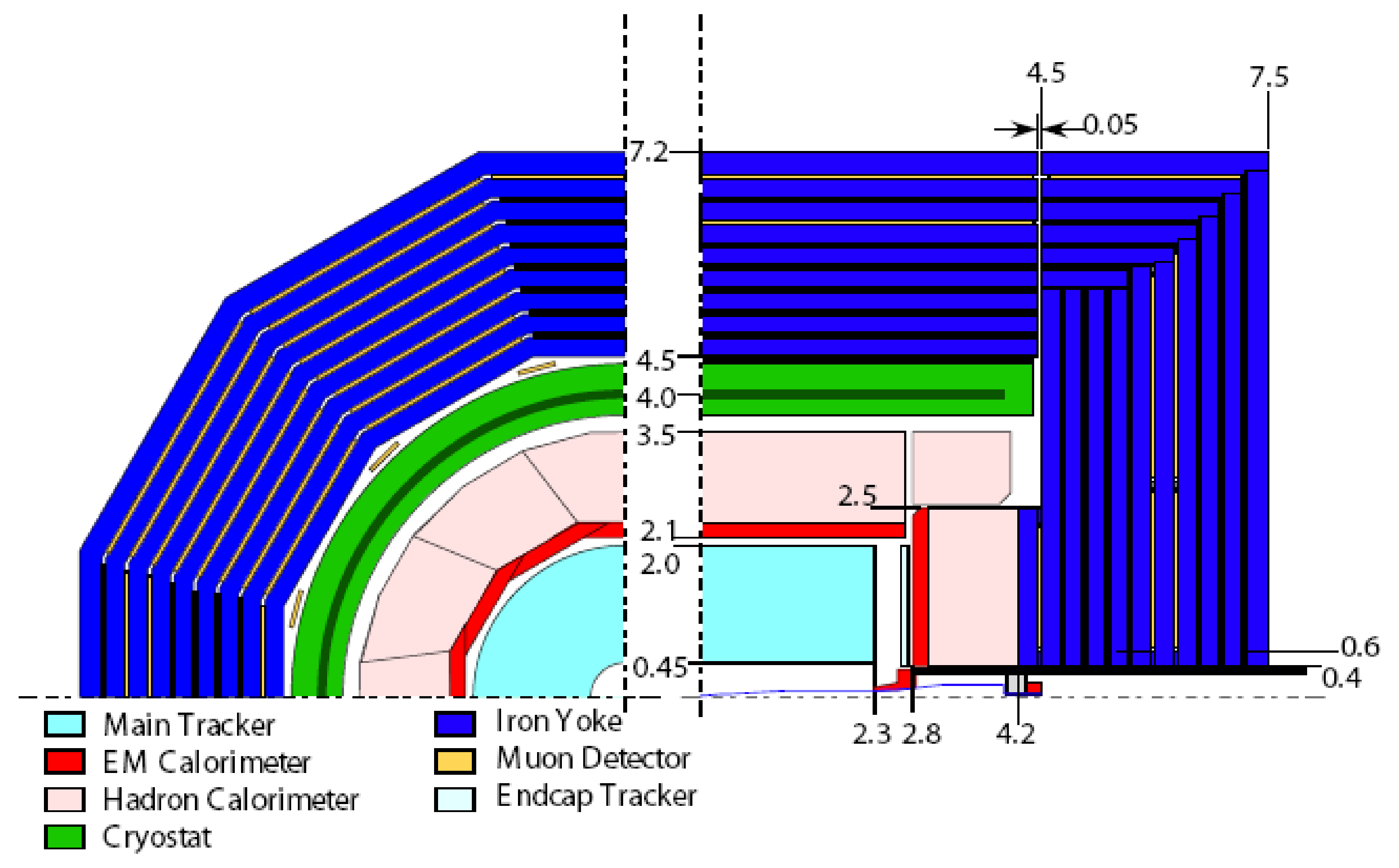
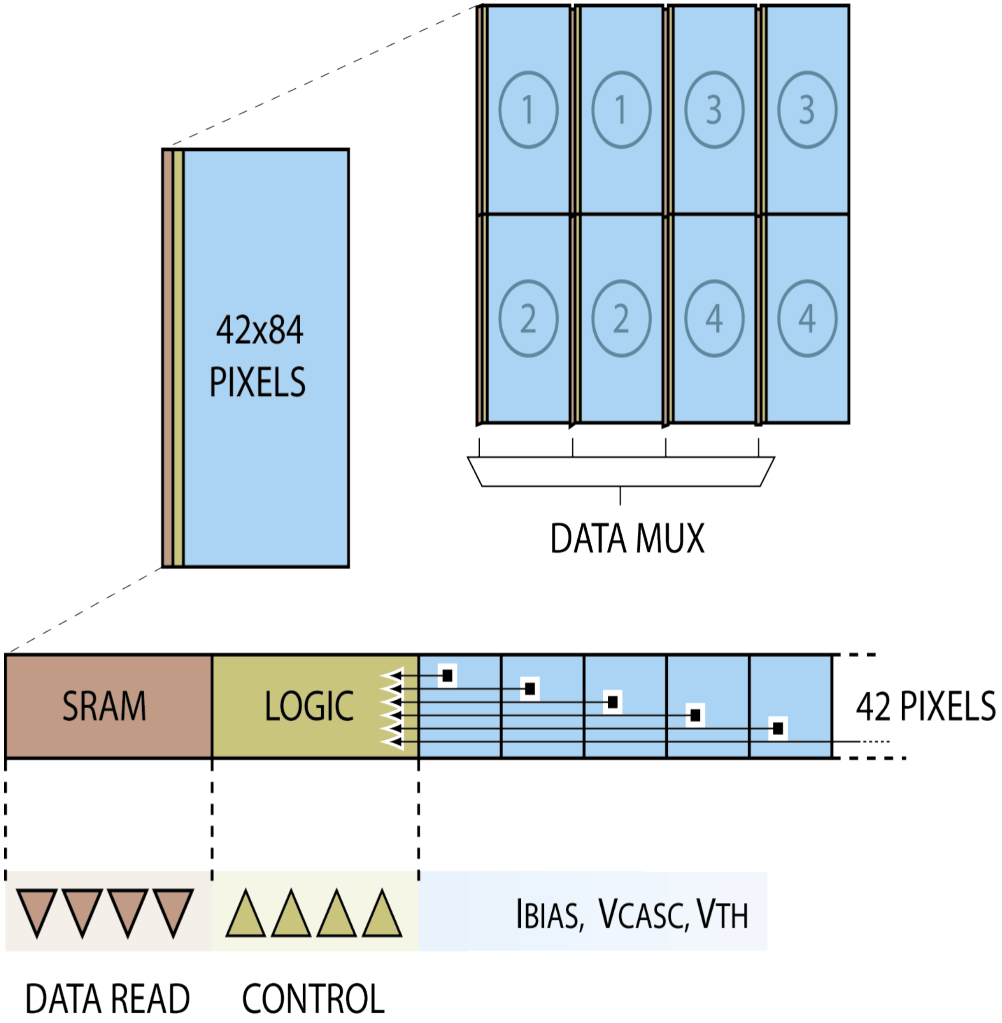
All distances in mm

Detector Cross-section: GLD

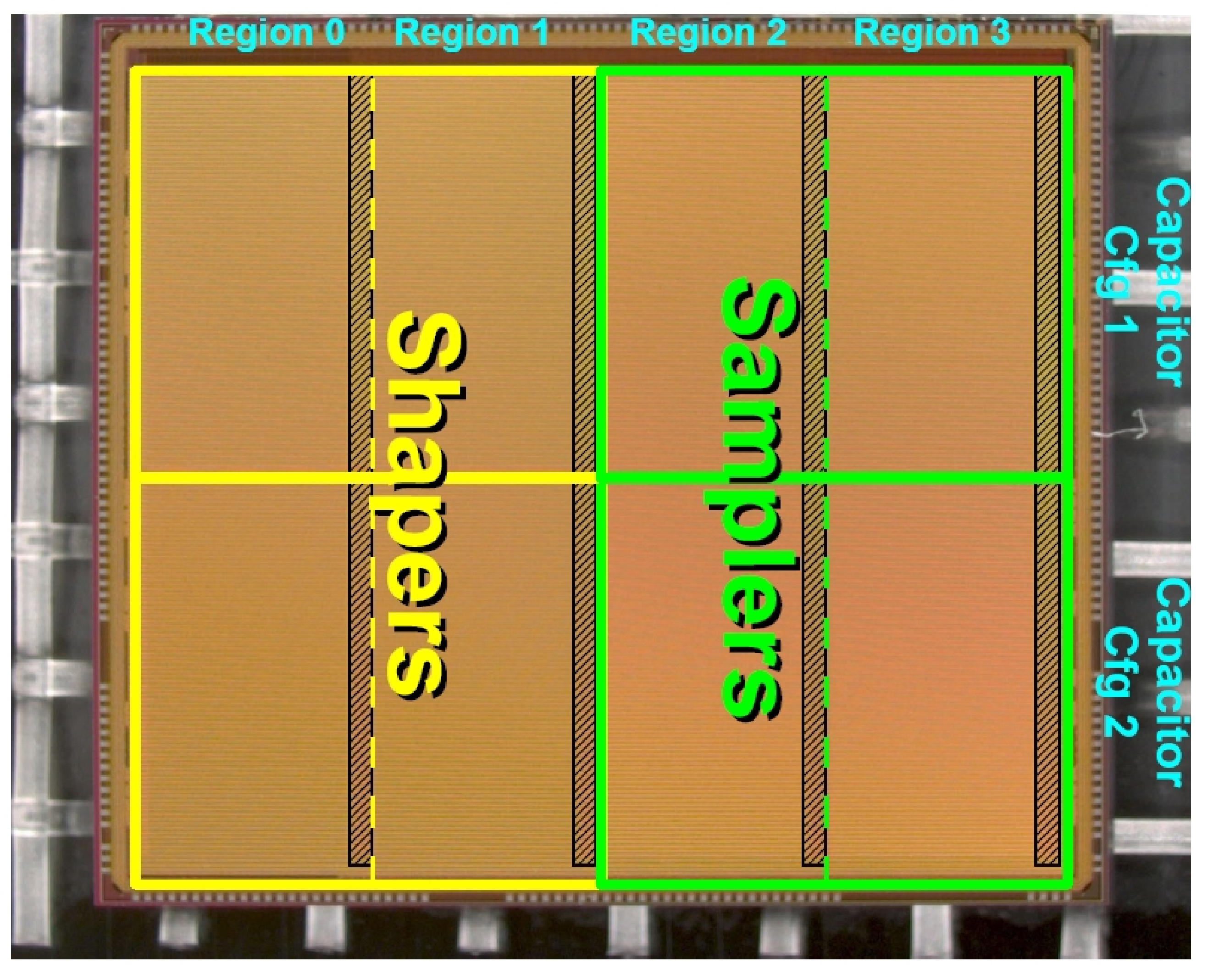


All distances in metres

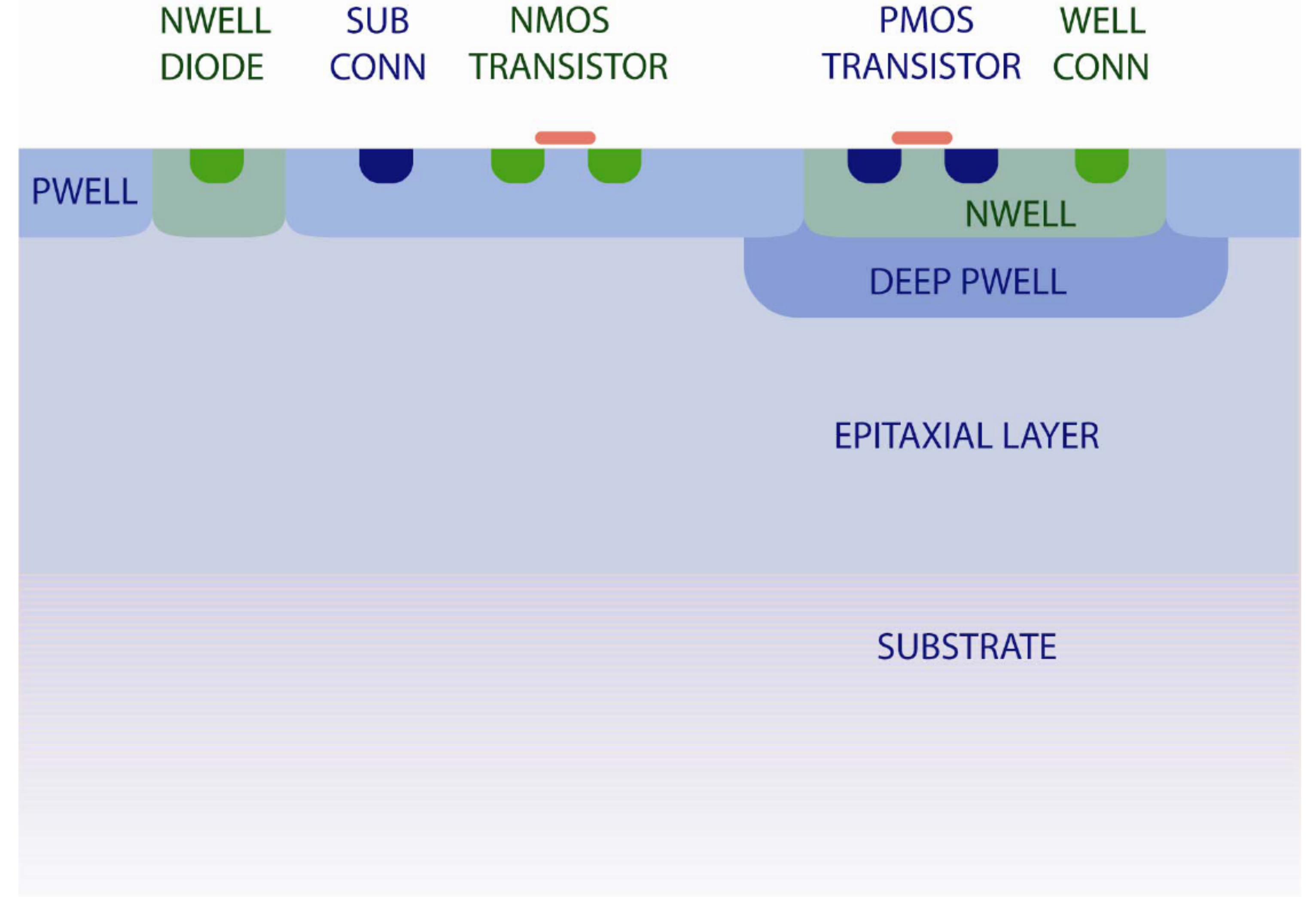
Test Sensor Layout



Test Sensor Layout



P-Wells and N-wells, pixel structure



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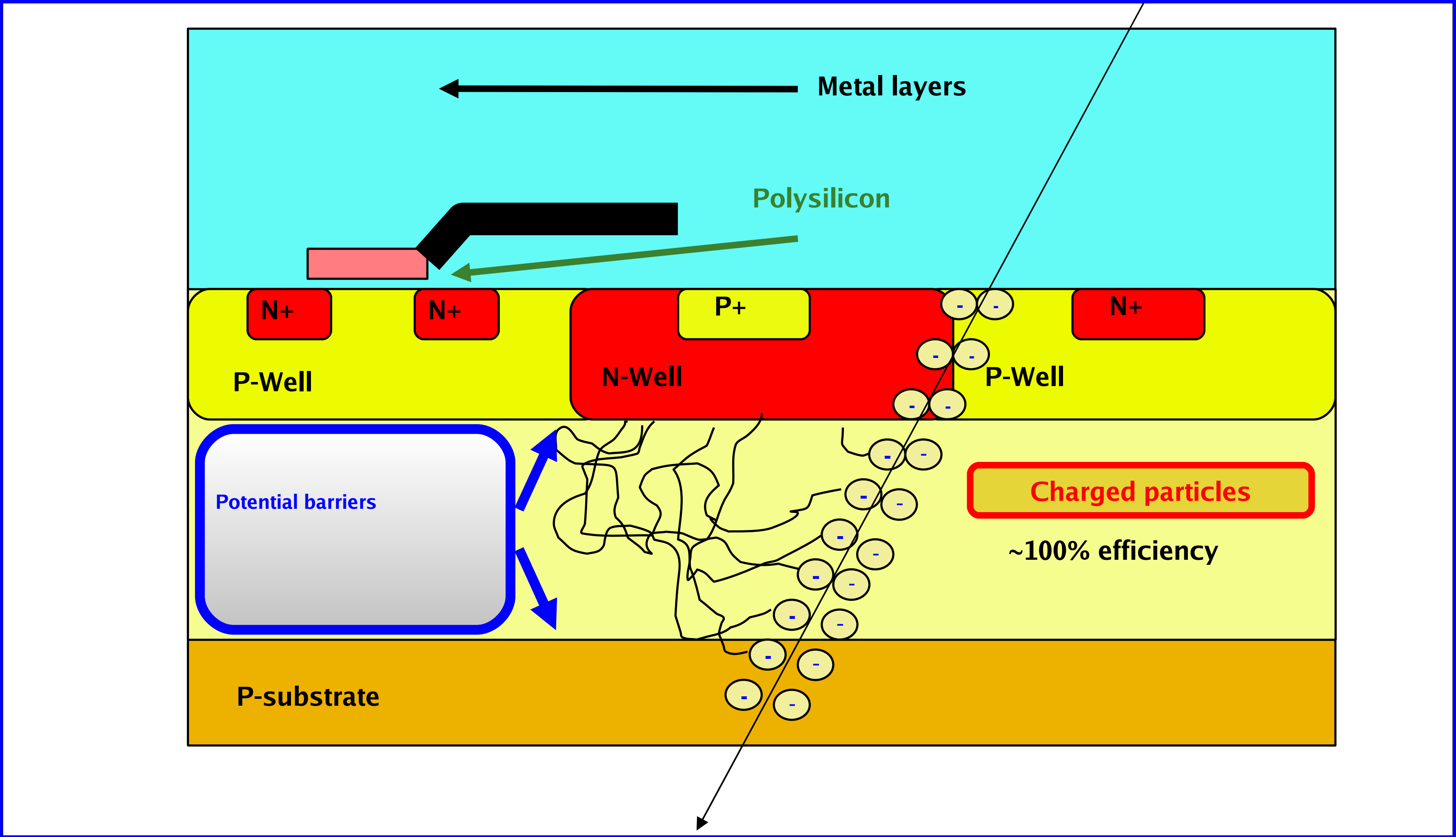

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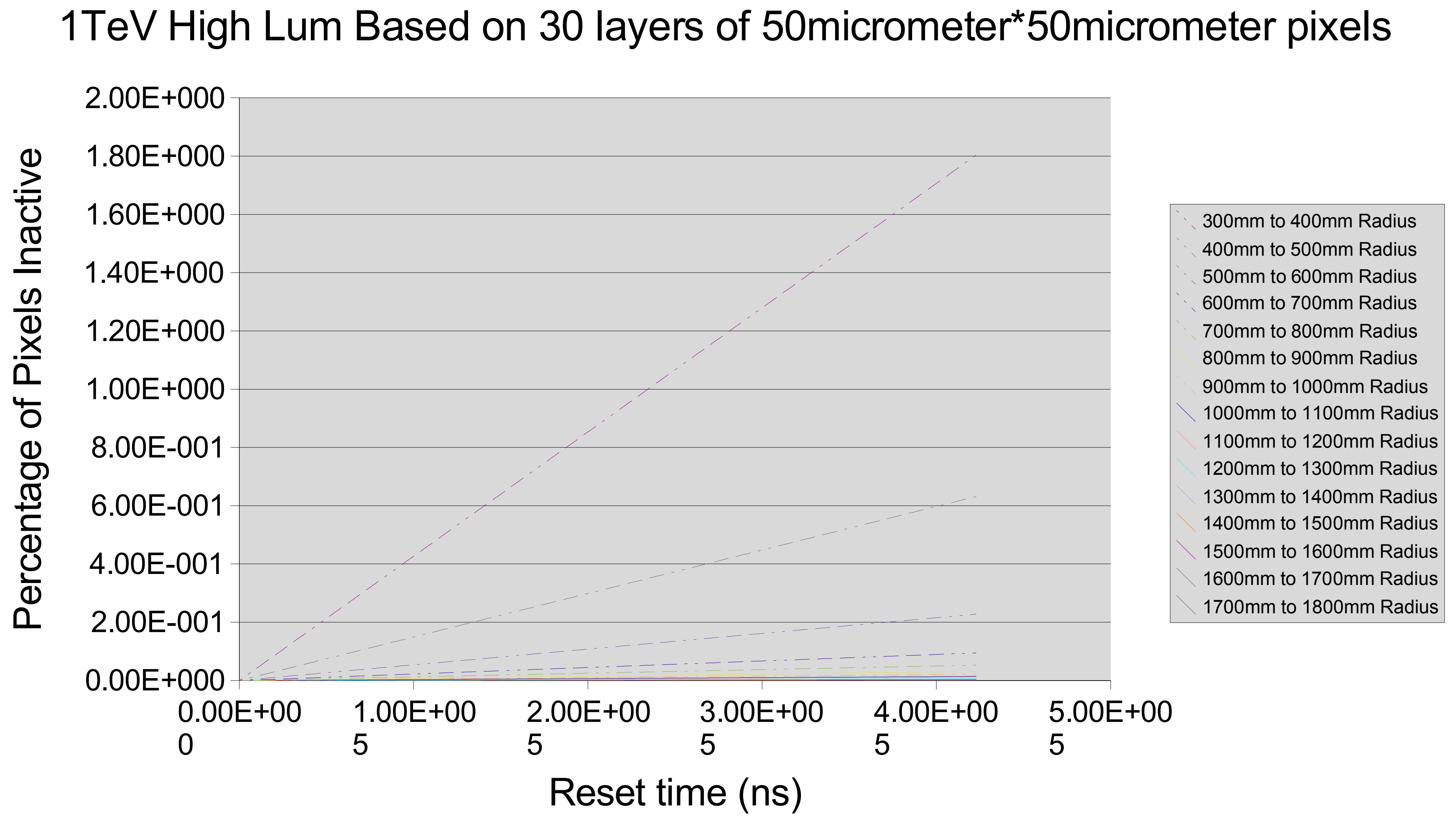
GuineaPig Study



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