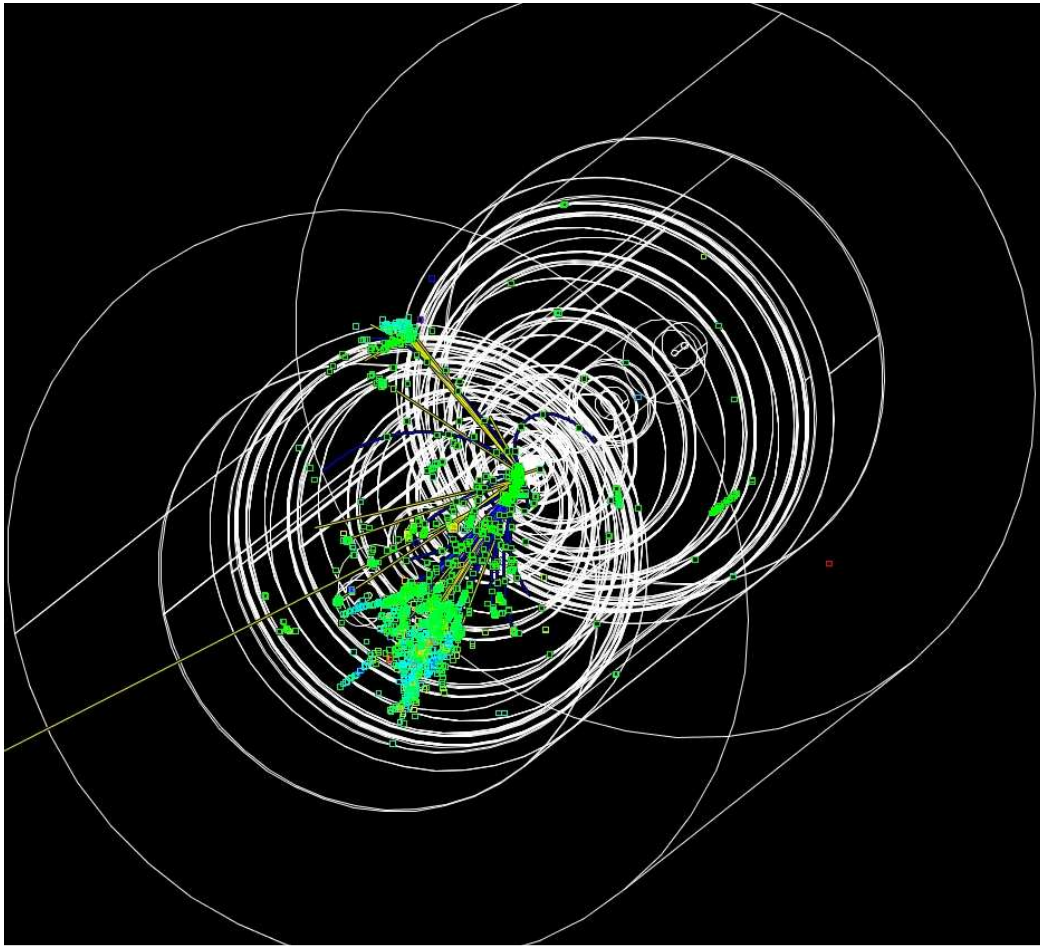
High Granularity ECAL Study Using SLIC

Nigel Watson

- Introduction
- Software Tools
- Framework
- Results
- Summary

[Simulations by J.Lilley, Birmingham/Durham summer student]



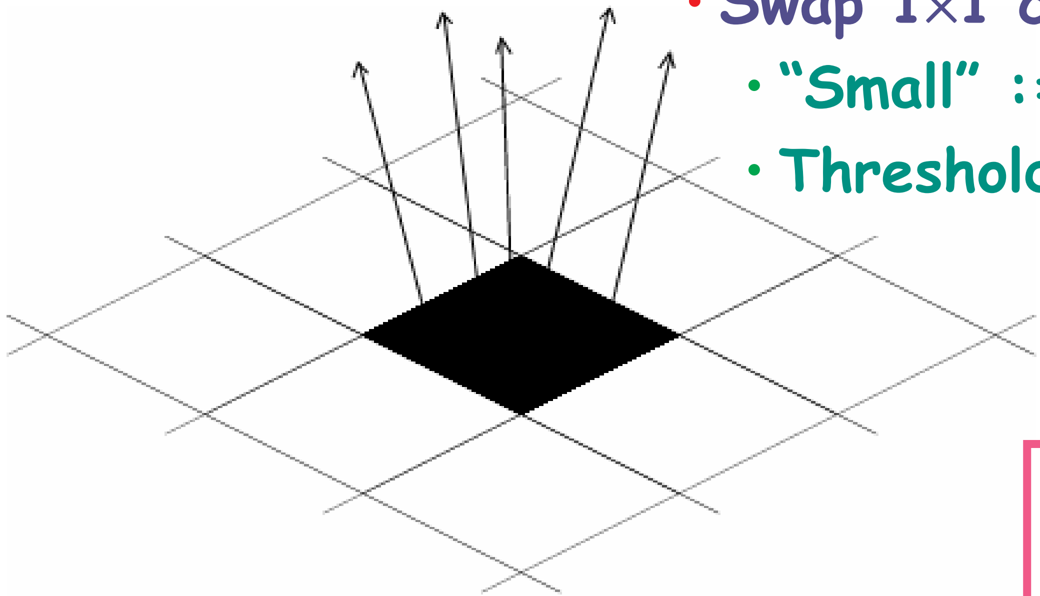
Monolithic Active Pixel Sensors

- Alternative to standard silicon diode pad detectors in ECAL
- CMOS process, more mainstream, *potential* to be
  - Less expensive
  - More performant
  - Better mechanical/thermal considerations

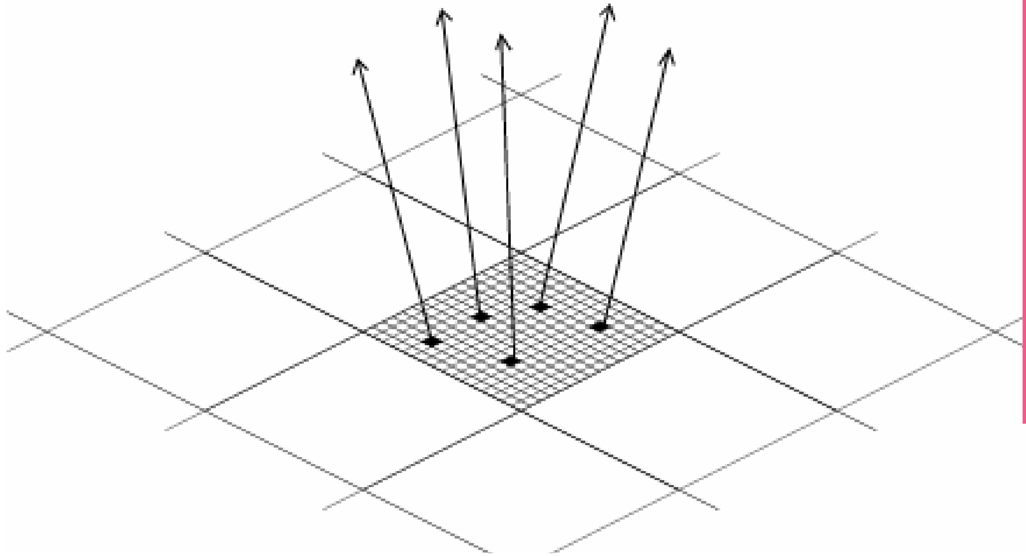
- Attempt to prove or disprove "MAPS-for-ECAL" concept over next 3 years

- R&D Programme includes…
  - Simulate effect on full detector performance in terms of PFLOW
  - Device level modelling of response to e.m. showers, test against hardware
  - 2 rounds of sensor fabrication and testing, including cosmics and sources
  - e^- beam test, check response in showers and single event upsets

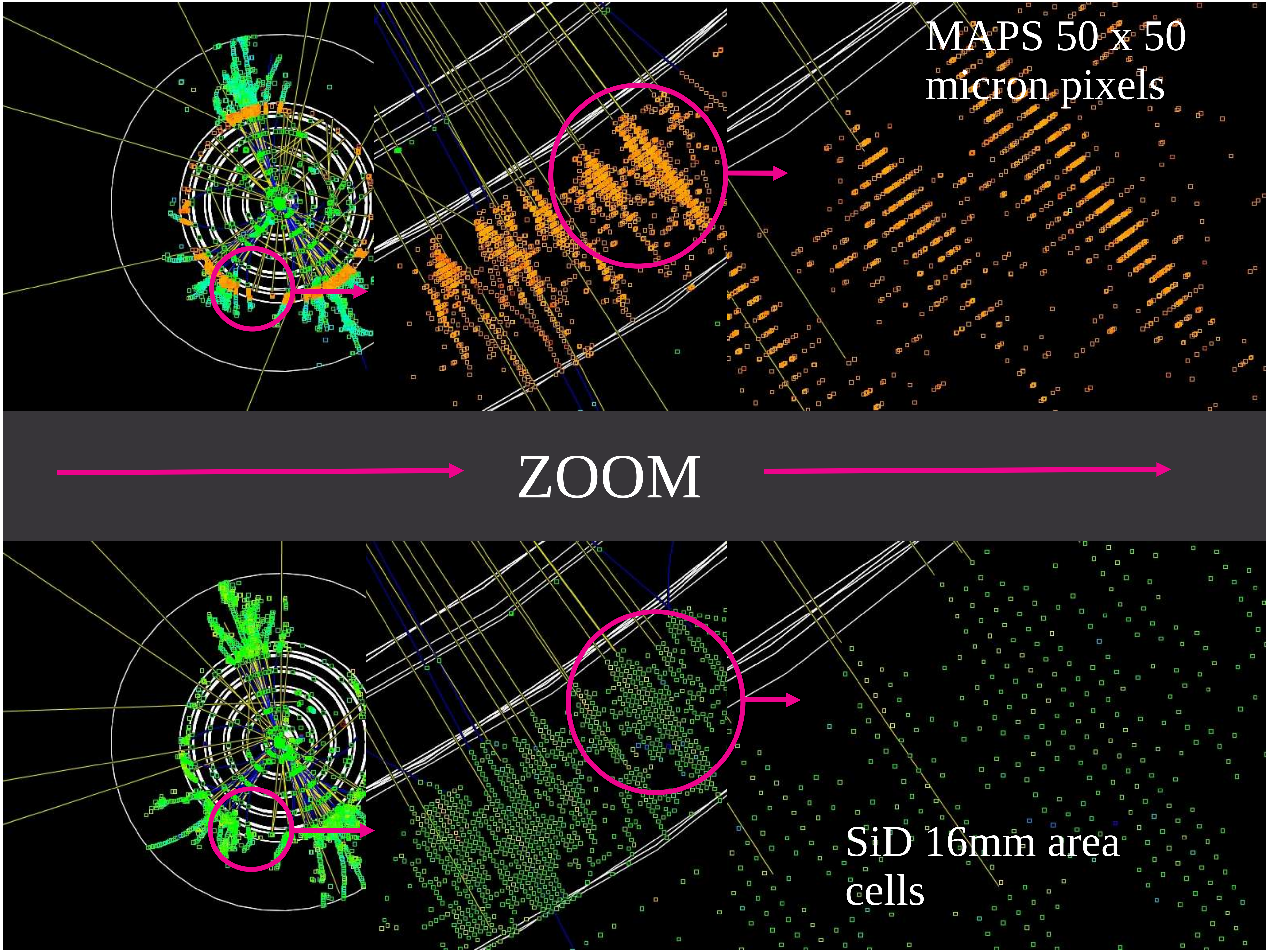
Basic concept for MAPS



- Swap 1×1 cm^2 Si pads with small pixels
  - "Small" := at most one particle/pixel
  - Threshold only/pixel, i.e. Digital ECAL

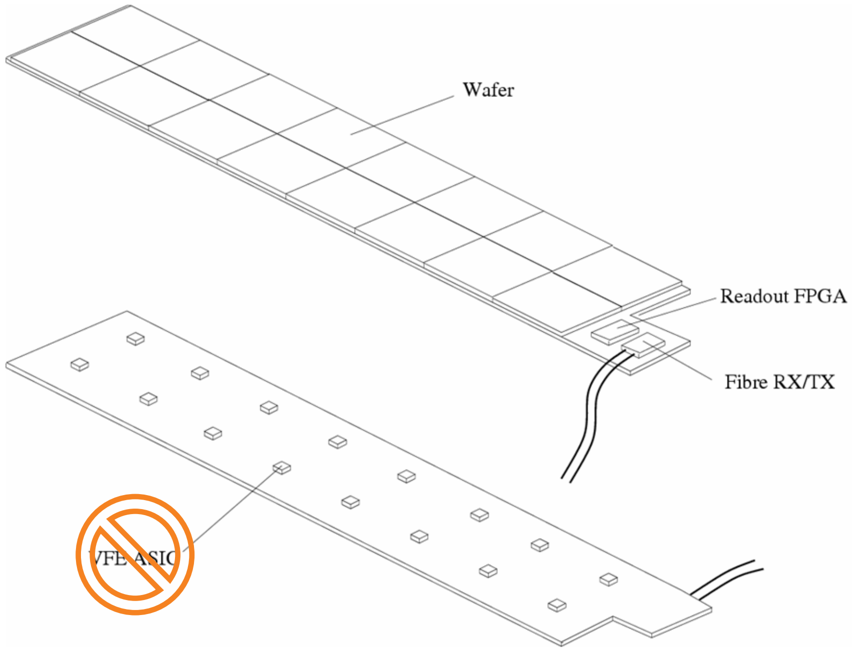


- How small is small?
  - EM shower core density at 500GeV is ~100/mm^2
  - Pixels must be < 100×100μm^2; working number is 50×50μm^2
  - Gives ~10^{12} pixels for ECAL!


MAPS 50 x 50
micron pixels
ZOOM
SiD 16mm area
cells

ECAL as a system

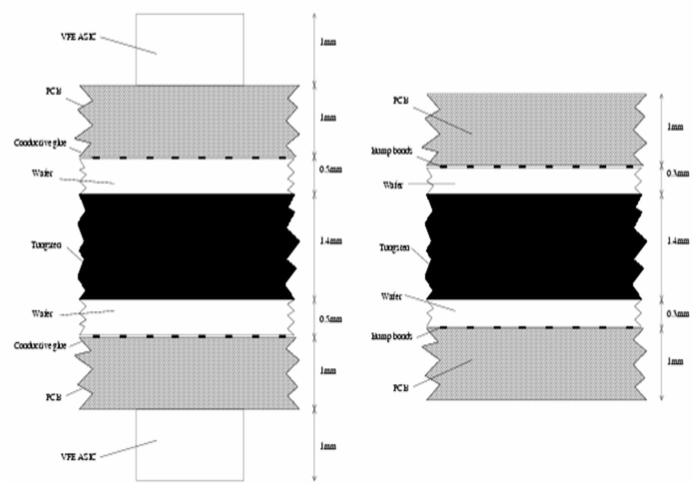
- Replace diode pad wafers and VFE ASICs with MAPS wafers
  - Mechanically very similar; overall design of structure identical
  - DAQ very similar; FE talks to MAPS not VFE ASICs
    - Both purely digital I/O, data rates within order of magnitude



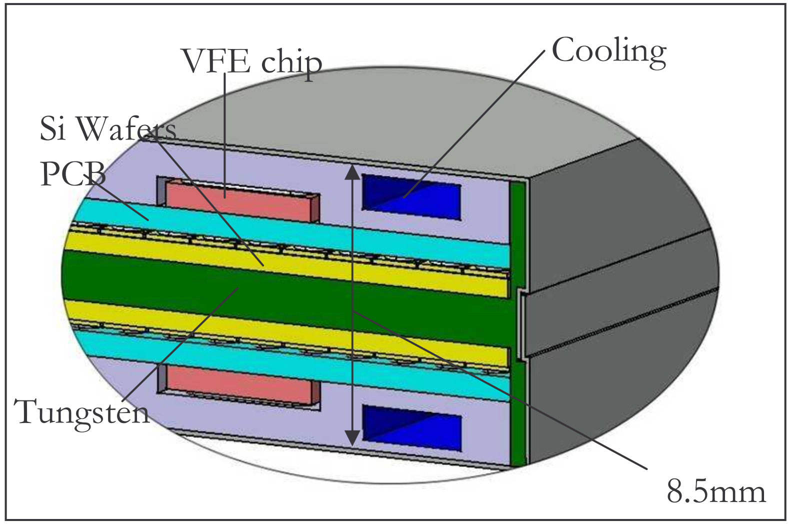
- Aim for MAPS to be a “swap-in” option without impacting too much on most other ECAL design work
- Requires sensors to be glued/solder-pasted to PCB directly
  - No wirebonds; connections must be routed on sensor to pads above pixels
  - New technique needed which is part of our study

Potential advantages

- Slab thinner due to missing VFE ASICs
  - Improved effective Moliere radius (shower spread)
  - Reduced size (=cost) of detector magnet and outer subdetectors



6.4mm thick   4.0mm thick



- Thermal coupling to tungsten easier
  - Most heat generated in VFE ASIC or MAPS comparators
  - Surface area to slab tungsten sheet ~1cm^2 for VFE ASIC, ~100cm^2 for final MAPS

- **COST!** Standard CMOS should be cheaper than high resistivity silicon
  - No crystal ball for 2012 but roughly a factor of two different now
  - TESLA ECAL wafer cost was 90M euros; 70% of ECAL total of 133M euros
  - That assumed 3euros/cm^2 for 3000m^2 of processed silicon wafers

Aims/Rationale

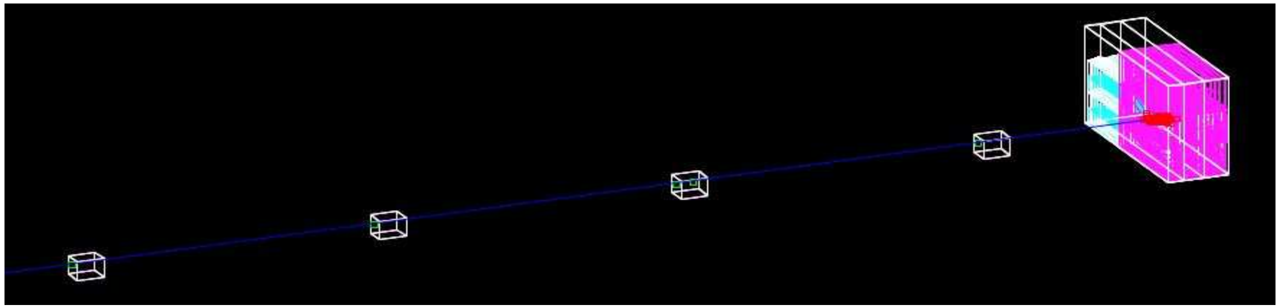
- Independent study of MAPS
- Try out evolving North American software suite
  - Event reconstruction framework
  - Easy to adapt geometry and implement MAPS

    ⇒ SLIC
- Comparison of baseline SiD analogue Si to MAPS ECAL
- SLIC
  - Is well documented and supported

    http://www.lcsim.org/software/slic
- Gets geometry defintion from LCDD format, typically generated from "compact" XML format using GeomConverter, attractive for MAPS study.
- Setting up SLIC is OK
  - Dependences CLHEP, GEANT4, LCPhys, LCIO, Xerces-C++, GDML, LCDD, …

Software Framework

- This study using JAS3/org.lcsim
- Other prototype data analysis summer project (M.Stockton) using
  - George M.'s cleaned+calibrated LCIO files
  - Marlin
  - JAS3 + AIDA + Wired (for event display)



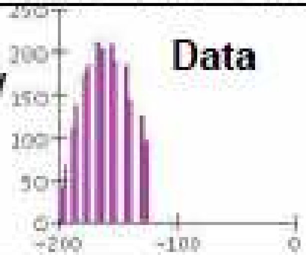
- Conclusion: very easy to use this lightweight framework, well adapted to getting started quickly with little overhead

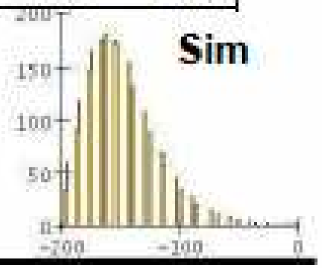
Particle leakage

- By looking at the first 14 layers in the simulations I created matching the 9 runs I had I could see how much of the event was contained in these layers
- For the 1 GeV runs it seems to be about 80% of the hits and 86% of the energy and no different for the run not at the centre of a wafer (100137)
- For the runs with increasing energy the amount measured drops but not by a constant amount (run 100123 and 100134 have energies 2GeV and 3GeV respectively)

Run	100121	100122	100123	100127	100128	100131	100132	100134	100137
% of hits	80.47	79.8	70.03	79.69	80.4	79.64	79.67	64.06	79.72
% of energy	86.25	85.83	80.68	85.81	86.28	85.81	85.72	77.33	85.74

- The hits weighted by energy shows that the data does follow the same trend as the full detector simulation



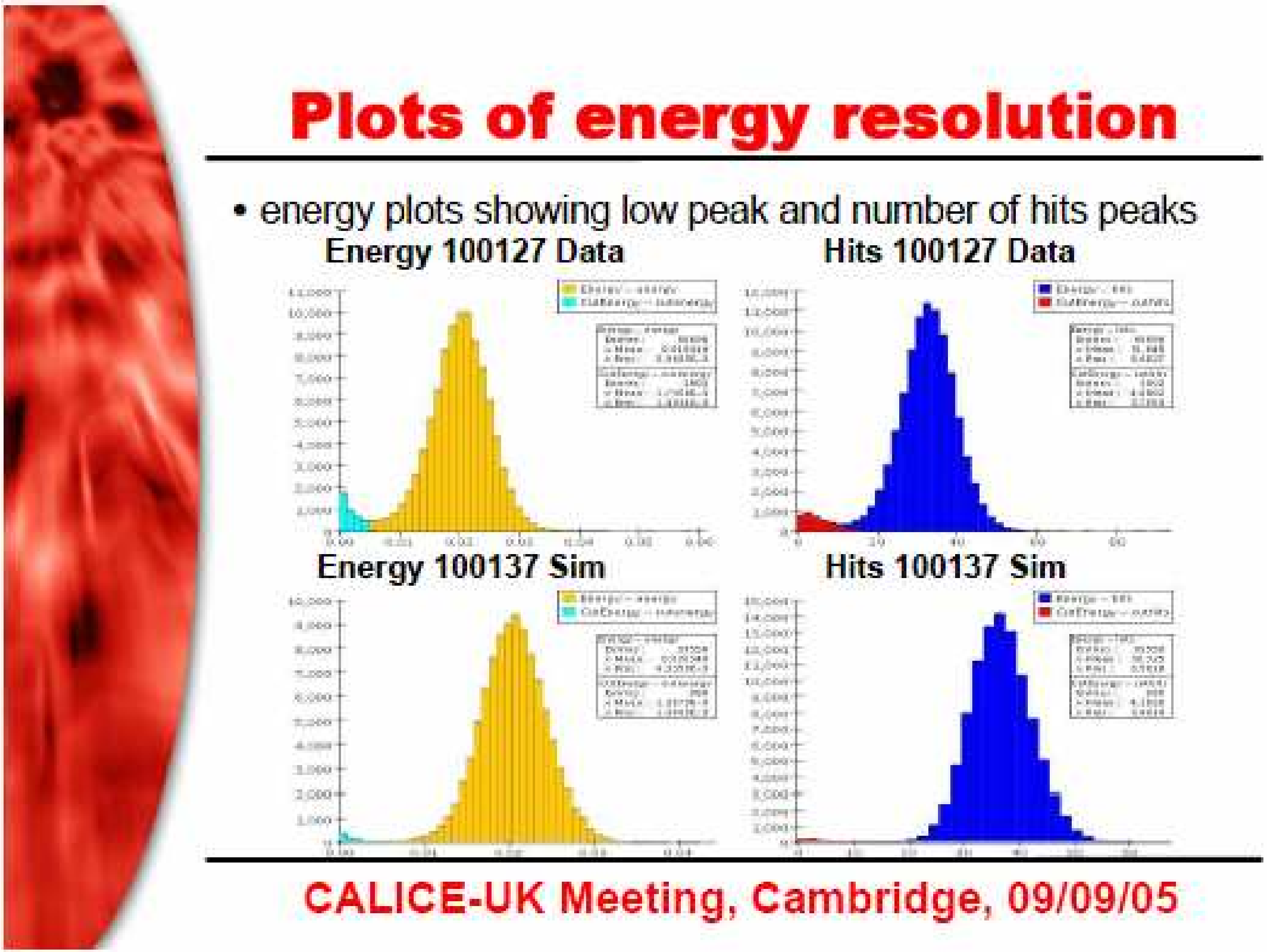


CALICE-UK Meeting, Cambridge, 09/09/05

Position resolution

- Using the fit of the line through the 4 drift tubes I made a predicted impact point in each layer
- By then averaging all the hits in a layer and converting the position I could look at the position resolution in each layer
- As expected the rms increases later in the detector
- For the simulations that passed through the drift tubes in the layout of model TB05 (those at wafer 5) the rms was larger compared to the matching data runs but still showed the same trend of increasing later on in the detector
- I also noticed in the x position in data that there was an offset in alternate layers
- I looked at the simulation and the version of ecal I was using seemed to have several layers with offsets but this does not show up in the position resolution

CALICE-UK Meeting, Cambridge, 09/09/05


Plots of energy resolution
• energy plots showing low peak and number of hits peaks
Energy 100127 Data
Hits 100127 Data
Energy 100137 Sim
Hits 100137 Sim
CALICE-UK Meeting, Cambridge, 09/09/05

Study

- Definition of MAPS geomtry in SLIC
- Estimating MIP thresholds
- Longitudinal response of ECAL
- Comparison of analogue/MAPS response
- Non-Projective Geometry

Implementing MAPS in SiD

- Based on SiD geometry 'cdcaug05',
  - 20 layers @ 0.25cm W, 10 @ 0.5cm W
- Adapt Si thickness to an epitaxial layer thickness of 5μm + 295μm substrate for MAPS

```
<!-- Electromagnetic calorimeter -->

    <detector id="2" name="EMBarrel"
type="CylindricalBarrelCalorimeter" readout="EcalBarrHits">
        <dimensions inner_r = "127.0*cm" outer_z = "182.0*cm"
/>
        <layer repeat="20">
          <slice material = "Tungsten" thickness = "0.25*cm" />
          <slice material = "G10" thickness = "0.068*cm" />
          <slice material = "Silicon" thickness = "0.032*cm"
sensitive = "yes" />
          <slice material = "Air" thickness = "0.025*cm" />
        </layer>
        <layer repeat="10">
          <slice material = "Tungsten" thickness = "0.50*cm" />
          <slice material = "G10" thickness = "0.068*cm" />
          <slice material = "Silicon" thickness = "0.032*cm"
sensitive = "yes" />
          <slice material = "Air" thickness = "0.025*cm" />
        </layer>
    </detector>
```

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        <dimensions inner_r = "127.0*cm" outer_z = "182.0*cm" />
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          <slice material = "Tungsten" thickness = "0.25*cm" />
          <slice material = "G10" thickness = "0.07*cm" />
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          <slice material = "Silicon" thickness = "0.0005*cm" sensitive
=               "yes" />
          <slice material = "Air" thickness = "0.025*cm" />
        </layer>
        <layer repeat="10">
          <slice material = "Tungsten" thickness = "0.50*cm" />
          <slice material = "G10" thickness = "0.07*cm" />
          <slice material = "Silicon" thickness = "0.0295*cm" />
          <slice material = "Silicon" thickness = "0.0005*cm" sensitive
=               "yes" />
          <slice material = "Air" thickness = "0.025*cm" />
        </layer>
    </detector>
```

MAPS projective segmentation

- 'cdcaug05' has a projective segmentation
- Use the number of 'bins' to give an average of 50x50 μm pixel pitch for MAPS.

```
<!-- Sensitive Detector readout segmentation -->
  <readouts>
        < .................>

        <readout name="EcalEndcapHits">
          <segmentation type="ProjectiveZPlane"
thetaBins="1024"              phiBins="1024"/>
          <id>layer:7,system:6,barrel:3,theta:32:11,phi:11</id>
        </readout>

        < .................>

      <readout name="EcalBarrHits">
            <segmentation type="ProjectiveCylinder"
thetaBins="1000"             phiBins="2000"/>
            <id>layer:7,system:6,barrel:3,theta:32:11,phi:11</id>
        </readout>
        < .................>

   </readouts>
```

```
<!-- Sensitive Detector readout segmentation -->
  <readouts>
        < .................>

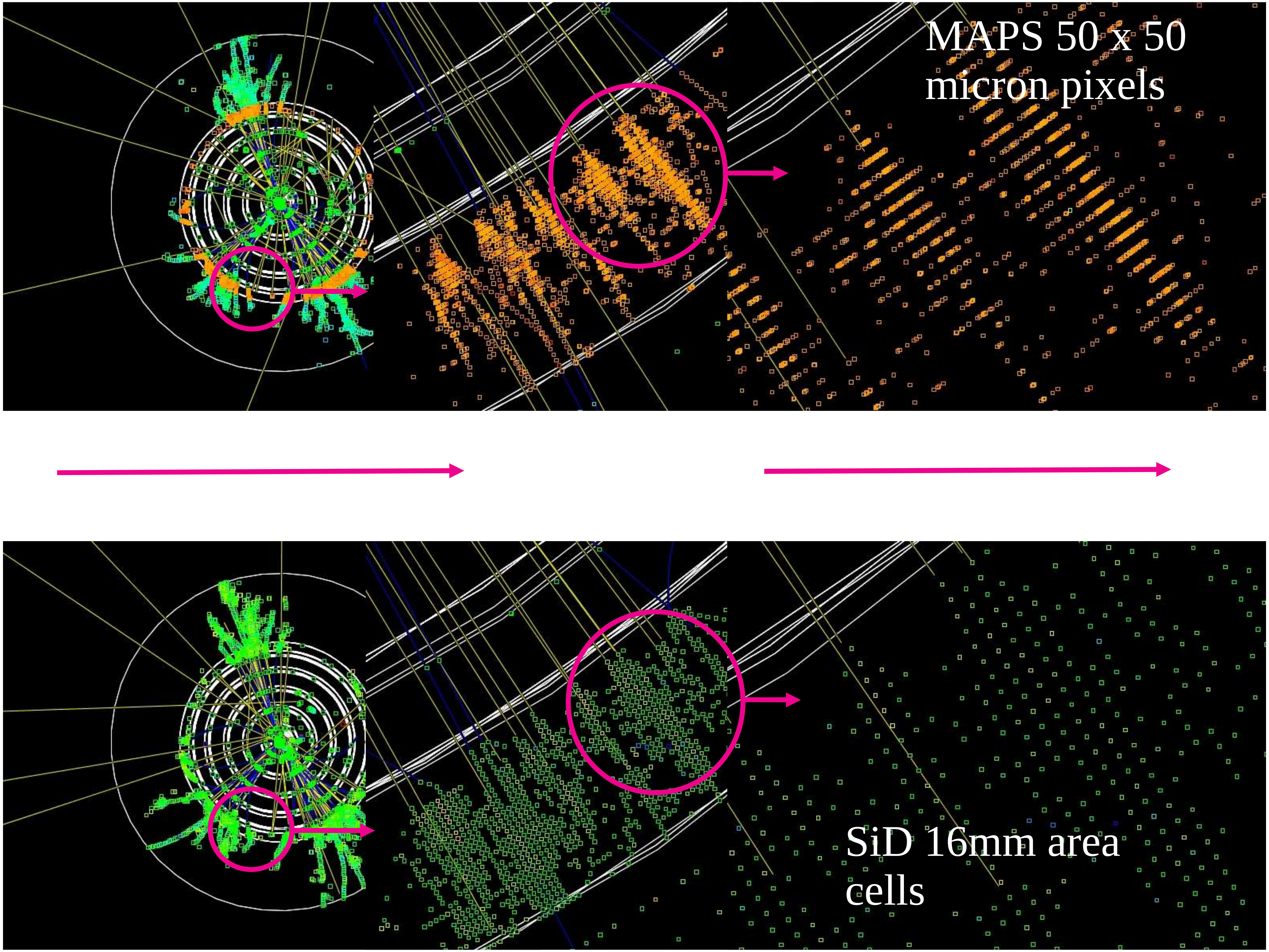
        <readout name="EcalEndcapHits">
          <segmentation type="ProjectiveZPlane"
thetaBins="95819"             phiBins="40200"/>
          <id>layer:6,system:6,theta:18,barrel:32:3,phi:18</id>
        </readout>

        < .................>

      <readout name="EcalBarrHits">
            <segmentation type="ProjectiveCylinder"
thetaBins="72800" phiBins="168239"/>
            <id>layer:6,system:6,theta:18,barrel:32:3,phi:18</id>
        </readout>
        < .................>

   </readouts>
```

Watch out for the number of bits assigned to each field – thanks to Jeremy McC for help!

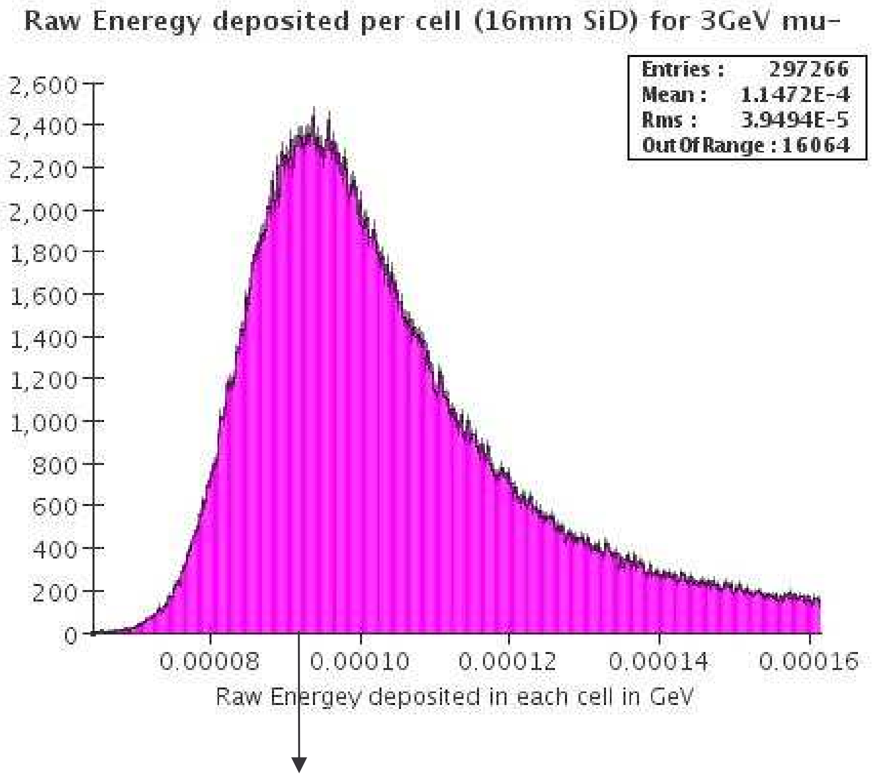

MAPS 50 x 50
micron pixels
SiD 16mm area
cells

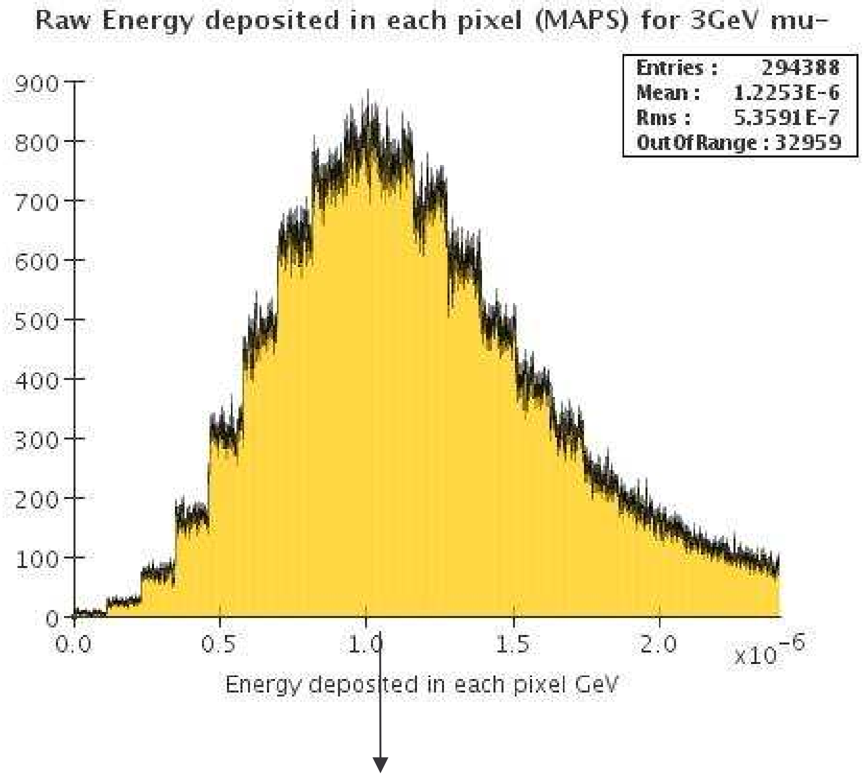
MIP Signal

- Estimate of MIP threshold

SiD Baseline, $16mm^2$ area cells

MAPS 50x50 micron pixels





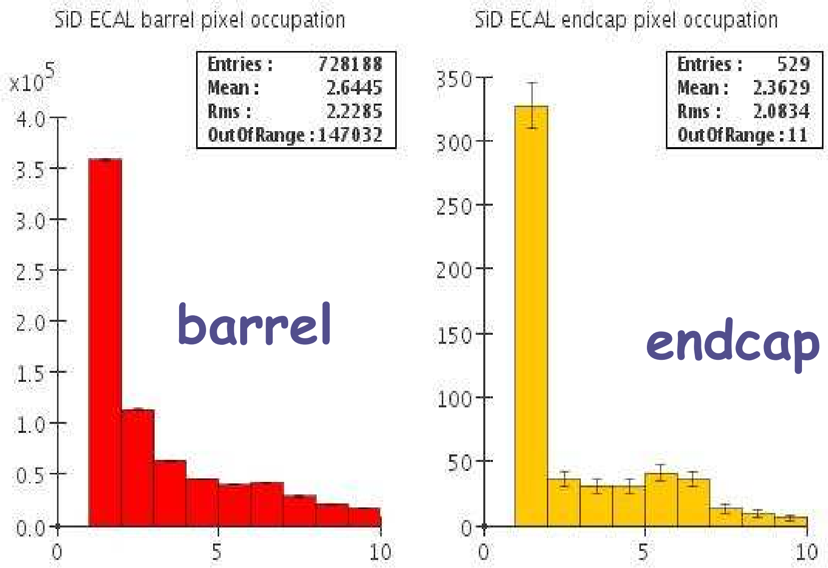
threshold of 0.5MIP = 47KeV

threshold of 0.5MIP = 0.5KeV

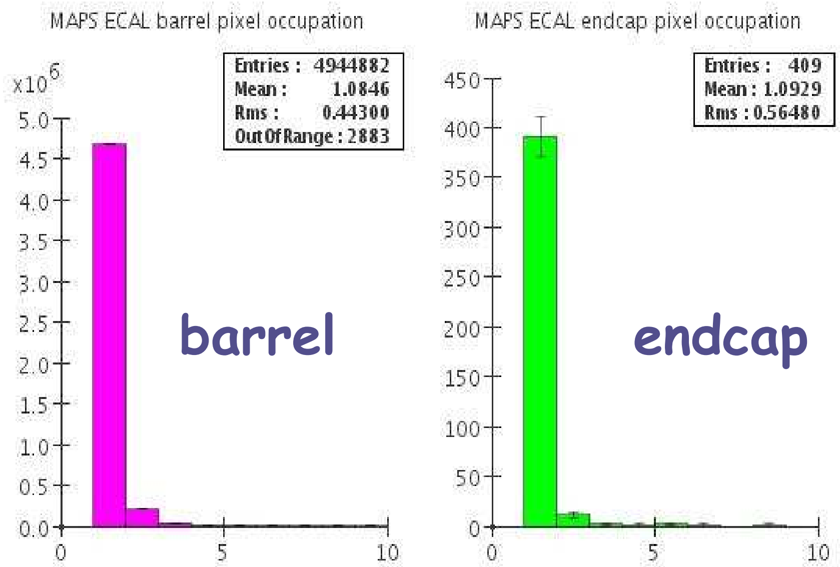
Pixel Occupancy

- MAPS concept requires binary readout... we need at most 1 hit per pixel or else lose information.

SiD, 100GeV electrons



MAPS, 100GeV electrons

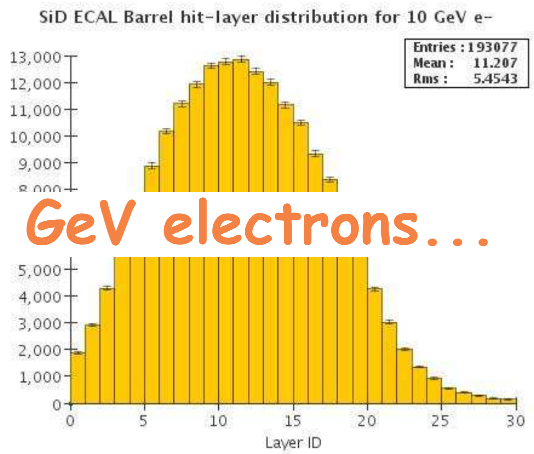


Select optimal pixel pitch from simulation studies

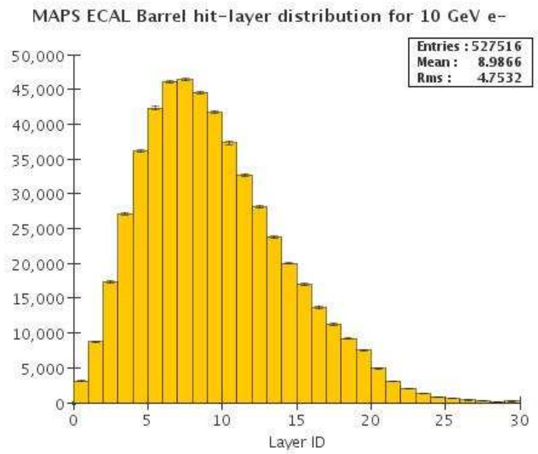
Longitudinal response

- Compare longitudinal shower development
- Compare hits/layer for SiD and MAPS, to energy/layer for SiD

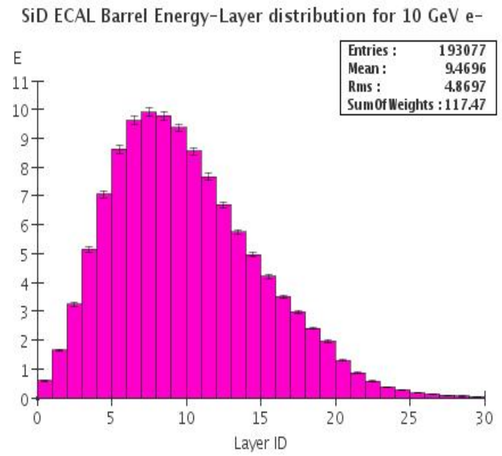
10 GeV electrons...



SiD hits/layer

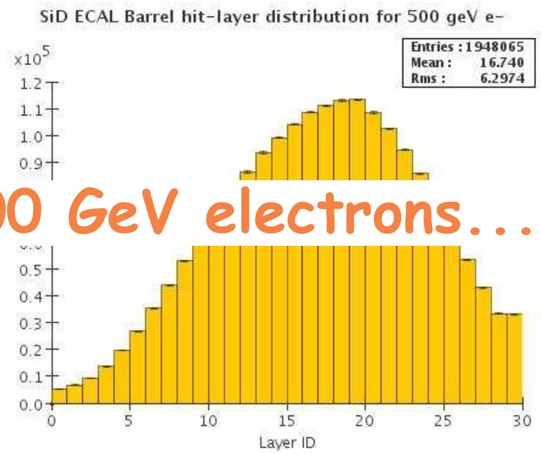


MAPS hits/layer

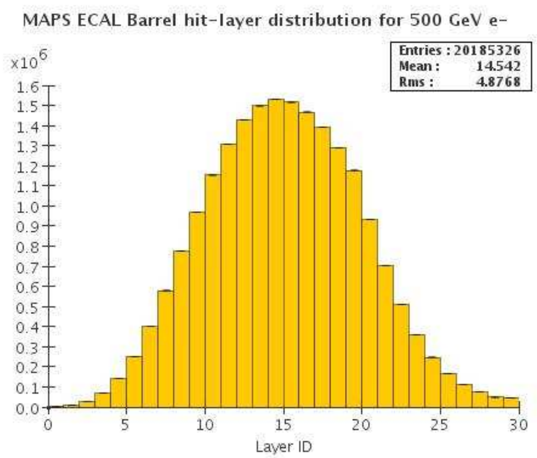


SiD Energy/layer

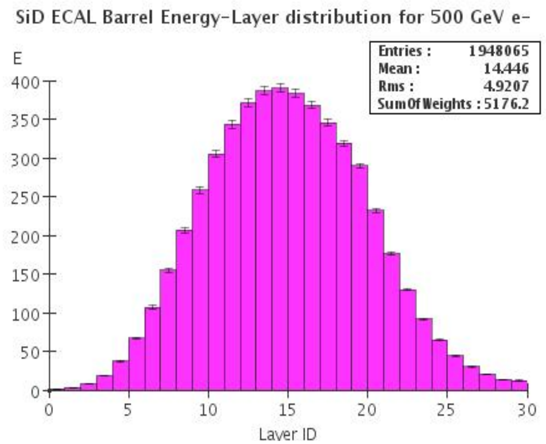
500 GeV electrons...



Ni... SiD hits/layer

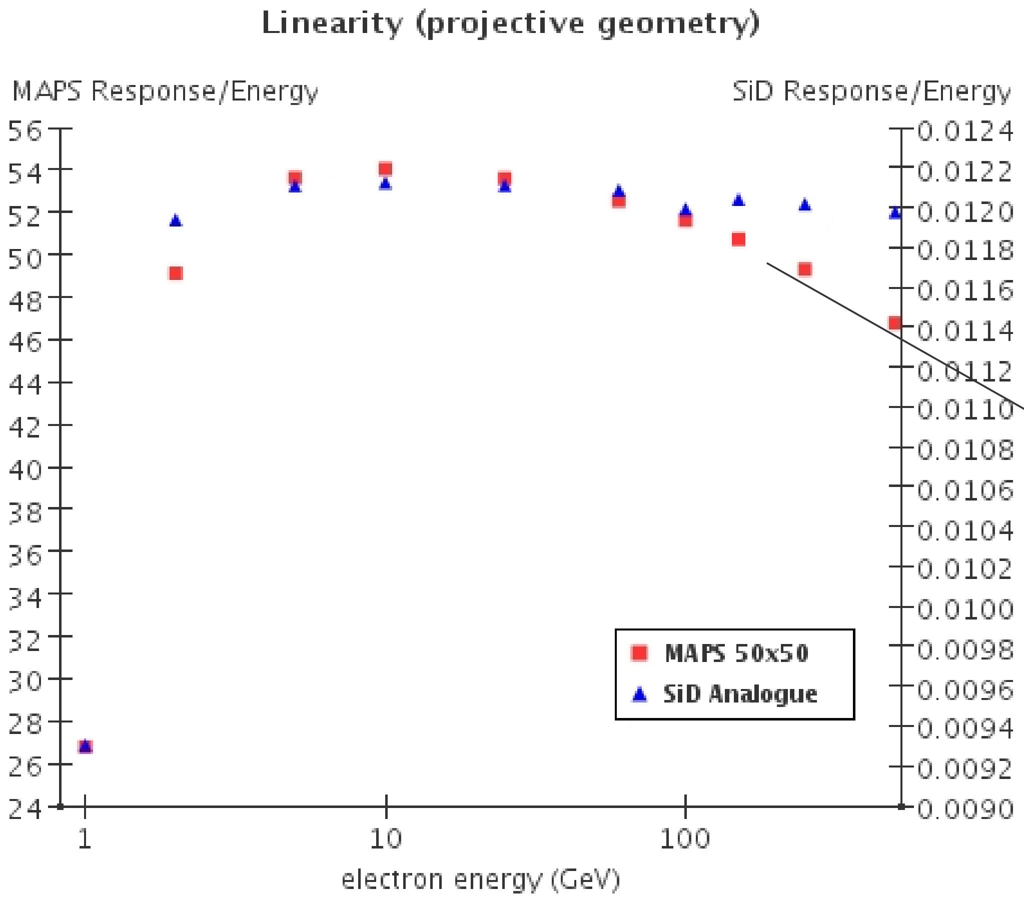


MAPS hits/layer



SiD Energy/layer

Comparing the Linearity



Slight reduction off in MAPS due to pixel occupation > 1 ??

Non-Projective Geometry

- Non-projective geometry available 'sidaug05_np'
- Get constant pixel size
- Used more likely epitaxial layer thickness (15 micron)

SiD

```
<!-- Electromagnetic calorimeter -->

   <detector id="2" name="EMBarrel"
type="CylindricalBarrelCalorimeter"
readout="EcalBarrHits">
      <dimensions inner_r = "127.0*cm" outer_z =
"179.5*cm" />
      <layer repeat="30">
        <slice material = "Tungsten" thickness =
"0.25*cm" />
        <slice material = "G10" thickness =
"0.068*cm" />
        <slice material = "Silicon" thickness =
"0.032*cm"          sensitive = "yes" />
        <slice material = "Air" thickness = "0.025*cm"
/>
      </layer>
   </detector>
```

30 layers constant thickness, 0.25cm W

MAPS

```
!-- Electromagnetic calorimeter -->

   <detector id="2" name="EMBarrel"
type="CylindricalBarrelCalorimeter"
readout="EcalBarrHits">
      <dimensions inner_r = "127.0*cm" outer_z =
"179.5*cm" />
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        <slice material = "Tungsten" thickness =
"0.25*cm" />
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"0.070*cm" /             >
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"0.0285*cm"  />
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"0.0015*cm" sensitive = "yes" />
        <slice material = "Air" thickness = "0.025*cm"
/>
      </layer>
   </detector>
```

Non-Projective Readout

- Defined three new detectors, pixel pitches of 25, 50, 100 μm

```
<readout name="EcalBarrHits">
    <segmentation type="NonprojectiveCylinder" gridSizePhi="0.05" gridSizeZ="0.05" />
    <id>layer:6,system:6,phi:20,barrel:32:3,z:-20</id>
  </readout>
```

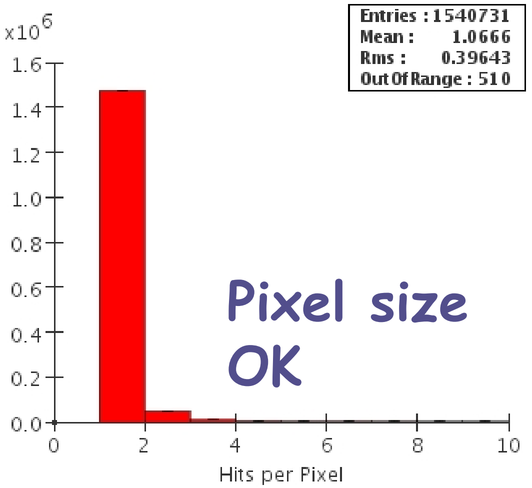
Change order of bit assignment

Set pixel size (mm)

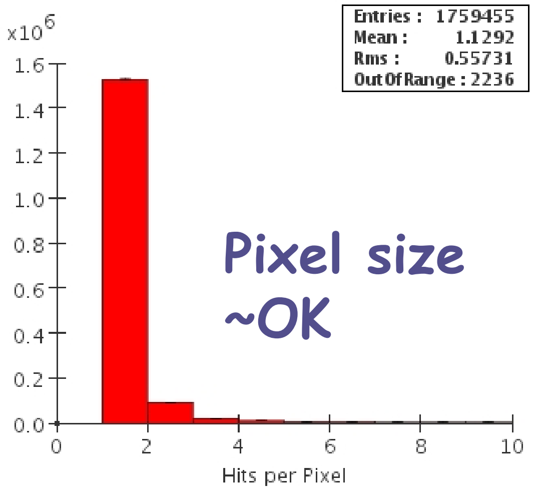
Re-evaluate MIP threshold for new epitaxial thickness = 1.6 KeV

Initial pixel occupation study, 250GeV electrons....

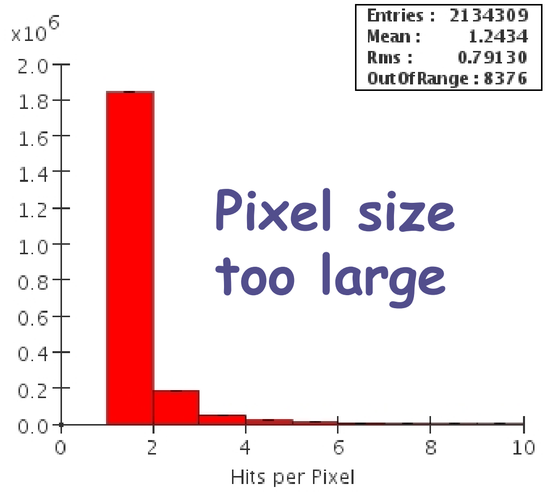
25x25 microns



50x50 microns

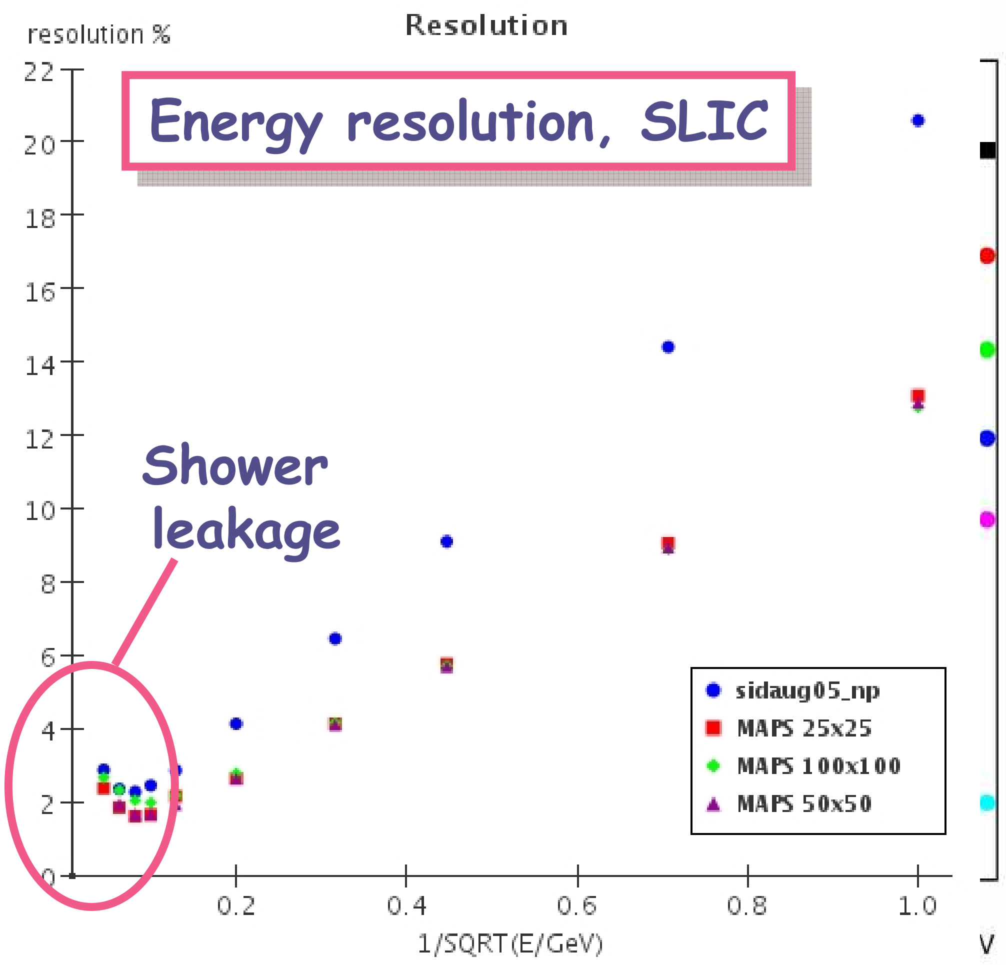


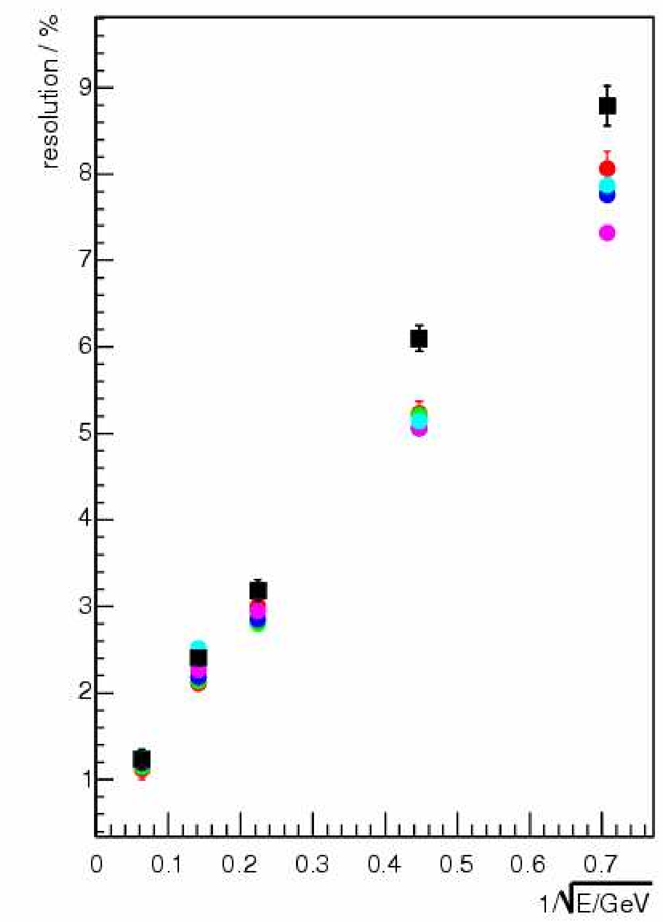
100x100 microns



Preliminary results

- Known problem below few GeV (artefact, plots not yet updated for this)
- Can compa... linearity ... resolution [D.Ward study]





Future Plans

- Need to investigate PFLOW using fine granularity, advent of tools in Marlin a big help
- Implement more detailed simulations in Mokka (reduce interlayer gaps)
- Look for problems with MAPS concept – any "showstoppers"?
- Plenty of time to prepare simulation for any beam test!

Other requirements

- Also need to consider power, uniformity and stability
  - Power must be similar (or better) that VFE ASICs to be considered
    - Main load from comparator; ~2.5μW/pixel when powered on
    - Investigate switching comparator; may only be needed for ~10ns
    - Would give averaged power of ~1nW/pixel, or 0.2W/slab
    - There will be other components in addition
    - VFE ASIC aiming for 100μW/channel, or 0.4W/slab
  - Unfeasible for threshold to be set per pixel
    - Prefer single DAC to set a comparator level for whole sensor
    - Requires sensor to be uniform enough in response of each pixel
    - Possible fallback; divide sensor into e.g. four regions
  - Sensor will also be temperature cycled, like VFE ASICs
    - Efficiency and noise rate must be reasonably insensitive to temperature fluctuations
    - More difficult to correct binary readout downstream

Planned programme

- Two rounds of sensor fabrication
  - First with several pixel designs, try out various ideas
  - Second with uniform pixels, iterating on best design from first round
- Testing needs to be thorough
  - Device-level simulation to guide the design and understand the results
  - "Sensor" bench tests to study electrical aspects of design
  - Sensor-level simulation to check understanding of performance
  - "System" bench tests to study noise vs. threshold, response to sources and cosmics, temperature stability, uniformity, magnetic field effects, etc.
  - Physics-level simulation to determine effects on ECAL performance
- Verification in a beam test
  - Build at least one PCB of MAPS to be inserted into pre-prototype ECAL
  - Replace existing diode pad layer with MAPS layer
  - Direct comparison of performance of diode pads and MAPS