Study of Monolithic Active Pixel Sensor for electromagnetic calorimeter

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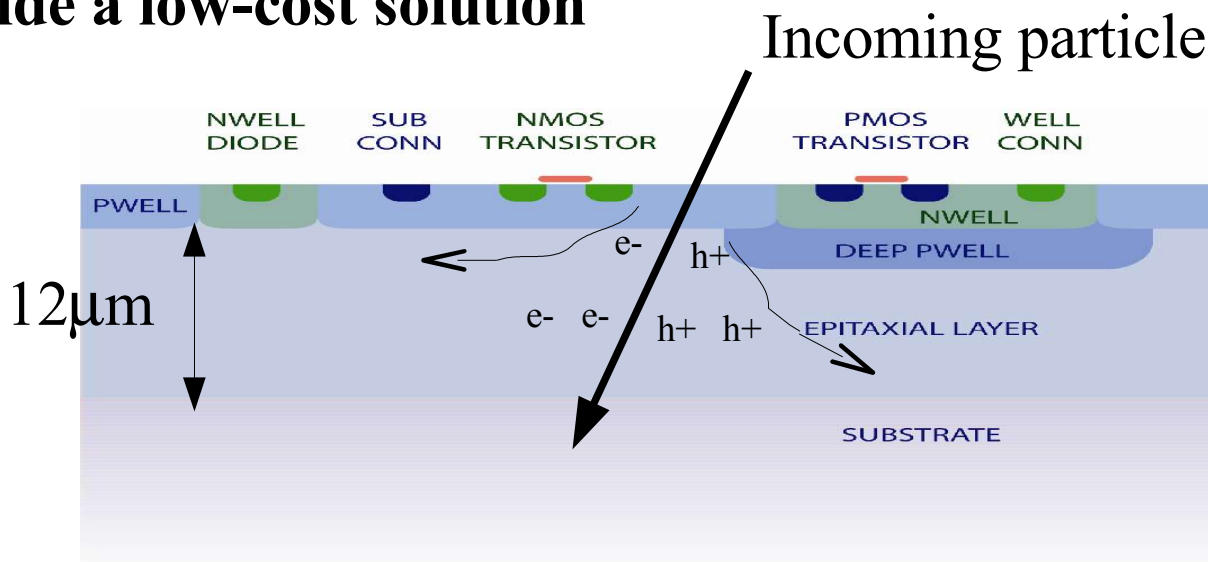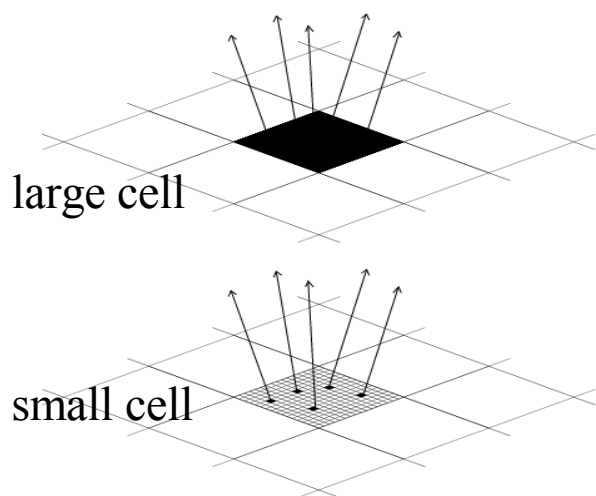*CALICE-UK MAPS group*

Outline

- MAPS (Monolithic Active Pixel Sensor) ECAL concept
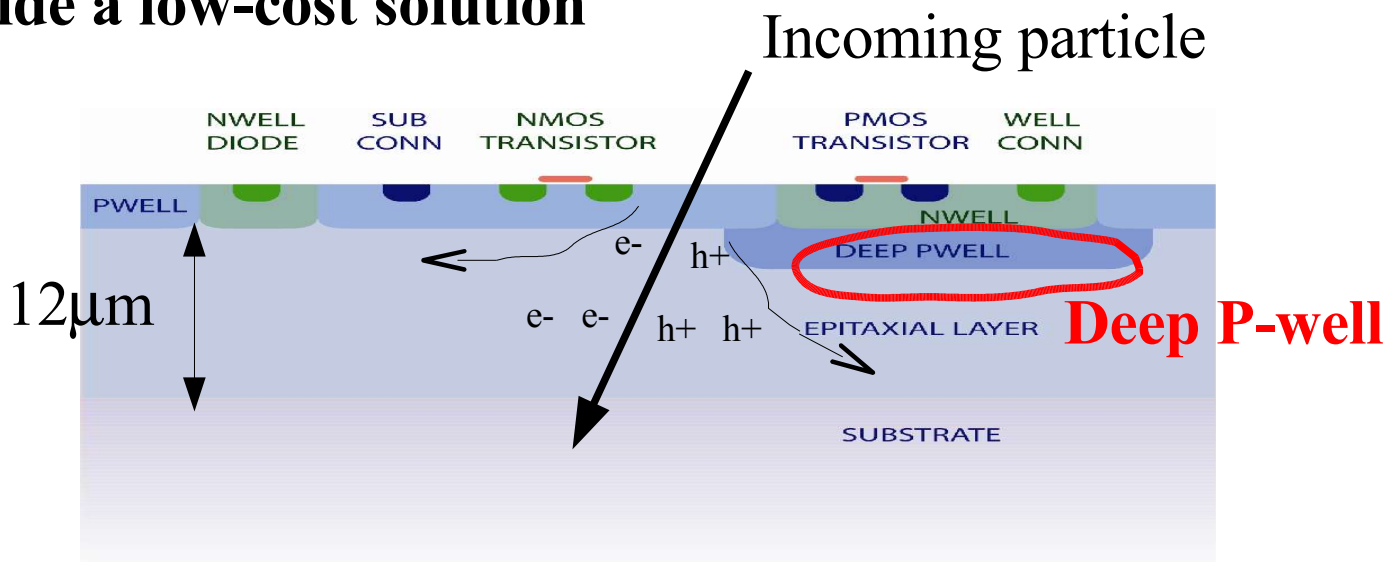
- Test sensor R&D activity

- Status summary

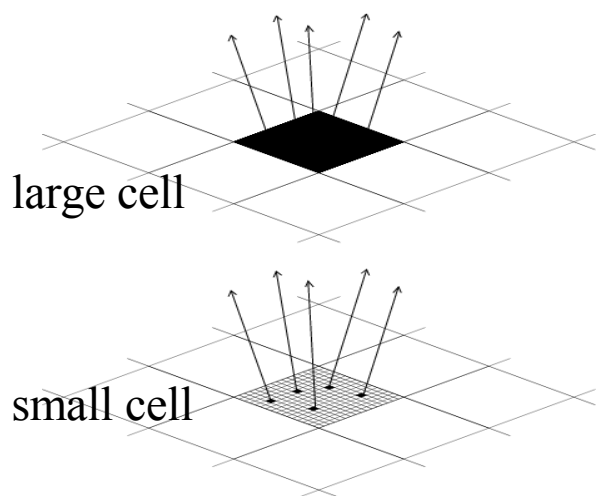# MAPS (Monolithic Active Pixel Sensor) ECAL concept

- 50μm X 50μm small cell size

- Each cell has only one secondary particle in most cases

(Counting hits for measuring energy)

- Charge is collected by diffusion (~100μm order)

- ECAL mechanical structure has no change (compared to analogue ECAL)

- CMOS MAPS can provide a low-cost solution

Incoming particle

large cell

small cell

12μm

NWELL DIODE | SUB CONN | NMOS TRANSISTOR | PMOS TRANSISTOR | WELL CONN

PWELL

NWELL

DEEP PWELL

e-   h+

e-   e-   h+   h+   EPITAXIAL LAYER

SUBSTRATE

MAPS (Monolithic Active Pixel Sensor) ECAL concept

- 50μm X 50μm small cell size

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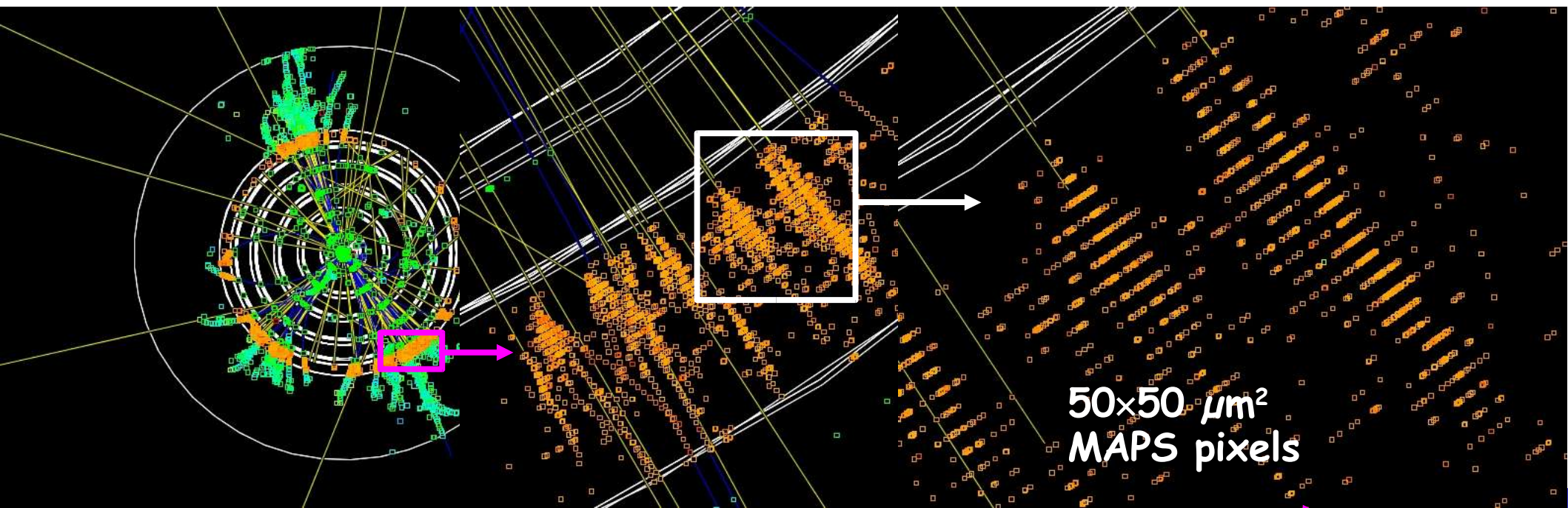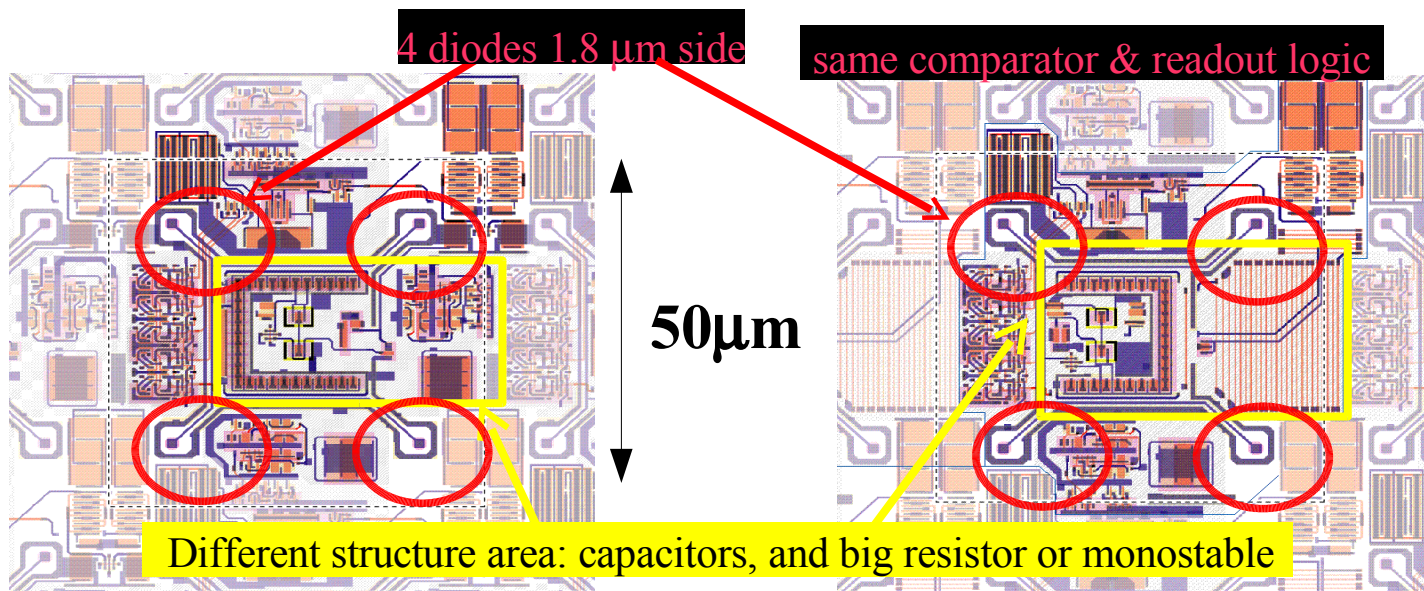
- CMOS MAPS can provide a low-cost solution

large cell

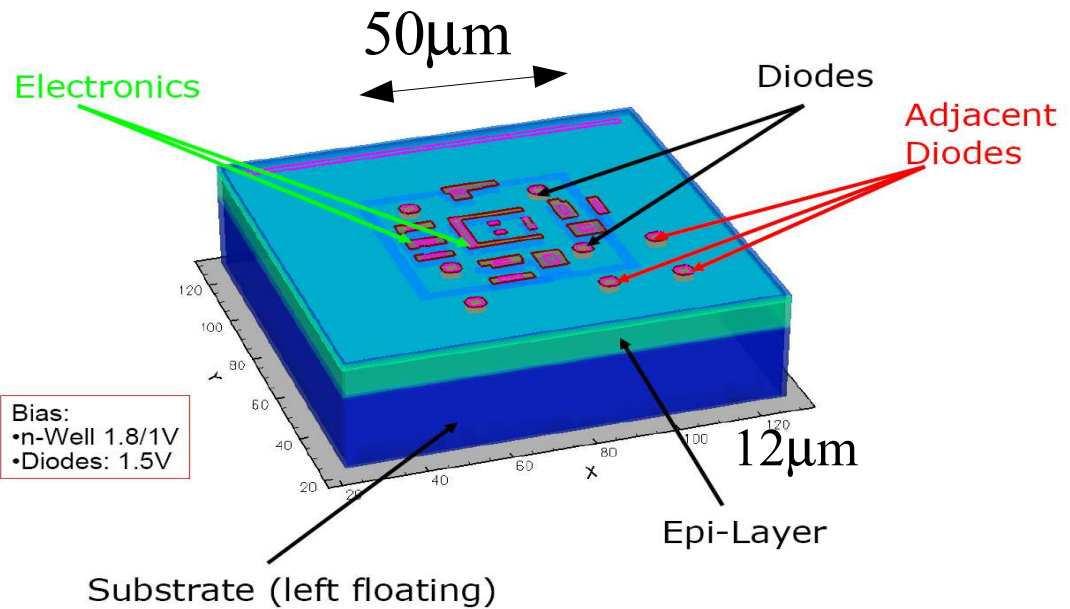small cell

Incoming particle

| NWELL DIODE | SUB CONN | NMOS TRANSISTOR | PMOS TRANSISTOR | WELL CONN |

PWELL

NWELL

DEEP PWELL

Deep P-well

12μm

e-   h+

e-   e-   h+   h+

EPITAXIAL LAYER

SUBSTRATE

Event display

ZOOM

50×50 μm² MAPS pixels

4x4 mm² area cells

Pixel layout

50μm

Electronics

Diodes

Adjacent Diodes

Bias:
• n-Well 1.8/1V
• Diodes: 1.5V

12μm

Epi-Layer

Substrate (left floating)

4 diodes 1.8 μm side

same comparator & readout logic

50μm

Different structure area: capacitors, and big resistor or monostable

Preshaper vs Presampler
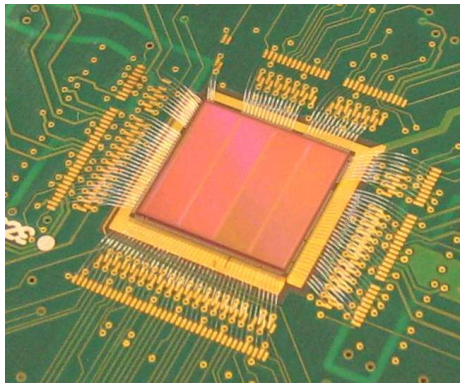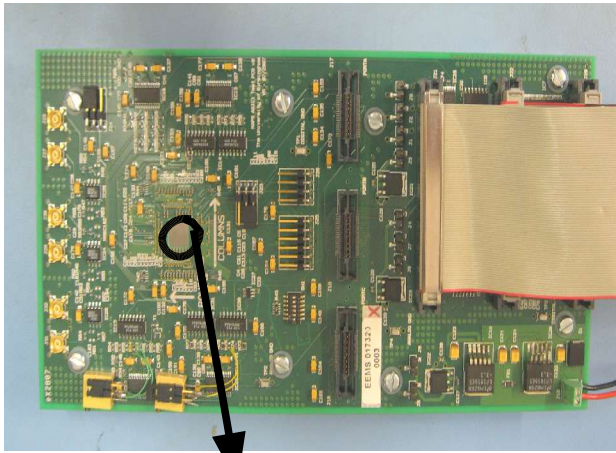
- **4 diodes**
- **160 transistors**
- **27 unit capacitors**

- **4 diodes**
- **189 transistors**
- **34 unit capacitors**
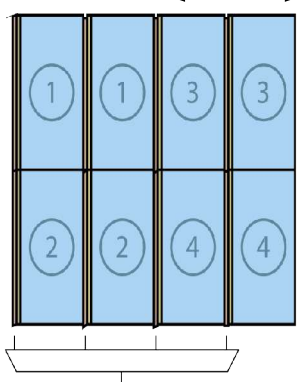- **1 resistor (4Mohm)**

Sensor layout

1cm

1cm X 1cm sensor

- **8.2 million transistors**
- **28224 pixels of 50x50 μm^2**
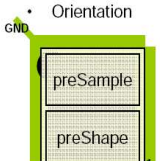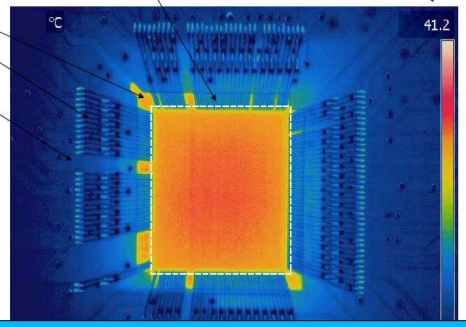- *11.1% dead area (logic)*

shapers   samplers

1cm

42x84 PIXELS

| 1 | 1 | 3 | 3 |
| 2 | 2 | 4 | 4 |

DATA MUX

- Temp scale
- Chip outline
- Ground pad
- Bond wires
- PCB

- Orientation

GND

preSample

preShape

°C   41.2

Thermal test

| SRAM | LOGIC | | | | | 42 PIXELS |

IBIAS, VCASC, VTH

DATA READ   CONTROL
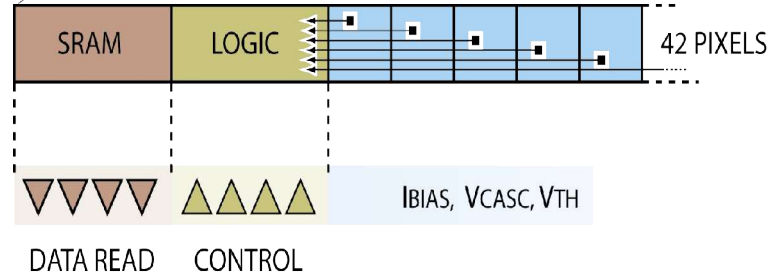
Preliminary tests: Laser Scan

Focussed Laser

- 4ns pulse at 1064nm wavelength
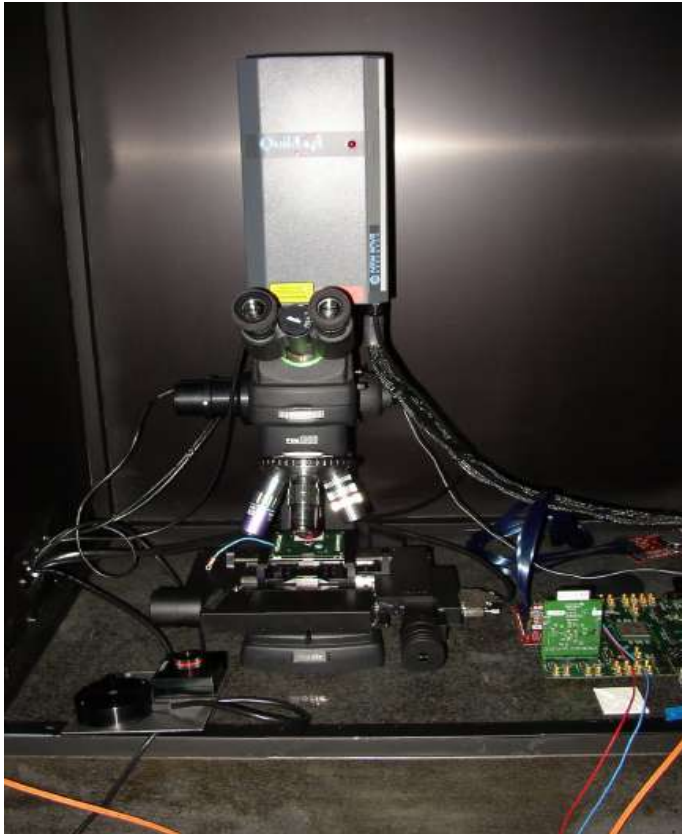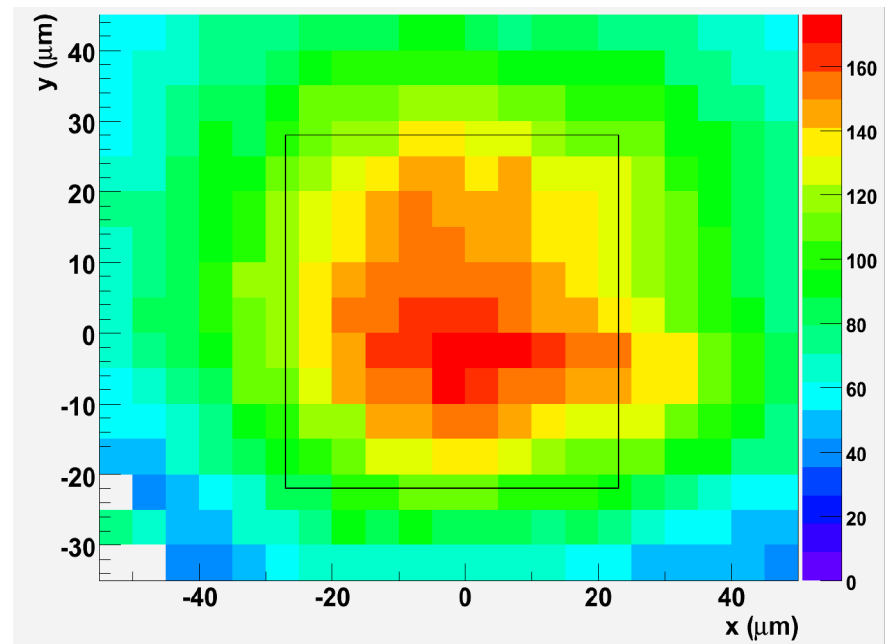- Focussed to **4x4 μm^2** on rear of sensor
- Uncalibrated analogue signal
- Step by 5μm in x and y
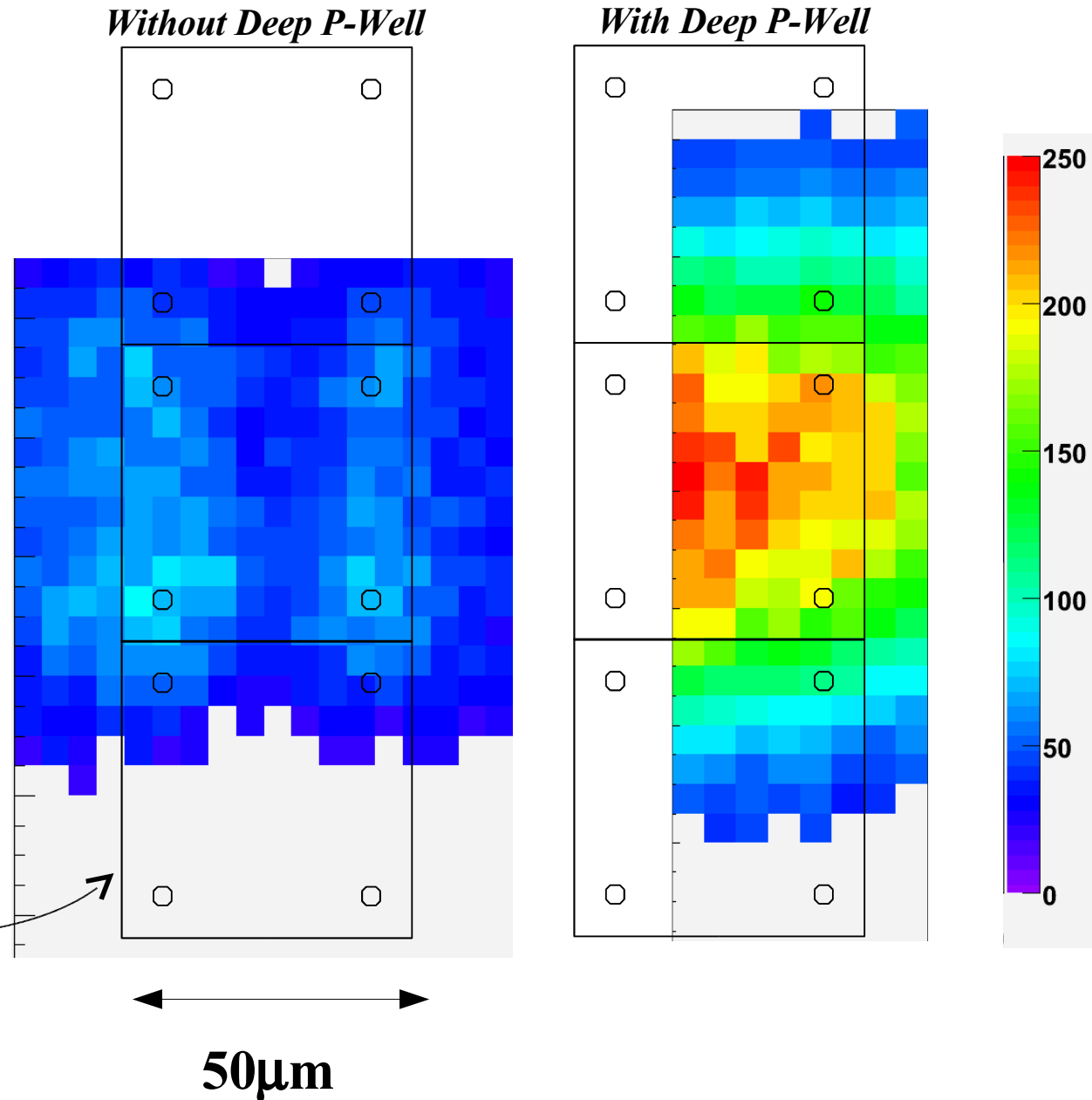- Record & plot signal size for each position

12μm epitaxial-layer + Deep P-well

Preliminary tests: Effect of Deep P-Well

Focussed Laser

- **Focussed to 5x5 μm^2 on rear of sensor**
- **Step by 5μm in x and y**

Test pixel outlines overlaid for scale: estimated position

Without Deep P-Well *With Deep P-Well*

50μm

α source test (preliminary)
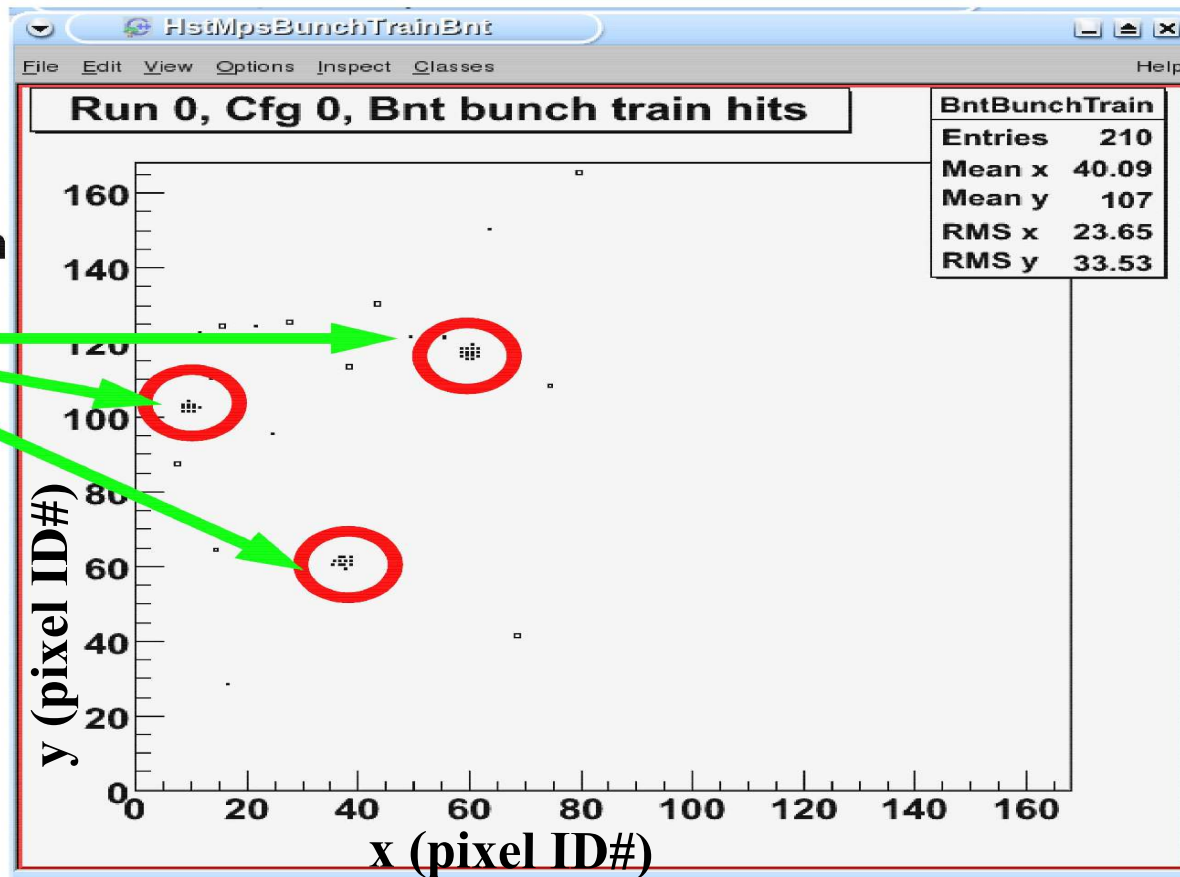
β source test (preliminary)

- β source (Thallium)

red ->with source, region0
green->with source, region1
blue->no source, region0
purple->no source, region1
(Both region1 and region0 are preshaper)

_hHitsByRegion0	
Entries	36392
Mean	151
Mean y	57.04
RMS	36.37
RMS y	139.1
Underflow	0
Overflow	0
Integral	3594

Beam test setup

DESY BEAM TEST CONFIGURATION
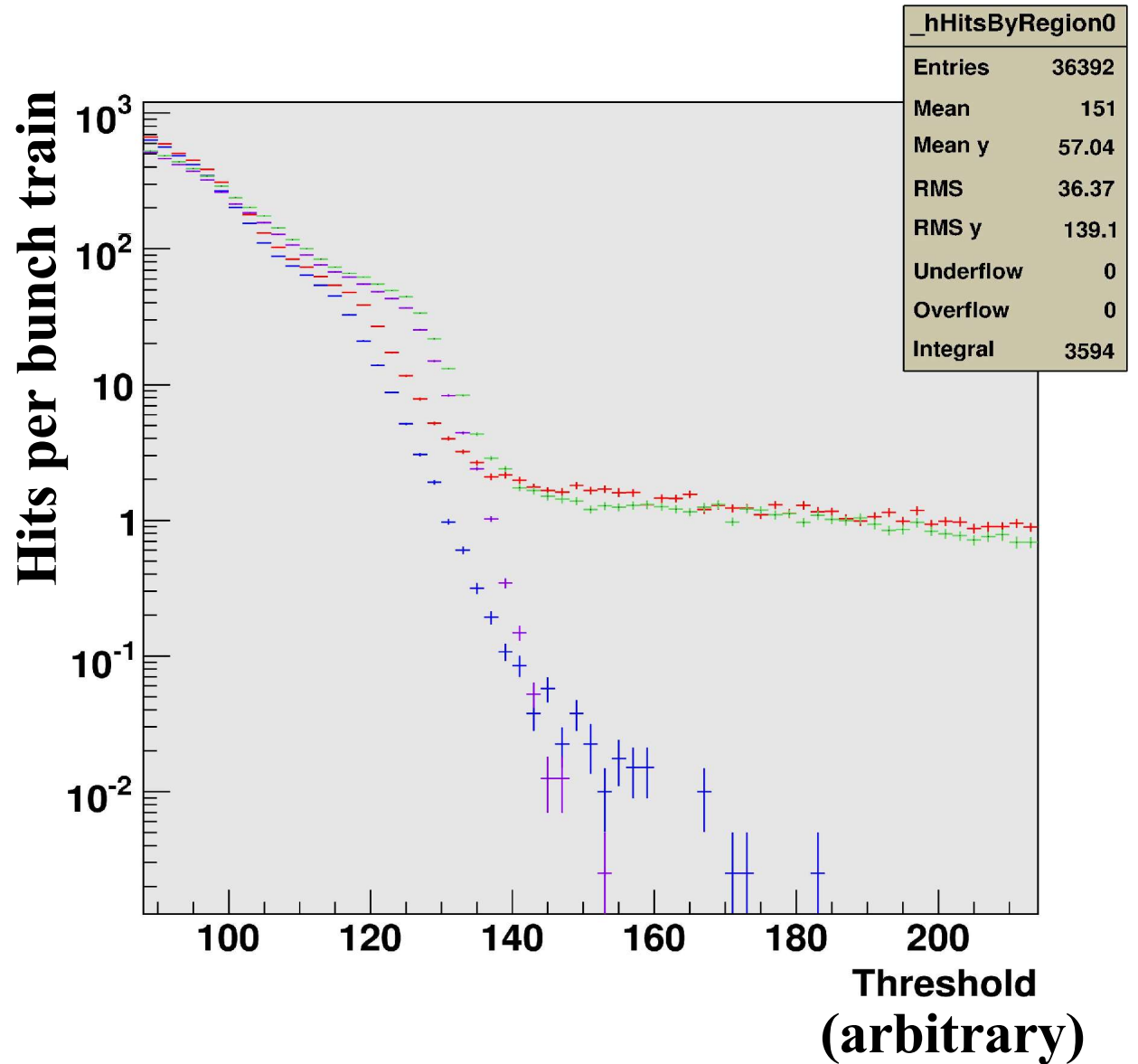
1cmX1cm Scint.
+
PMT finger 2

- **4 layers of MAPS sensors**
- **1 GeV~6 GeV electron beam**
- **With and without tungsten**
- **1 week first test (Dec. 2007)**
- **Analysis is ongoing**

N
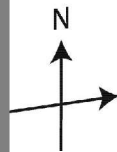
TRACKING CONFIGURATION		
Slot	Item	Cable
19	PMT 1	N
11	6	W
8	4	E
5	7	W
2	8	E
0	PMT 2	N

W plates

1cmX1cm Scint.
+
PMT finger 1
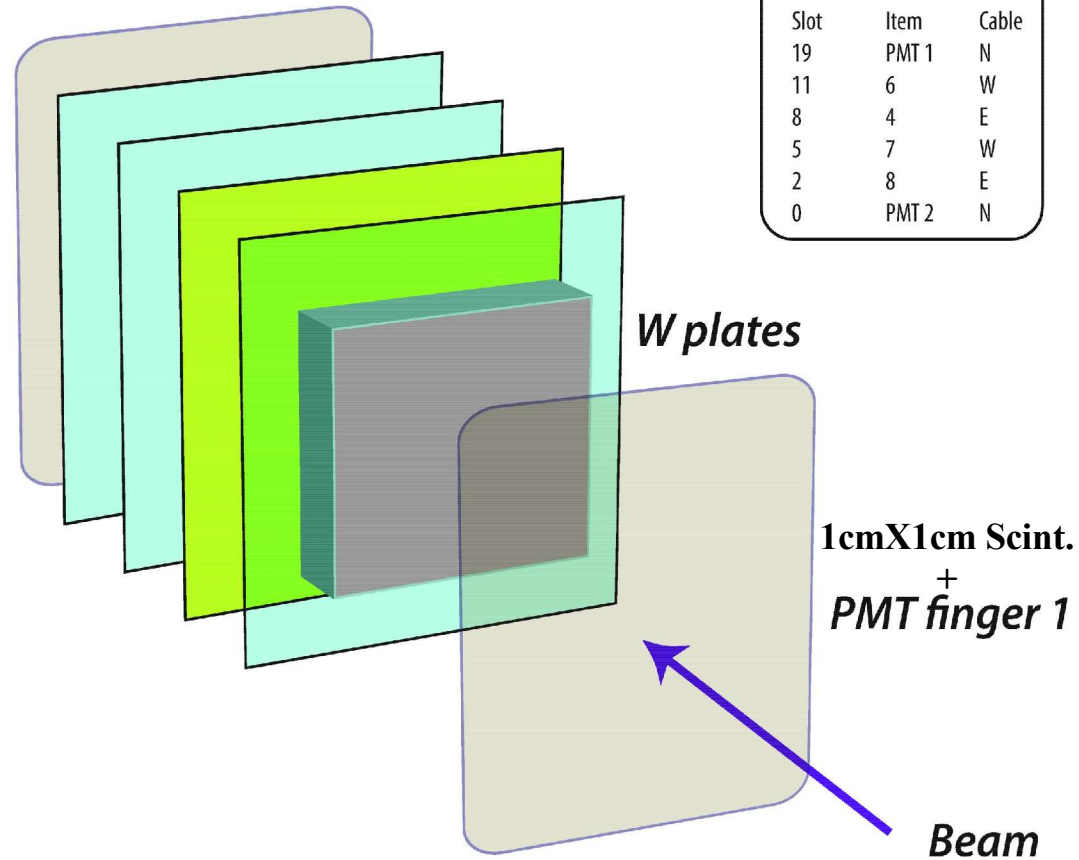
Beam

BEAM

DESY test beam area setup

Beam test DAQ
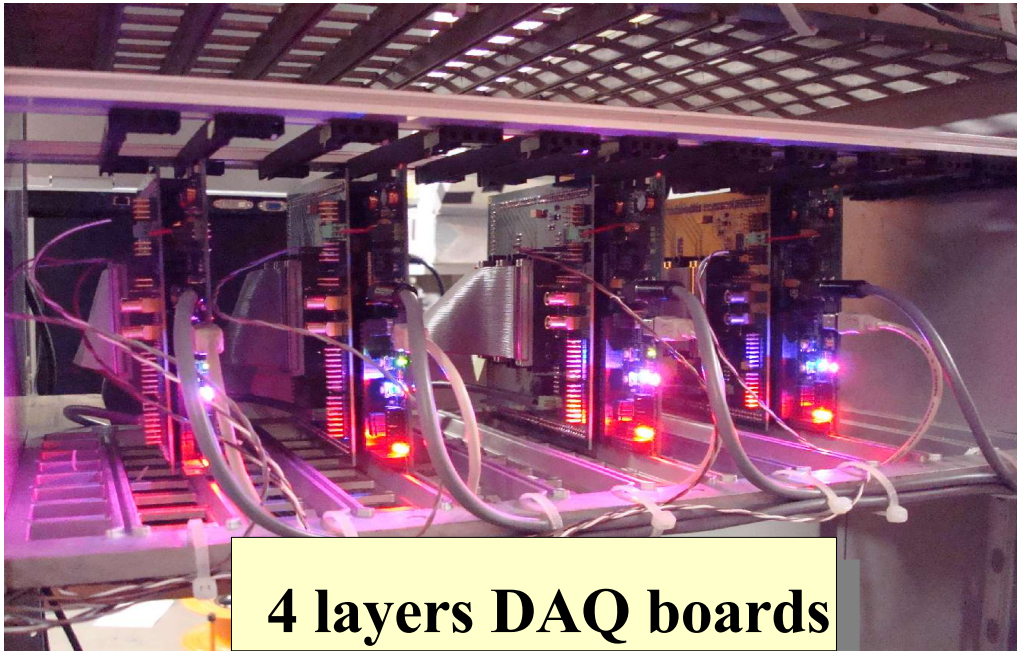
4 layers DAQ boards

**Example for
X correlation plot of two layers
(Very preliminary)**

Status summary

- MAPS based ECAL being studied.

- Test beam was operated as first test.

- Various analyses are ongoing for characterizing test sensor.

- Simulation will be improved by input from sensor test result.

- We may have second beam test in this year.

Backup(1) Geant4 Simulation

- 20 GeV single e⁻ or μ⁻
- 15μm (Si sensitive thickness) X **50μm X 50μm (cell size)**
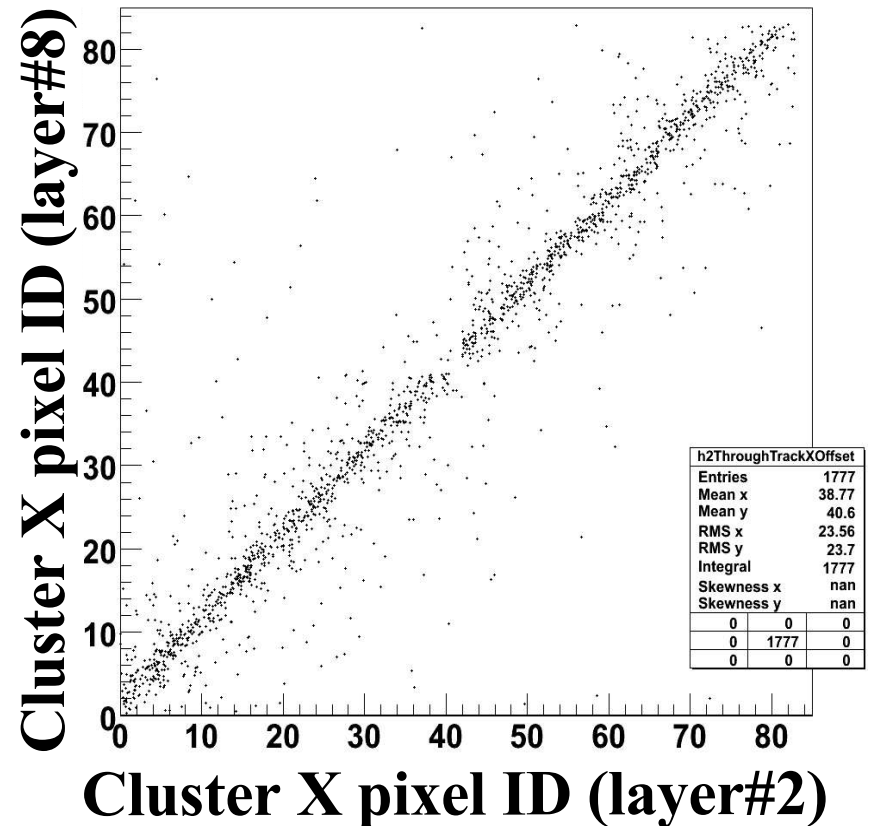- **No charge diffusion, no threshold and no noise is applied yet.**

Minimum Ionization Particles
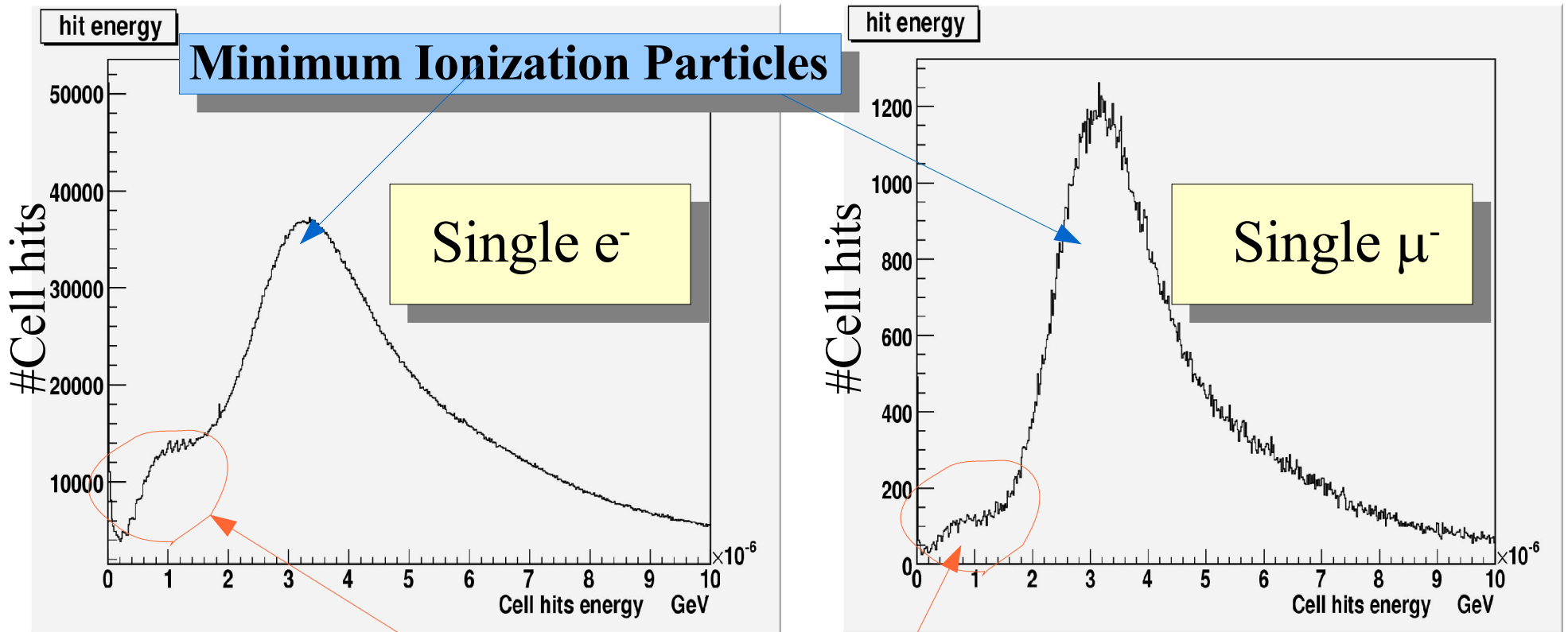
Single e⁻

Single μ⁻

Charge sharing effects at cell boundary

Backup(2) Geant4 Simulation

- 1 GeV or 180 GeV single e⁻
- 15μm (Si sensitive thickness) X **50μm X 50μm (cell size)**
- **No charge diffusion, no threshold and no noise is applied yet.**

1 GeV single e⁻

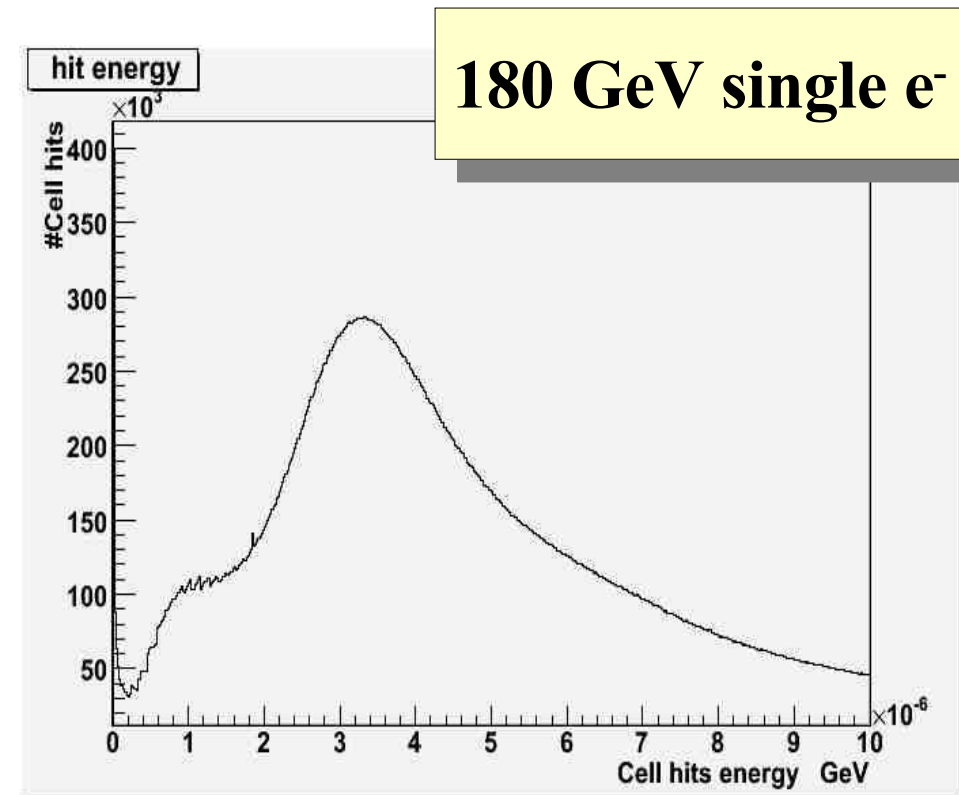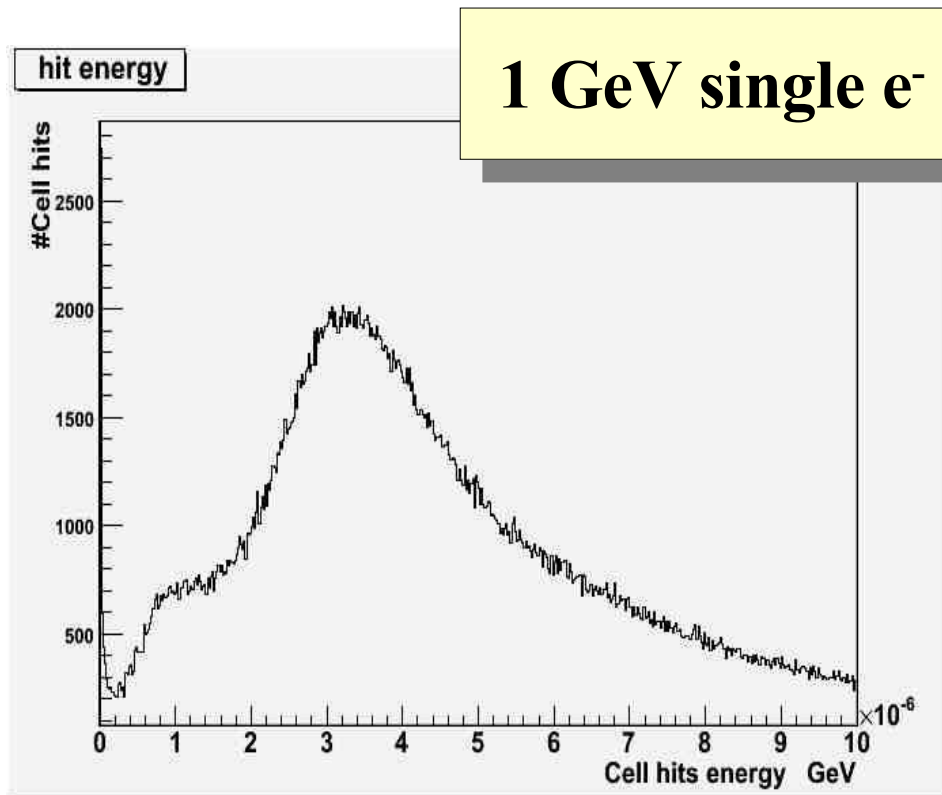**180 GeV single e⁻**

Similar cell hit energy distributions except for number of cell hits

Backup (3) Charge collection simulation

e- (×0.1)

Charge lost in the N-well

Charge collected by diodes

Q

μm

μm

x

y

150

100

50

60

40

20

0

150

100

50

0
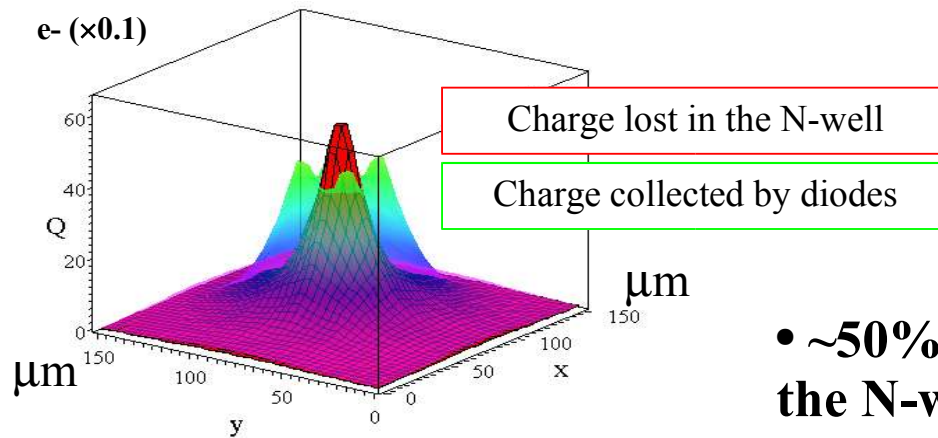
- **~50% of the charge collected when a MIP hits the N-well**

- **Collected charge increases with the diode size**

Collected charge on the diodes vs MIP impact position

e-

400

200

0

0   50   100   150

x

μm

1000
900
800
700
600
500
400
300
200
100
0

Charge (e-)

0.9μm
1.8μm
3.6μm

0   1   2   3   4   5   6

Distance to Diode (μm)
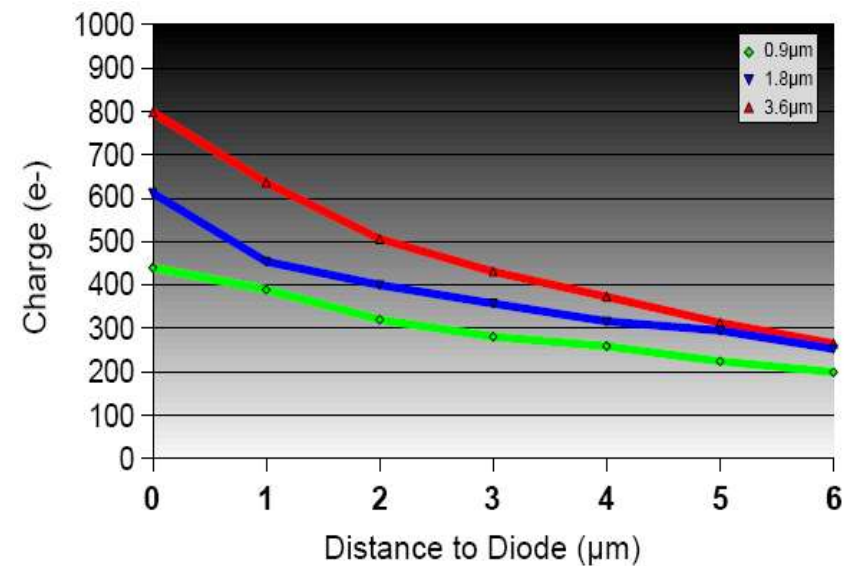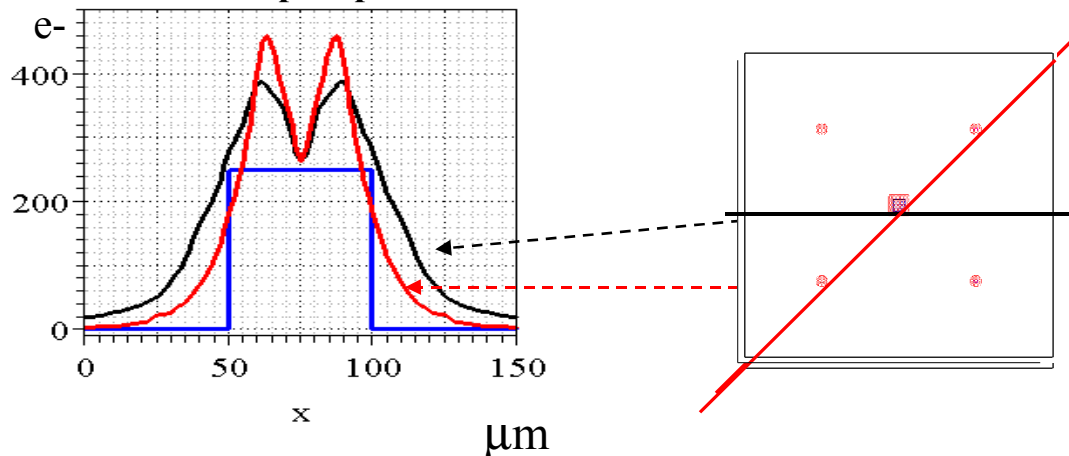
Backup(4) Digitization process

Digital ECAL, essential to simulate charge diffusion, noise, in G4 simulations

Take energy deposited in 5 μm x 5 μm cells from Geant4

Register those pixels with hits above threshold

Apply charge spread $E_{post\ charge\ spread}$

Effect of charge spread: $\sum(E_{neighbours}) \approx (50\% \text{ to } 80\%) \times E_{init}$

Sum energy post charge spread in 50 μm x 50 μm pixels

Add noise to signal hits

Effect of noise: $\sigma_{noise} = 100$ eV, or 35 e– (1 e– $\approx$ 3 eV)

Add noise only hits: $P(noise) = 10^{-6}$ =>10^6 hits in LDC-like detector

5 μm simulation grid

$E_{post\ charge\ spread}$

fraction of E_{init}

"0" "1"

"1"

Backup(5)
Example of energy resolution simulation after digitization

$\sigma(E)/E$ vs Threshold, photon 20 GeV
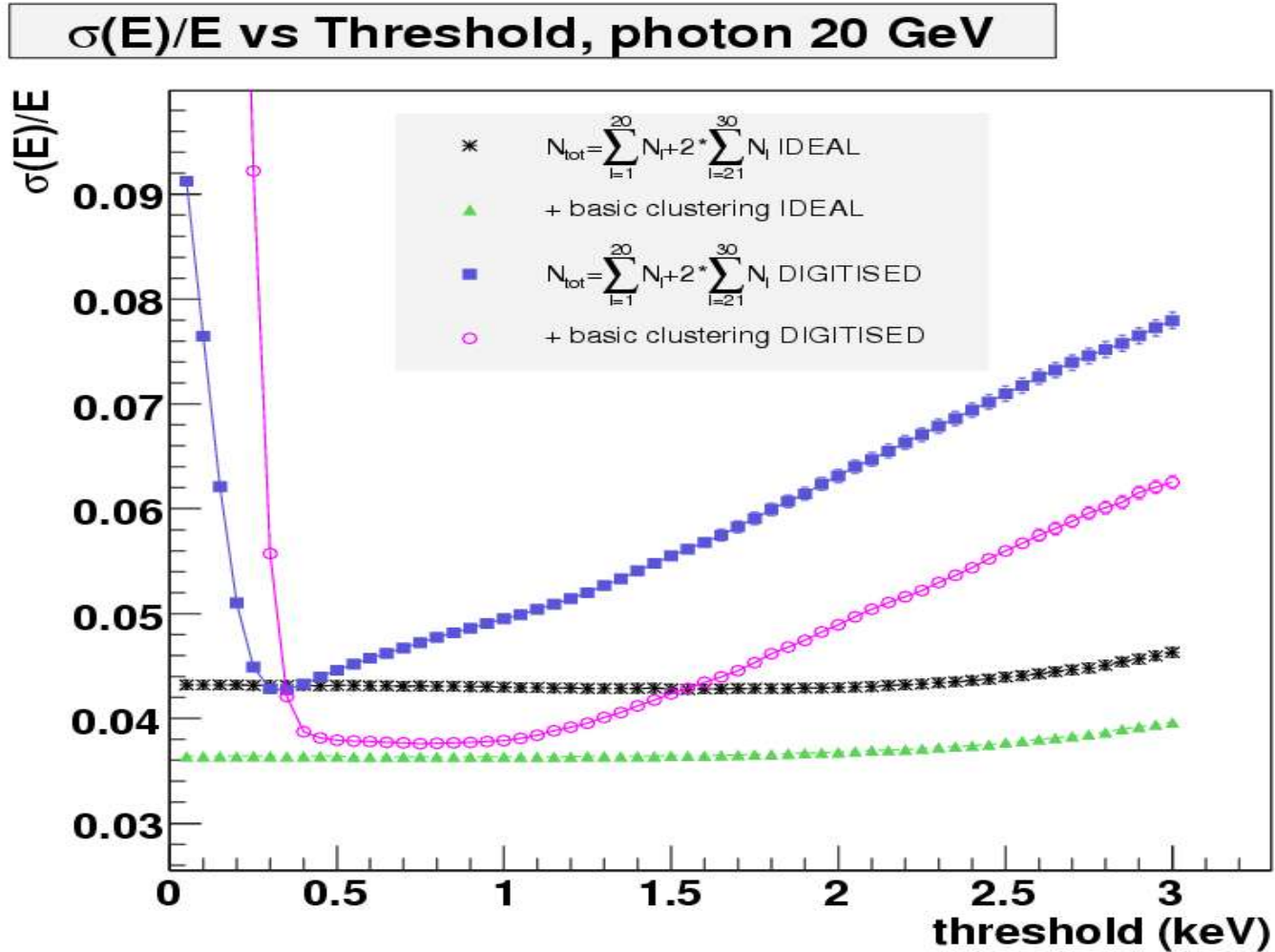
Backup (6)
Geant4 simulation for Si thickness dependence at 1cmX1cm cell

- **20 GeV single electron**
- **Cell size is 1cm X 1cm**
- **No charge diffusion, no threshold and no noise is applied.**

Mean of cell hits with Si sensitive thickness dependence

Energy / Cell
vs
Si sensitive thickness

Number of cell hits with Si sensitive thickness dependence

#Cell_hits / Event
(30 layers sum)
vs
Si sensitive thickness

Only a few % dependence
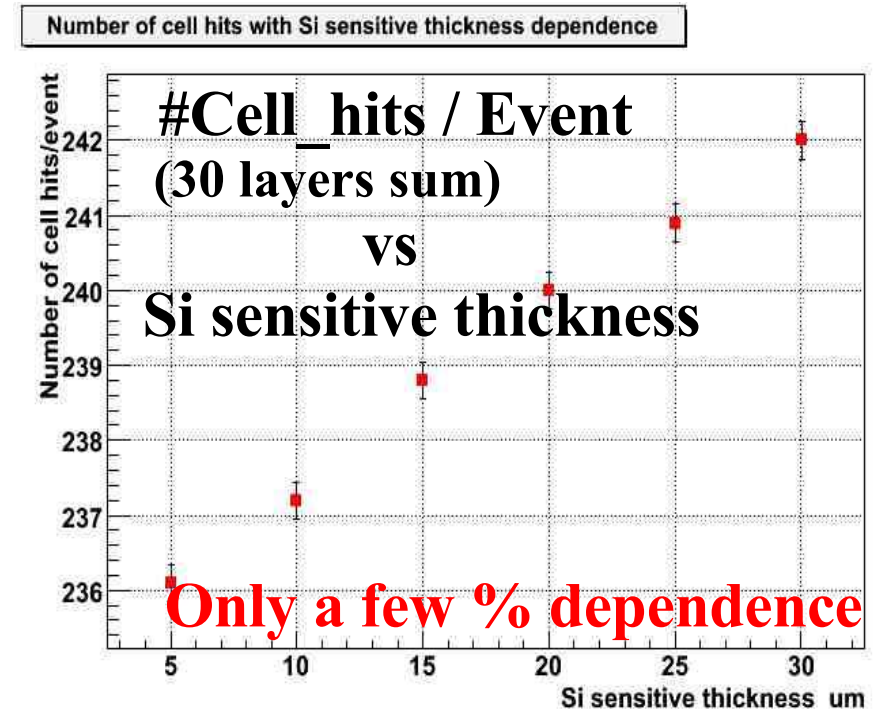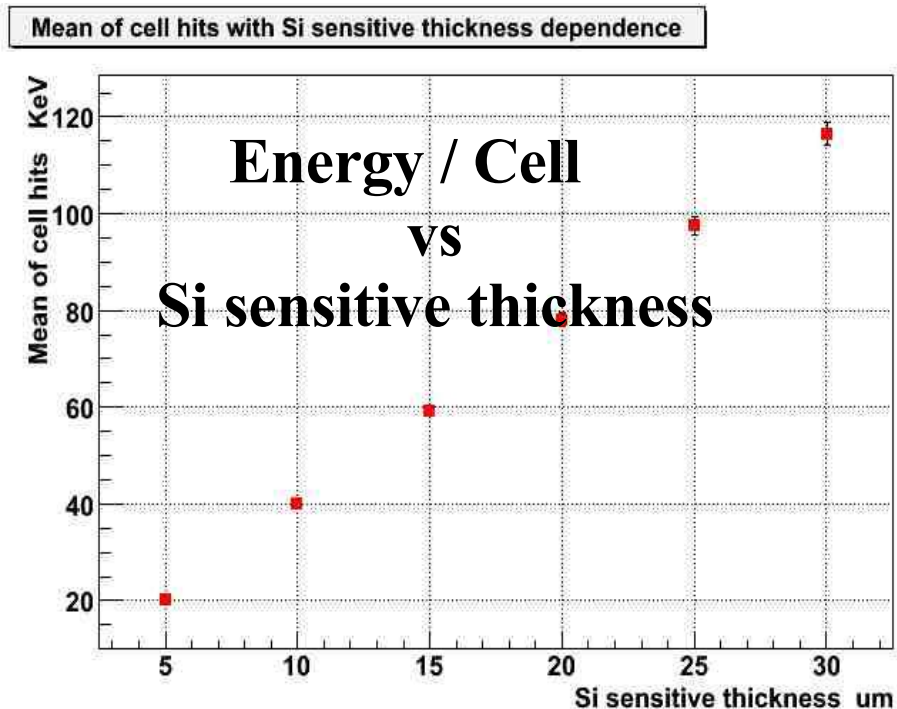
Backup (7) Geant4 simulation of cell size dependence

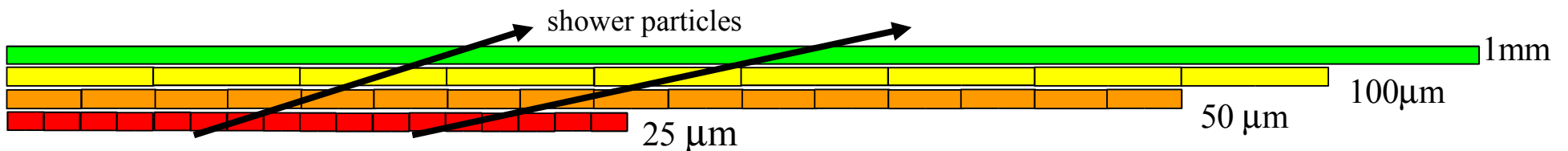- 100GeV single e⁻
- 15μm Si sensitive thickness
- **No charge diffusion, no threshold and no noise is applied.**
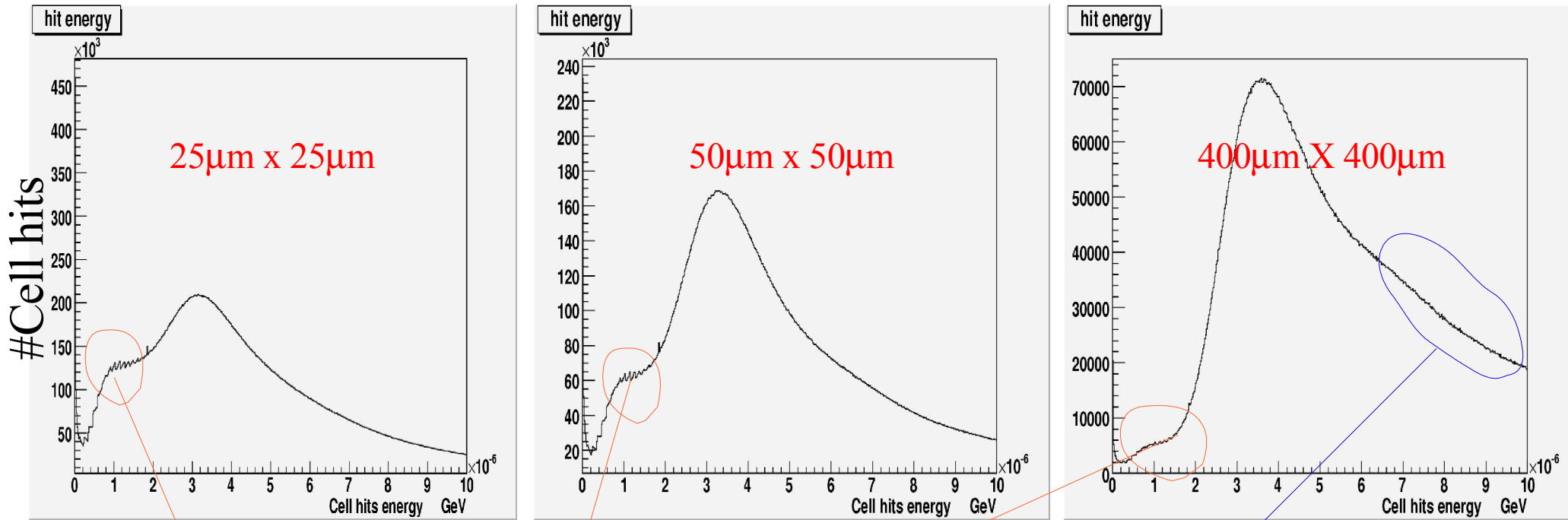
Charge sharing effects at cell boundary

Multi MIPs increase Landau tail

Backup(8) The Designs

Pre-Shape Pixel Analog Front End

Rst

Cpre

Rfb

Cfb

Cin   Rin

Preamp

Shaper

big resistor

Low gain / High Gain Comparator

Vth+
Vth-

Hit Logic

Hit Output

150ns

Trim&Mask
SRAM SR

Pre-Sample Pixel Analog Front End

Vrst

PreRst

Rst

Buffer

s.f

Cin

Preamp

Cfb

Buffer

s.f

Reset
Sample

Cstore

Low gain / High Gain Comparator

Vth+
Vth-

Hit Logic

150ns

Hit Output

+50ns

Self Reset

Trim&Mask
SRAM SR

Monostable

Backup (9) Cooling and power

- **Power Savings due to Duty Cycle (1%)**
- **Target Value for existing ECAL ASICS**
  - **4 µW/mm²**

- **Current Consumption of MAPS ECAL:**
  - **40 µW/mm² depending on pixel architecture**
  - **Not optimized at all for power consumption**

- **Compared to analogue pad ECAL**
  - **Factor 10000 more Channels**
  - **Factor 10 more power**

Backup (10): DAQ issues

- **$O(10^{12})$ channels**

- **Physics rate is not the limiting factor**

- **Beam background and Noise will dominate**

- **Assuming 2625 bunches per 1ms and 32 bits per Hit**
  - **10^6 Noise hits per bunch**
  - **Beam background per bunch would be less than noise hits (roughly estimated from GuineaPIG)**

- **Per bunch train**
  - **~80 Gigabit / 10 Gigabyte**
  - **Readout speed required 400 Gigabit/s**
  - **CDF SVX-II can do 144 Gigabit/s already**

Shift crews