Simulation of Monolithic Active Pixel Sensors for ILC ECAL

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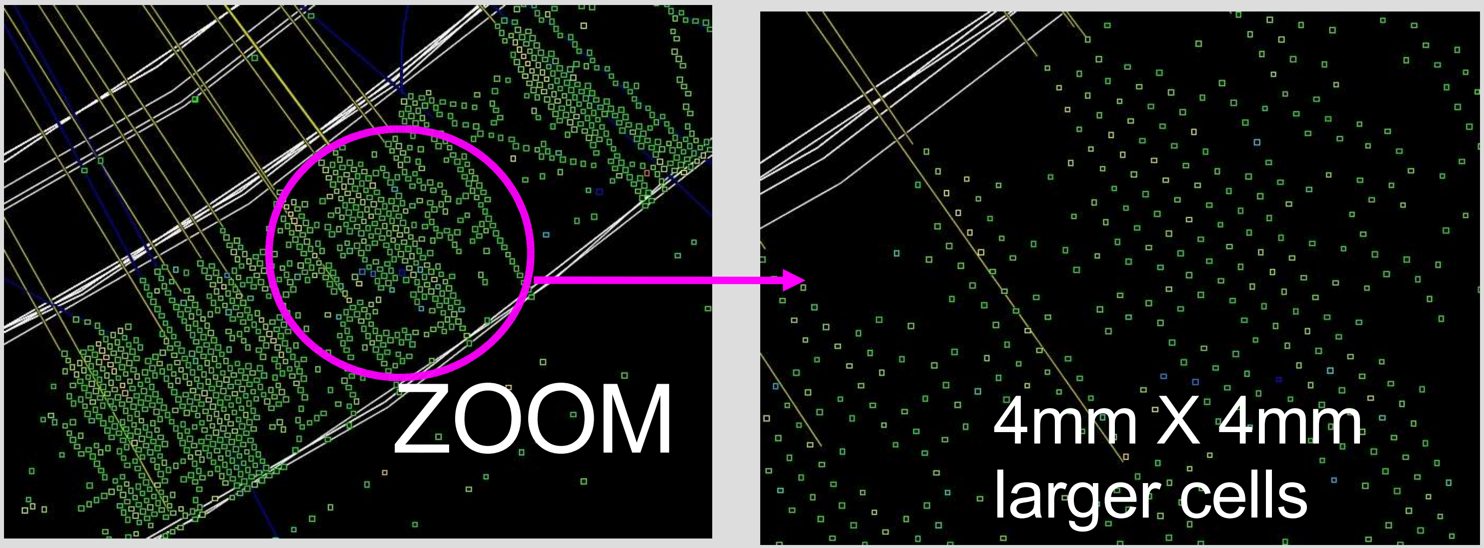
Outline

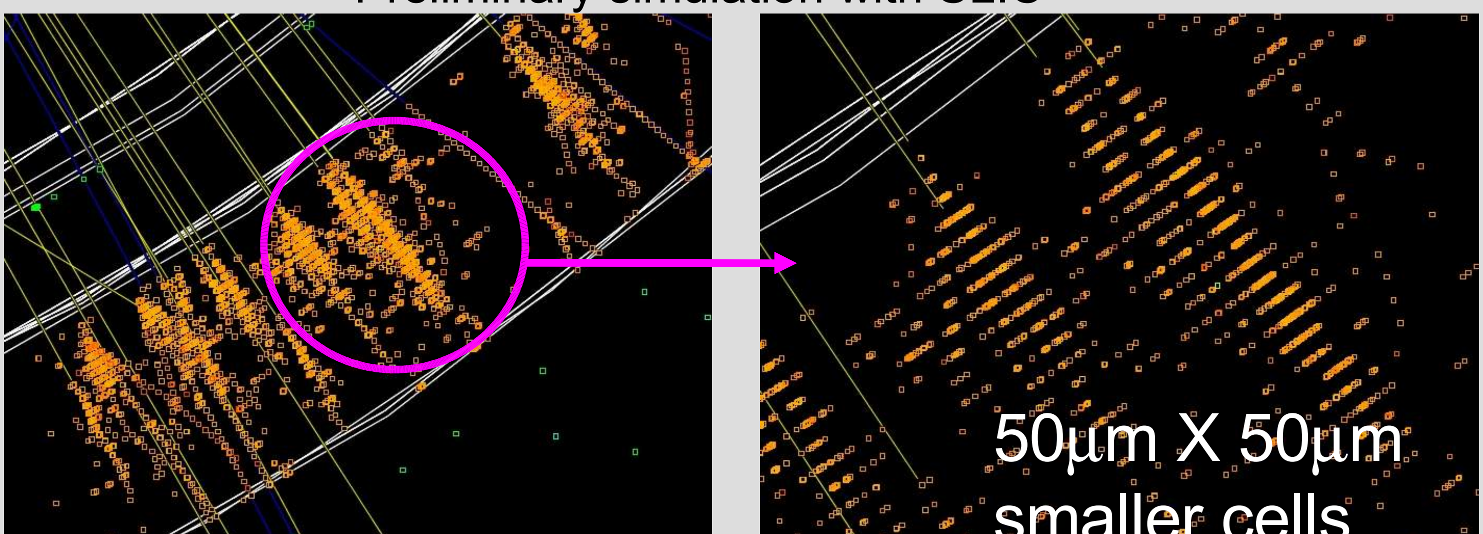
- **MAPS (Monolithic Active Pixel Sensors) ECAL**
  - Concepts
  - Design
- **Geometry modification in GEANT4 simulation**
- **Demonstration of single e^-/μ^- events using full detector simulation**
- **Sensor simulation**
- **Summary of status**
- **Future prospects**

MAPS ECAL concept

- **High granularity**
  - Small cells
  - Digital calorimetry
  - Detecting individual particles after electromagnetic shower
  - Result in measuring a single particle in each cell
  - Binary readout
    - → Higher spatial resolution
    - → Better performance for particle separation inside jets
- **Cost saving**
  - CMOS (Complementary Metal Oxide Semiconductor) silicon
    - → Cheaper than higher resistive pure silicon



Preliminary simulation with SLIC



MAPS Introduction

Analogue design in Mokka simulation

- 1cm X 1cm cell
- 500µm Si sensitive thickness
- Analogue readout

MAPS design

- 50µm X 50µm cell
- 15µm Si sensitive thickness
- Binary readout

Si-W sandwich:

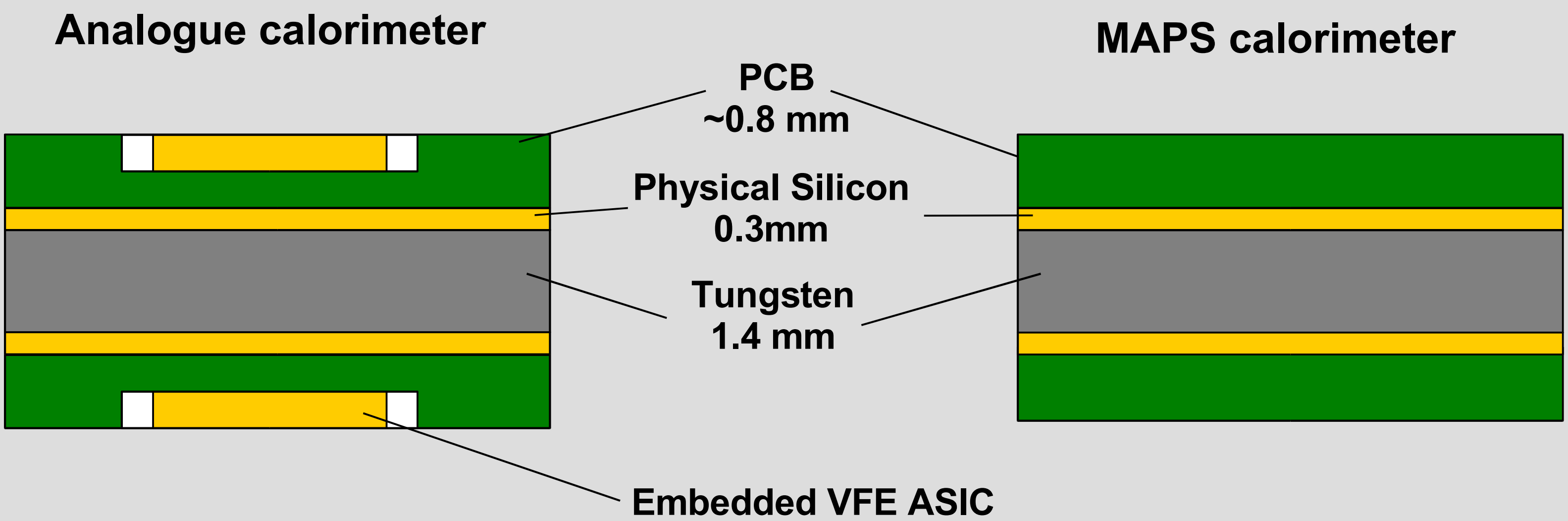
Si physical thickness and W thickness are the same for both default design and MAPS design in LDC01.

Si physical thickness: 500µm

W thickness: 2.1mm for first 20 layers

4.2mm for last 10 layers

Physical detector slabs

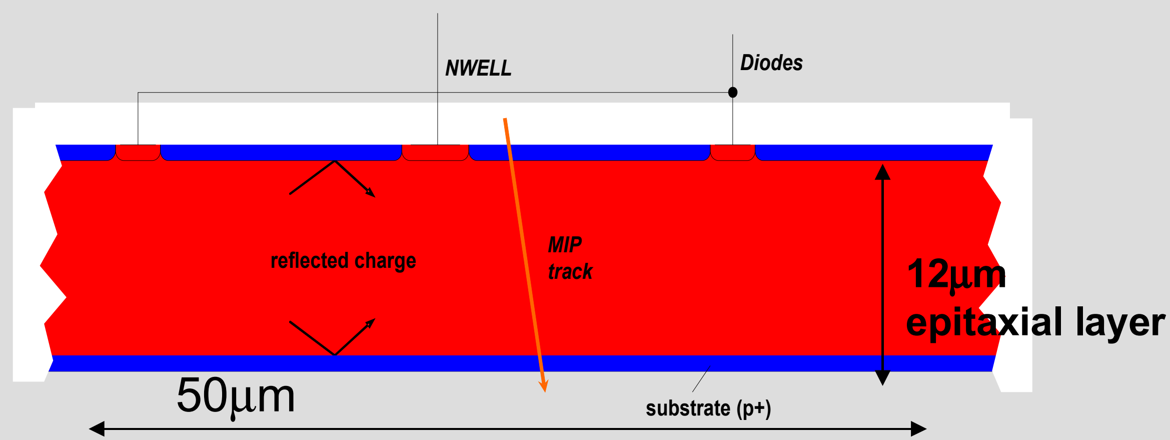


Mechanical structure is the same both for analogue and MAPS designs.

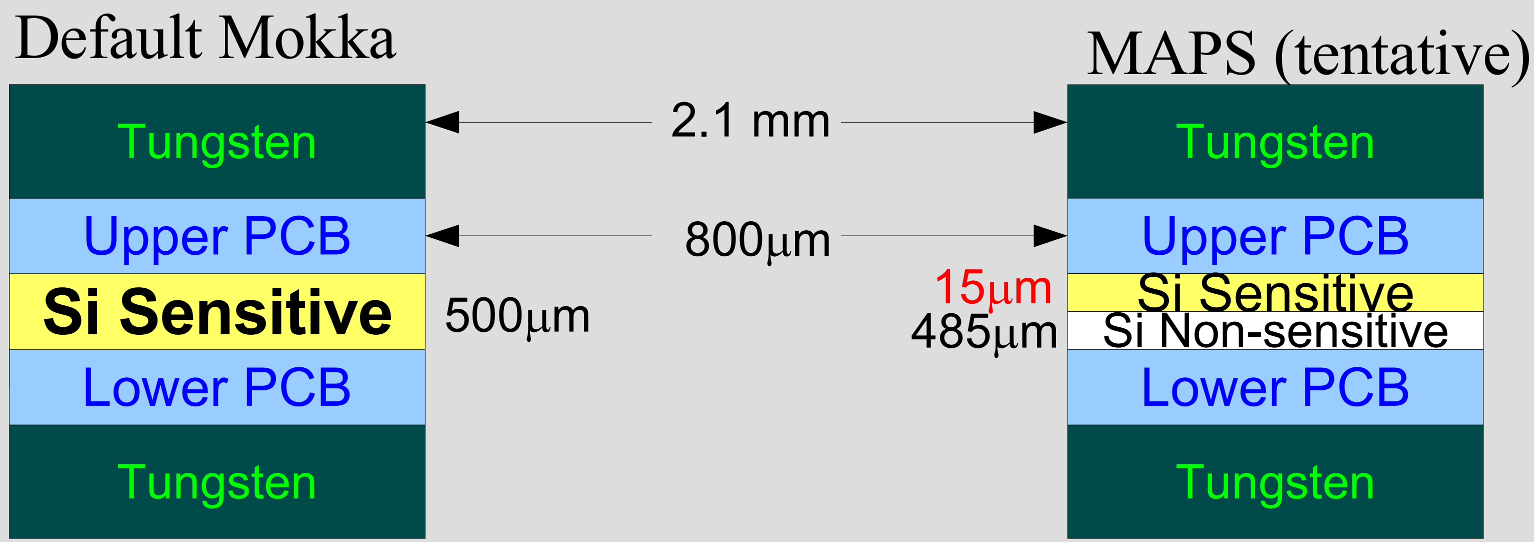
Charge collected mainly by diffusion:

(This is not yet modelled for the result of Geant4 simulation which I will show in later slides.)

- Optimization of the diode location and size is necessary.



Geometry modification in Geant4 full detector simulation



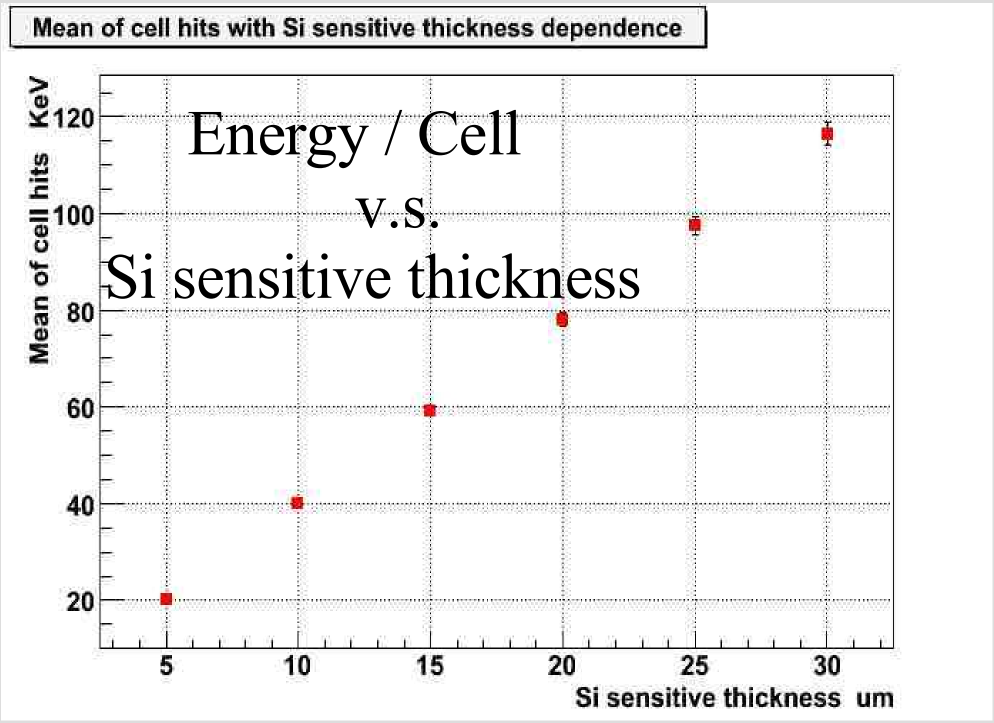
- Mokka 06-00, LDC01
- Ecal02.cc (ECAL Geant4 driver) is modified.

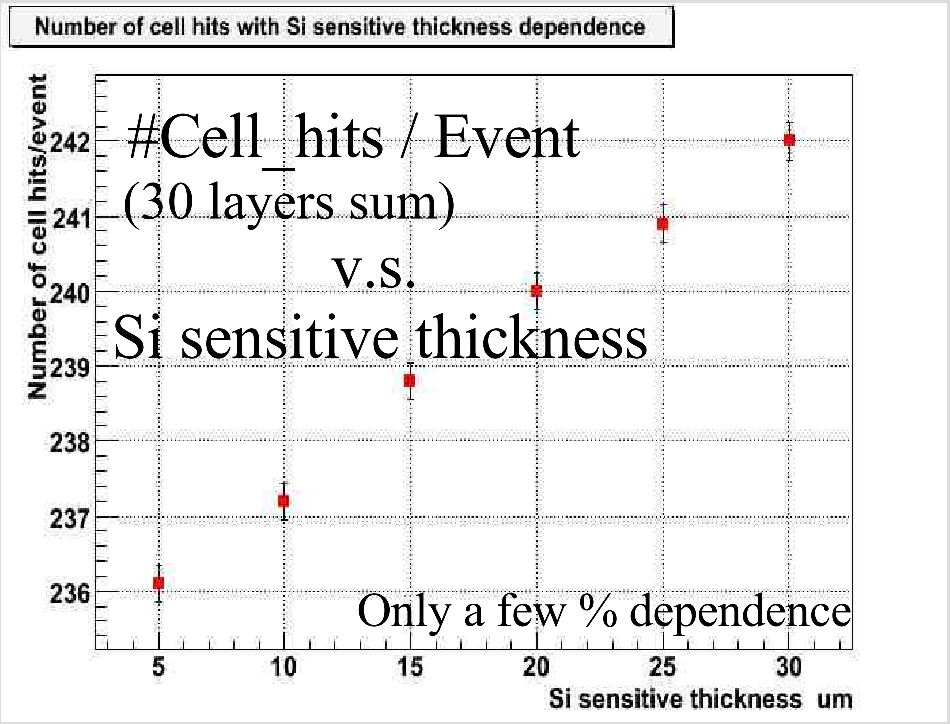
→ Consistency checks:

- Geant4 Adaptive GUI output is fine.
- Energy deposit ratio agrees with expectation. (i.e. 15μm/500μm =3.0%)
- Layer position shift agrees with expectation.
- Linearity for sensitive thickness dependence is represented. (Please see next slide)

Single e$^-$ simulation (1)
(Si sensitive thickness dependence)

- 20 GeV single electron (from IP to zenith with 4T magnet on)
- Cell size is 1cm X 1cm
- No threshold is applied for energy of cell hits.

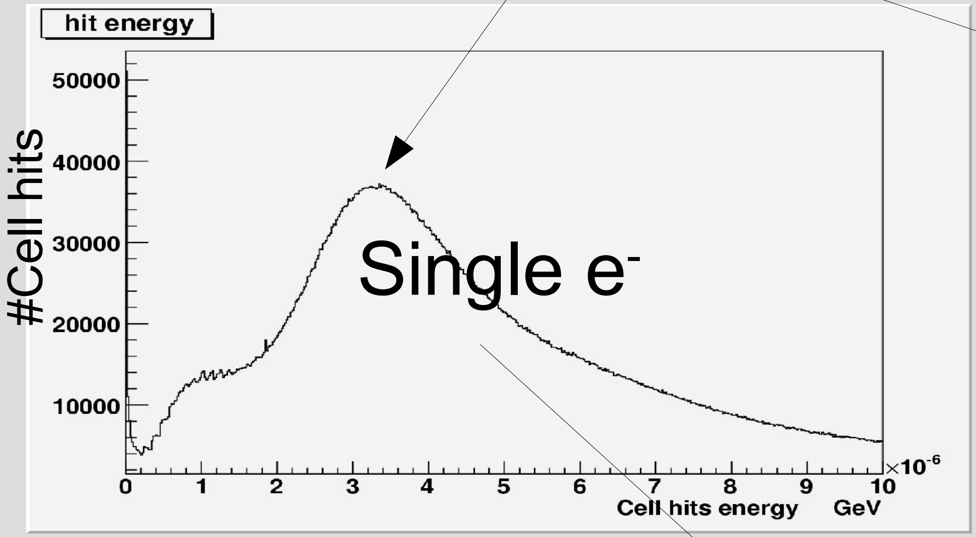


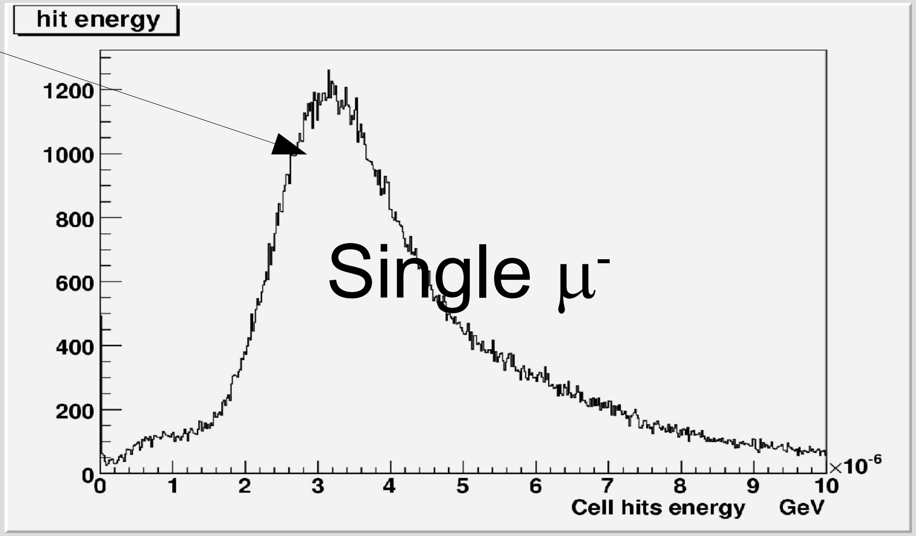


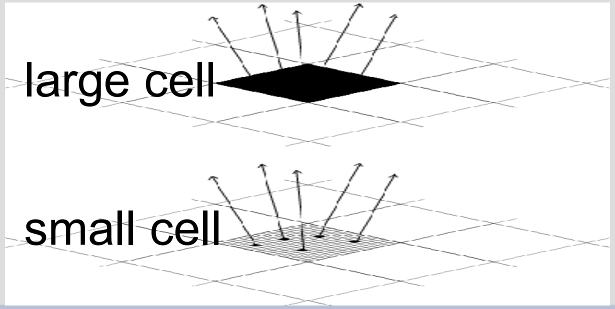
Single e^-/μ^- simulation (2)
(Energy deposit of cell hits)

- **20 GeV single e^-/μ^-**
- **15µm Si sensitive thickness**
- **50µm X 50µm cell size**
- **No threshold and no noise is applied.**
- **Before sensor level response is implemented.**

Minimum Ionization Particles





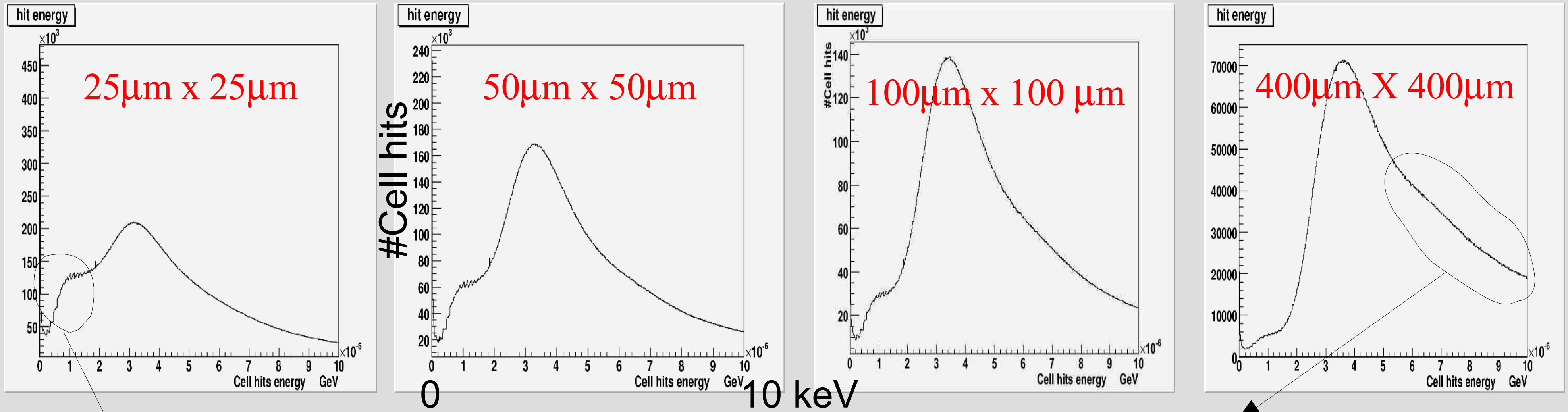


Individual secondary particles are detected after electromagnetic shower cascade !!

Single e$^-$ simulation (3)
(Cell size dependence)

- **100GeV single e$^-$**
- **15µm Si sensitive thickness**
- **No threshold and no noise is applied.**
- **Before sensor level response is implemented.**

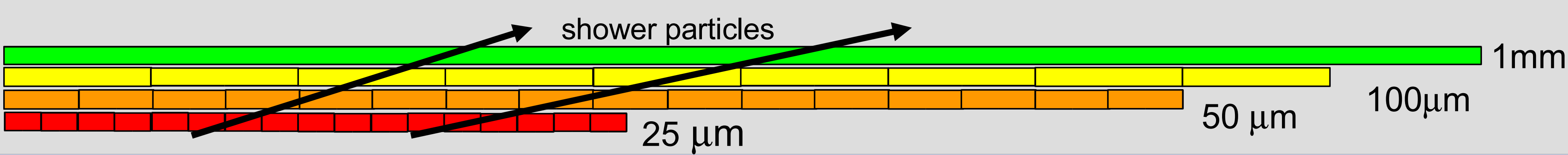
Cell hit energy distributions:



Charge sharing effects at cell boundary

Multi MIPs increase Landau tail

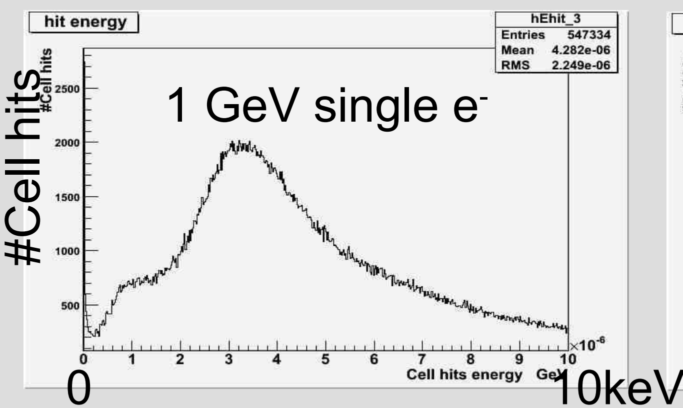
50µm x 50µm cell size is good working assumption.

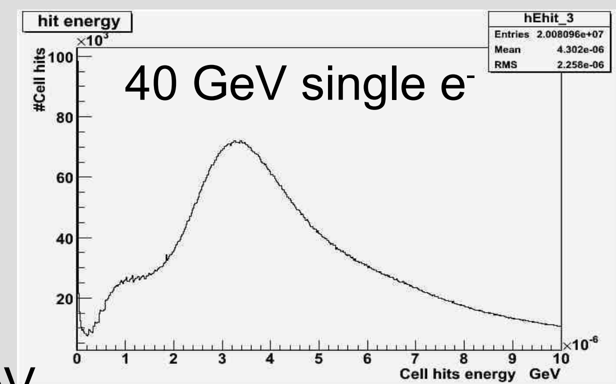


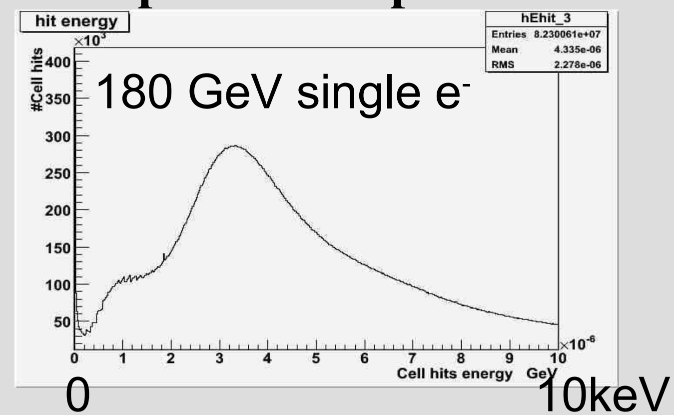
Single e$^-$ simulation (4)
(Incoming electron energy dependence)

- **15μm Si sensitive thickness**
- **50μm X 50μm cell size**
- **No threshold and no noise is applied.**
- **Before sensor level response is implemented.**

Cell hit energy distributions:

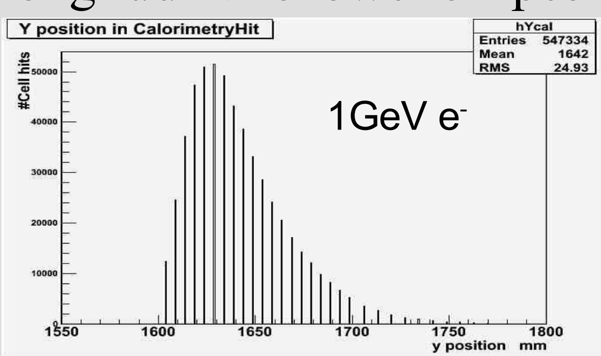


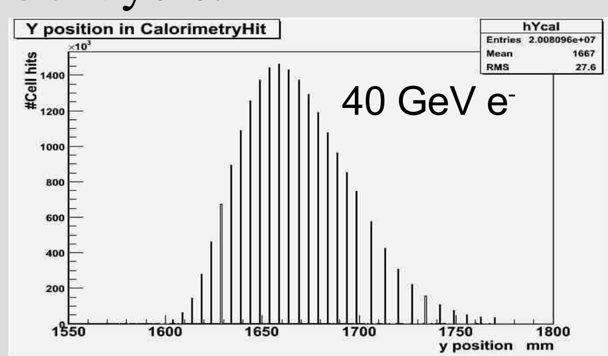


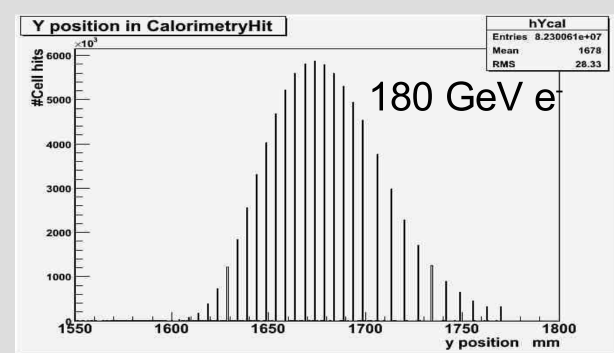


Similar cell hit energy distributions except for number of cell hits.
-> **One MIP per cell** -> **Digital calorimetry**

Longitudinal shower shapes in 30 layers:





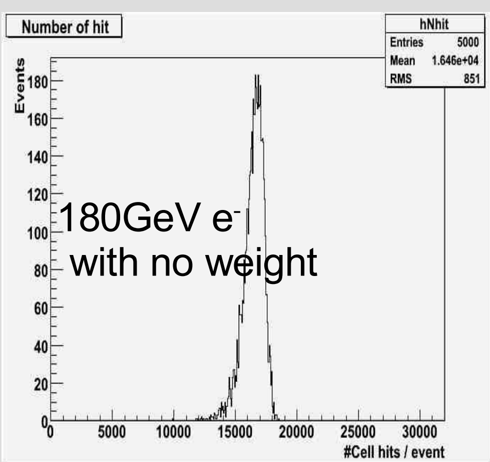


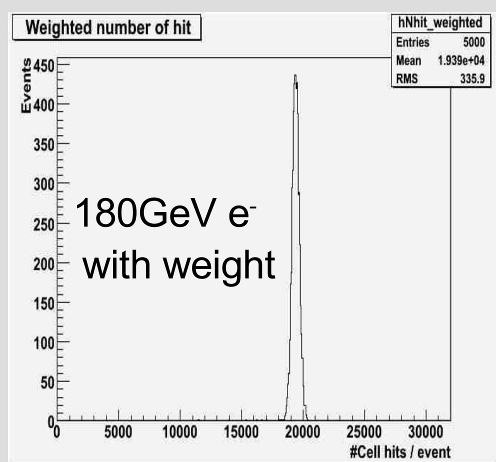
Linearity for energy measurement

- **Energy proportional to counting number of cell hits.**
- **4T B field (1GeV e^- is injected just in front of ECAL, other energy e^- is from IP.)**
- **No threshold and no noise is applied for cell hit energy.**
- **Before sensor level response is implemented.**
- **Counting number of cell hit in a event without clustering.**
- **Weighted number of cell hits is used for different W thickness layers.**

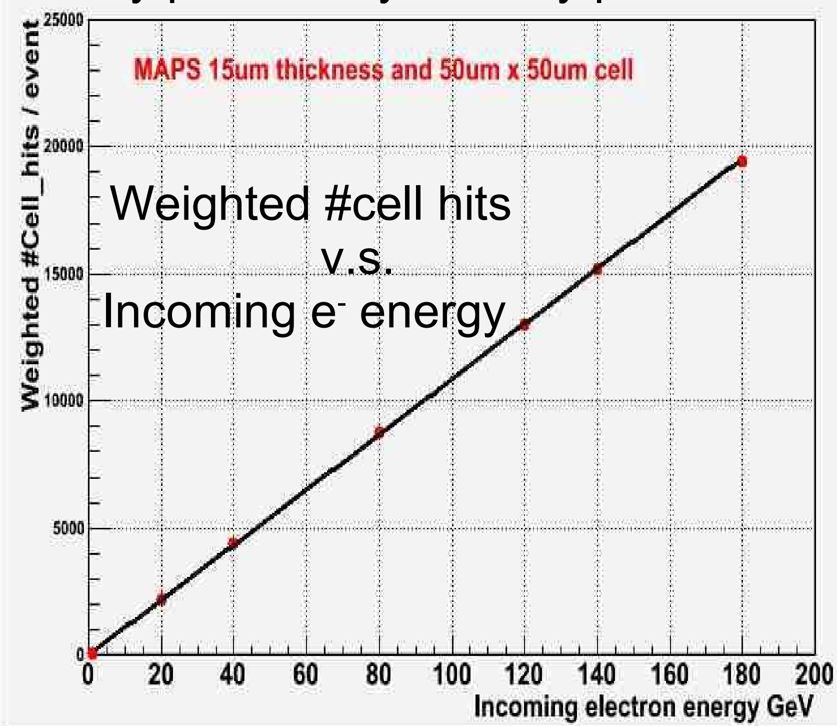
W thickness: 2.1mm for first 20 layers
4.2mm for last 10 layers

$$N_{weight} = \sum_{layer\#=1}^{20} N^{hit} + 2 \sum_{layer\#=21}^{30} N^{hit}$$

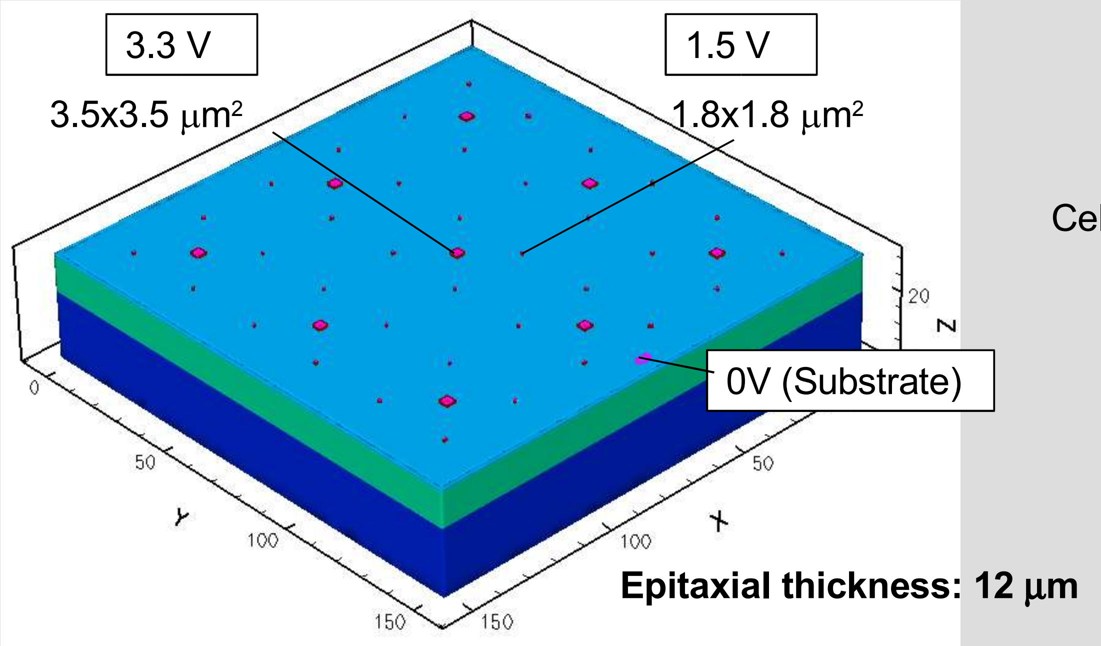


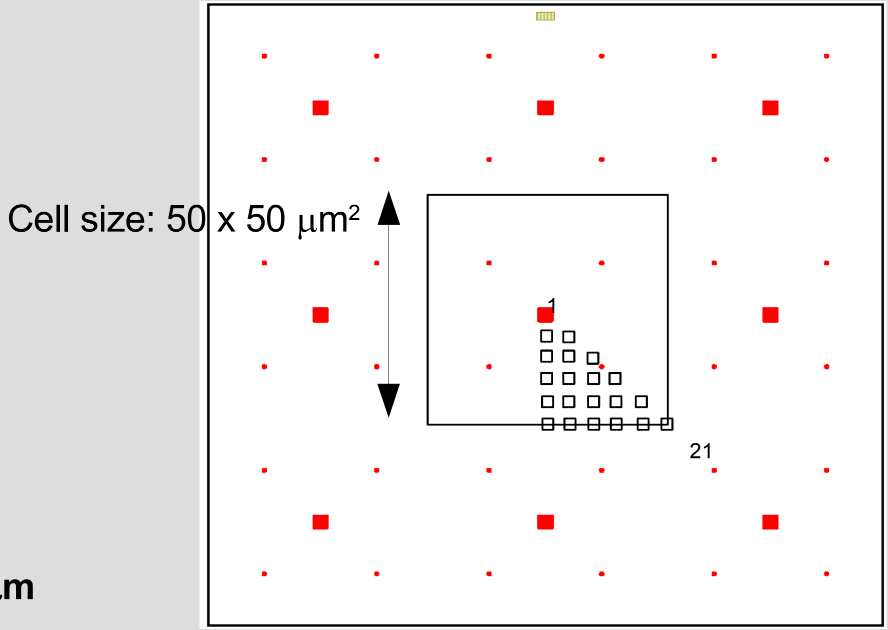


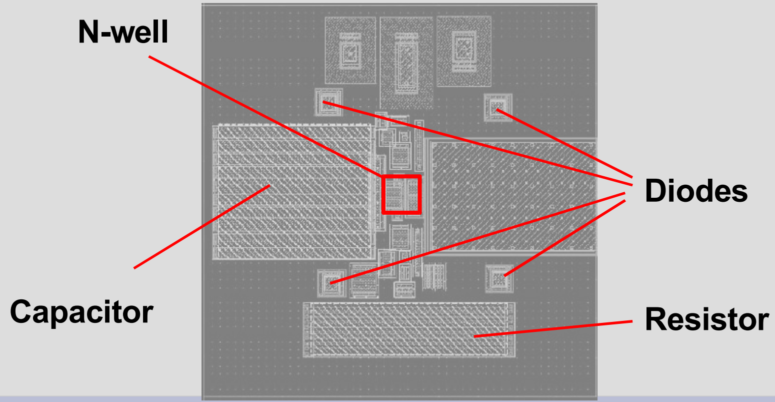
Very preliminary linearity plots:



Adding realism: Including sensor level response
Charge collection simulation (1)





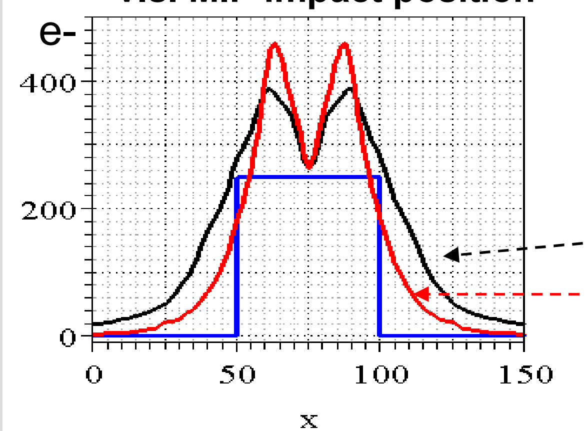


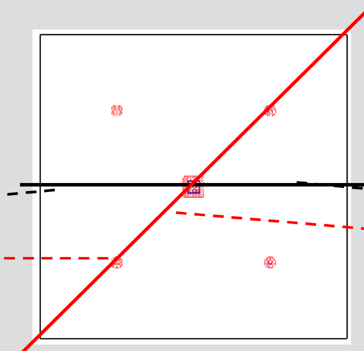
- **Full 3D device simulation**
- **Injected 1 MIP charge at 21 separate positions on a grid of 5 μm pitch.**
- **Using the symmetry the collected charge in the rest of the device is extrapolated**

Charge collection simulation (2)

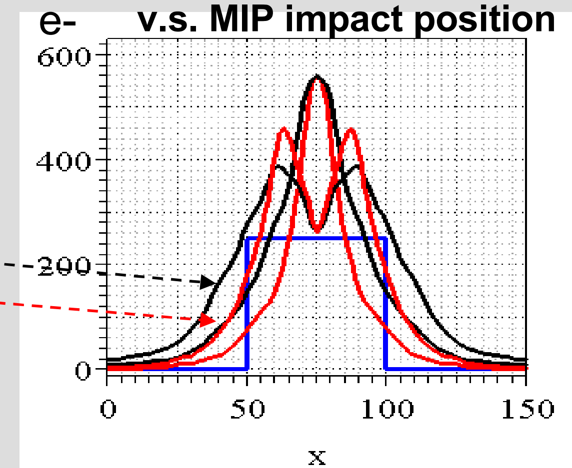
- ~50% of the charge collected when a MIP hits the N-well
- Collected charge increases with the diode size

Collected charge on the diodes v.s. MIP impact position



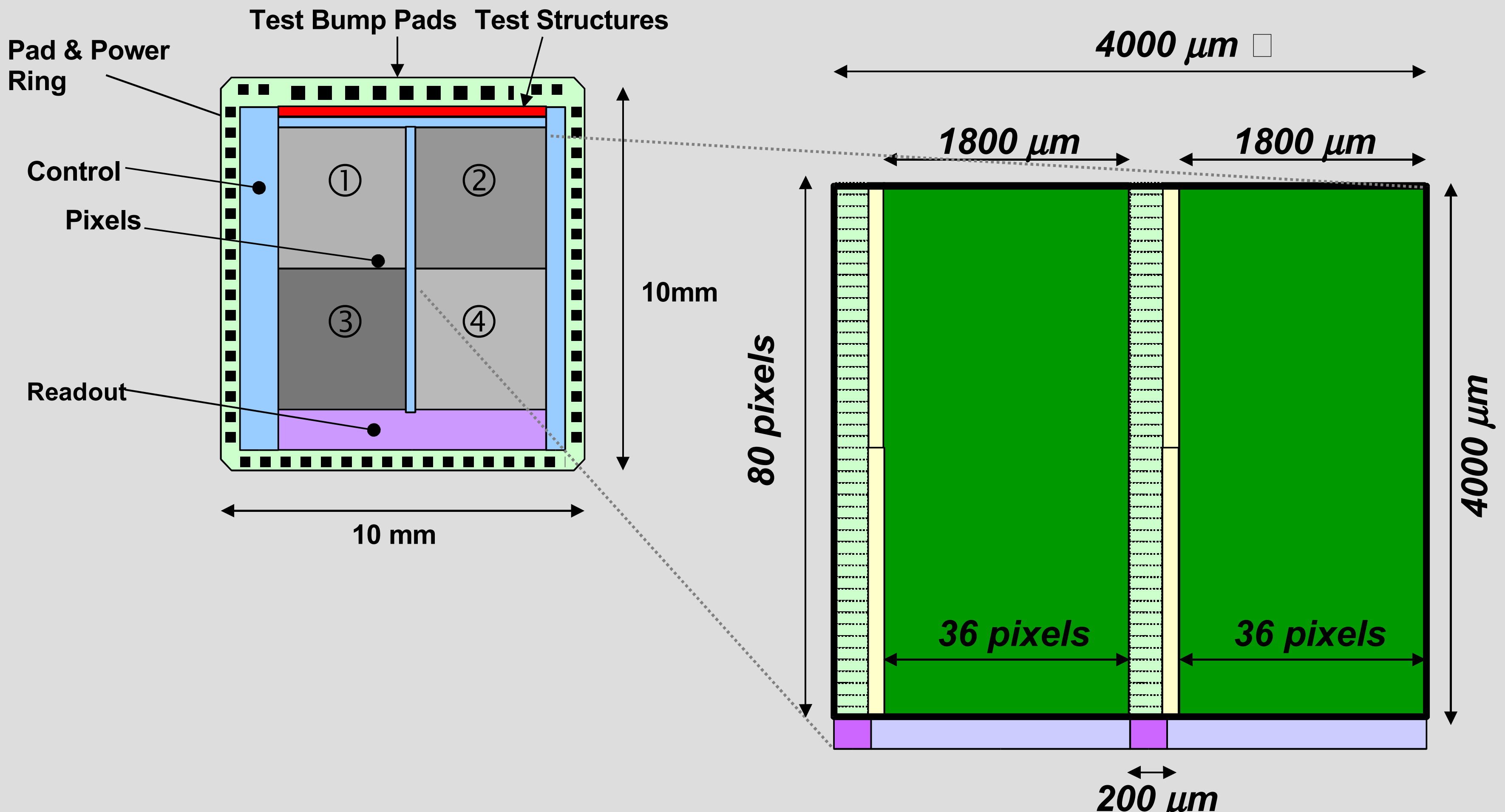


Collected charge on the diodes and on the N-well v.s. MIP impact position



Sensor layout example

Actual test structure design



- Sensors from foundry arrive at RAL July 2007
- 200µm dead area in every 2mm in test structure -> will be reduced.

Summary of status

- **MAPS geometry is implemented in full detector simulation.**
- **Each cell has only one secondary particle in most cases.**
- **50μm X 50μm cell size is reasonable starting assumption.**

- **Other ongoing studies**
  - Sensor level simulation
  - Noise and digitization
  - MAPS Electronics
  - MAPS DAQ

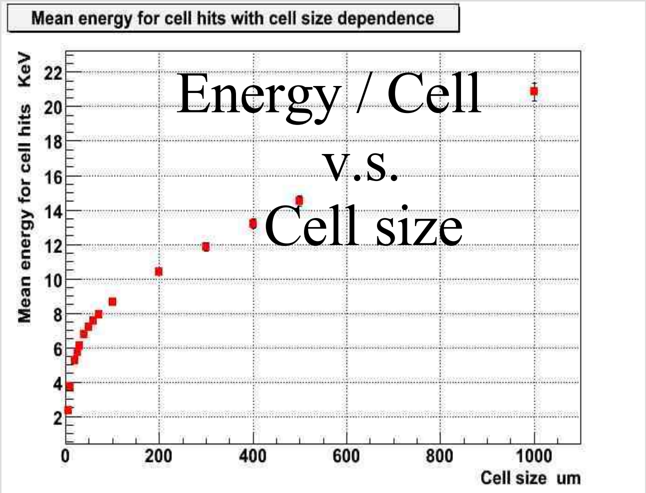
Future Prospects

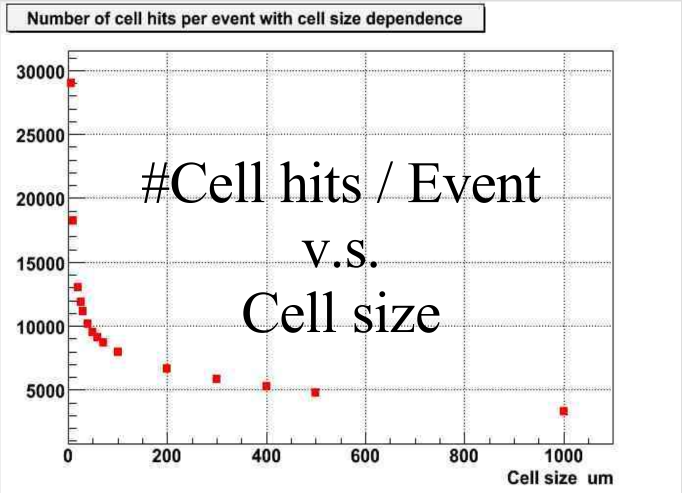
- **First sensors fabricated in August 2007**
- **Second sensor fabrication run, delivery July 2008**
- **Comparison between data and simulation**
  - MAPS geometry (After 2007 MAPS sensor is available.)

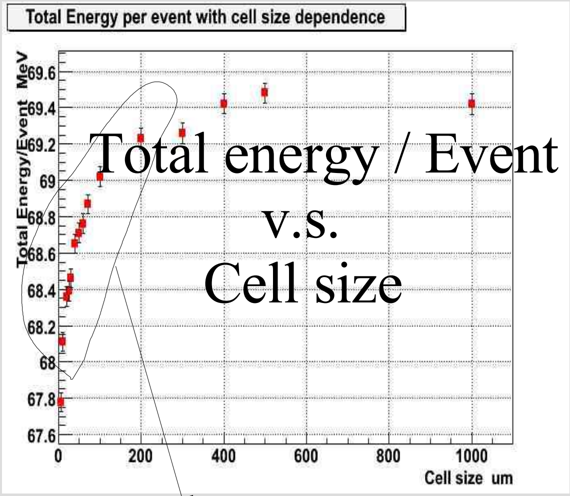
- **Energy resolution study with sensor response**
- **Clustering algorithm development**
- **Spatial resolution study**
- **Physics studies**

Back up(1)
Single e^- simulation (3.b)
(Cell size dependence)

- **100GeV e^-**
- **15µm Si sensitive**
- **No threshold and no noise is applied.**
- **Before sensor level response is implemented.**







3% bias:
Minimum step size effect ?

In small cell case (less than ~100 µm X 100 µm):

- **Only one secondary particle pass each cell in most case.**
- **One MIP's energy deposit is sharing by neighbour cell.**